Modeling Discourse Acts in Computer-Assisted Collaborative Decision Making

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Abstract

This paper presents a model of discourse acts that agents use to communicate their attitudes to each other, or affect the attitudes of others, in a multi-agent decision making process. Such processes usually raise a lot of intricate debates and negotiations among participants, where conflicts of interest are inevitable and support for achieving consensus and compromise is required. Furthermore, they are often performed in the presence of ill-structured information, brought up by parties with different backgrounds and interests. Focusing on the argumentation process itself, and in the context of an already implemented system, the paper also comments on the associated machinery needed in a computer-assisted decision making environment.

1 Introduction

Traditional decision making techniques, coming from areas such as mathematical economics, operations research, game theory and statistics, build on a probabilistic view of uncertainty, where possible actions are evaluated through their expected utility. The use of such crisp values has been extensively criticized; the specification of the complete sets of probabilities and utilities required renders such approaches impractical for the majority of decision making tasks that involve common sense knowledge and reasoning [Tan and Pearl, 1994]. On the other hand, Artificial Intelligence (AI) approaches basically attempt to reduce the burden of numerical information required, while pay much attention to the automation of the process.

Furthermore, traditional approaches are built on the assumption of a predefined set of alternatives and criteria, and provide methods to quantify and aggregate subjective opinions (consider, for instance, the Analytic Hierarchy Process [Saaty, 1980]). Everyday practices, however, make obvious that there is a lot of room for debate here. We view multi-agent decision making as a collaborative process, where agents have to follow a series of *communicative actions* in order to establish a common belief on the dimensions of the problem. Such dimensions may concern the choice criteria, the existing or desired alternatives, or the objective function, to mention some. Issues of knowledge elicitation and representation are inherent in these environments and an appropriate machinery is needed.

More specifically, approaches to collaborative decision making (CDM) may be divided into two large classes. In the first one, a set of alternatives is determined *a priori* and the task is one of deciding between them. In the second class, an *ideal case* is decided upon first, and a subsequent task is to find a real case that best approximates the ideal. In both approaches, however, there is a number of common elements:

- an overall task goal is specified;
- a set of alternatives is selected;
- a collection of choice criteria must be settled upon by the participants;
- a decision function must be composed which combines criteria to decide between alternatives.

The overall task goal is generally not a subject of debate, although it may be ill-defined and the decision process may involve sub-processes to clarify the goal. These sub-processes may be also considered as CDM processes themselves. In fact, each element of the decision process may itself be the subject of a sub-decision process. Decision making can, therefore, be recursive.

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The set of alternatives can be a predetermined, closed set (no further alternatives can later be considered), a predetermined open set (leeway is given to allow integration of new alternatives), or a postdetermined set (in the case of finding a match to an ideal case). Interesting conclusions concerning the implicit goals, *a priori* positions, and biases of the participants in the process may often be inferred from the manner in which they present alternatives. It is often the case that participants have applied unspecified choice criteria before proposing alternatives (eliminating what they consider to be useless alternatives). In cases where the participants are of unequal stature in the CDM process (as, for instance, when a mixture of middle and upper management are involved), this can have a profound implicit effect on the collaborative aspects of the decision process; modeling of the hierarchical relations between participants may be necessary to understand what may appear to be illogical or contradictory decisions.

The choice criteria are the basis of any decision process. They provide the metrics upon which alternatives are compared, and accepted or rejected. As the foundations of the CDM process, they may be the subject of much debate. The inclusion of particular criteria may cause one to consider alternatives that would otherwise not figure in the process, while the exclusion of certain criteria may automatically eliminate certain alternatives that would *prima facie* be included. They can, therefore, be a preliminary battleground for power struggles between factions involved in the process.

The decision function, however, is where most argumentation is centred, since it is here that the relative value of choice criteria is established and applied to select between the alternatives. The argumentation used is often authoritative or based on voting.

2 Background and Motivation

Research on various aspects of CDM has been receiving growing interest in the AI and CSCW community in recent years (see, for instance, [De Michelis and Grasso, 1994], [Di Eugenio et al., 1997]). Computer tools to aid the CDM process vary from simple classical tools (e-mail mailing lists, dedicated newsgroups and news servers) and web-based discussion forums, to more dedicated systems that address the needs of a user to interpret and reason about knowledge during a discourse. For instance, *QuestMap* [Conklin, 1996] (based on the *gIBIS* hypertext groupware tool [Conklin and Begeman, 1988]) captures the key issues and ideas during meetings and creates shared understanding in a knowledge team. All the messages, documents, and reference material for a project can be placed on the system's ''whiteboard'', and the relationships between them can be graphically displayed. Users end up with a ''map'' that shows the history of an on-line conversation that led to key decisions and plans. Among other systems that address interesting knowledge management and representation issues, we only mention here *Euclid* [Smolensky et al., 1987], *Janus* [Fischer et al., 1989] and *Belvedere* [Suthers et al., 1995] (for a comparative analysis, see [Karacapilidis and Papadias, 1998a]).

Although this category of systems provides a cognitive argumentation environment that stimulates discussion among participants, it lacks decision making capabilities. On the contrary, the HERMES system [Karacapilidis and Papadias, 1998a, 1998b] focuses on aiding decision makers reach a decision, not only by efficiently structuring the discussion, but also by providing reasoning mechanisms for it. Following Conklin's terminology [Conklin, 1992], HERMES not only ''captures the informal organizational memory'' embodied in such environments, but also helps the users during the decision making process itself by integrating features based on concepts from well-established areas such as Knowledge Representation, Decision Theory, Non-Monotonic Reasoning, Constraint Satisfaction, and Truth Maintenance. Note that HERMES is intended to act as an *assistant* and *advisor*, by facilitating communication and recommending solutions, but leaving the final enforcement of decisions and actions to the agents.

The argumentation framework of HERMES is a variant of the informal IBIS model of argumentation [Rittel and Webber, 1973] (as is the case for *QuestMap* and *gIBIS*). HERMES supports as argumentation elements *issues, alternatives, positions,* and *preferences*. Figure 1 illustrates an instance of the system's *Discussion Forum* that concerns a real discussion about the planning of cyclepaths in the city of Bonn. The agents involved in the discussion, namely the representatives from the Cyclists Union and the related City Hall departments, bring up the necessary argumentation in order to express their interests and perspectives. As shown, HERMES maps a multi-agent decision making process to a discussion graph with a hierarchical structure.

While this latter system provides significant automatisation of the decision making process, it is still relatively low-level as far as the *discourse acts* that can be represented are concerned; further refinement of those already integrated is needed. Moreover, there are at least two areas in which further automatisation would be desirable:

- an *argument assistant* that can follow and advise on the *details* of an argument, and not just its form;
- an *argument support tool* that can peruse a document collection. The goal of such a tool would be to find excerpts from the collection that can be used as referal material by the agent to support or refute a given argument.

A prerequisite for such tools is the ability for the computer to understand (at least partially) the dialogue in a decision-related argument between people, and the discourse structure used in presenting supportive material in a document. This requires a computational model of the discourse acts which are used in these cases. Although there has been work in AI on dialogue and discourse in collaboration and negotiation, that work is not sufficient for modeling dialogues in the collaborative decision making process.

For instance, Sidner [1994] presents a model of collaborative negotiation based on the idea of establishing *mutual beliefs*, that is, things that we hold in common. This model

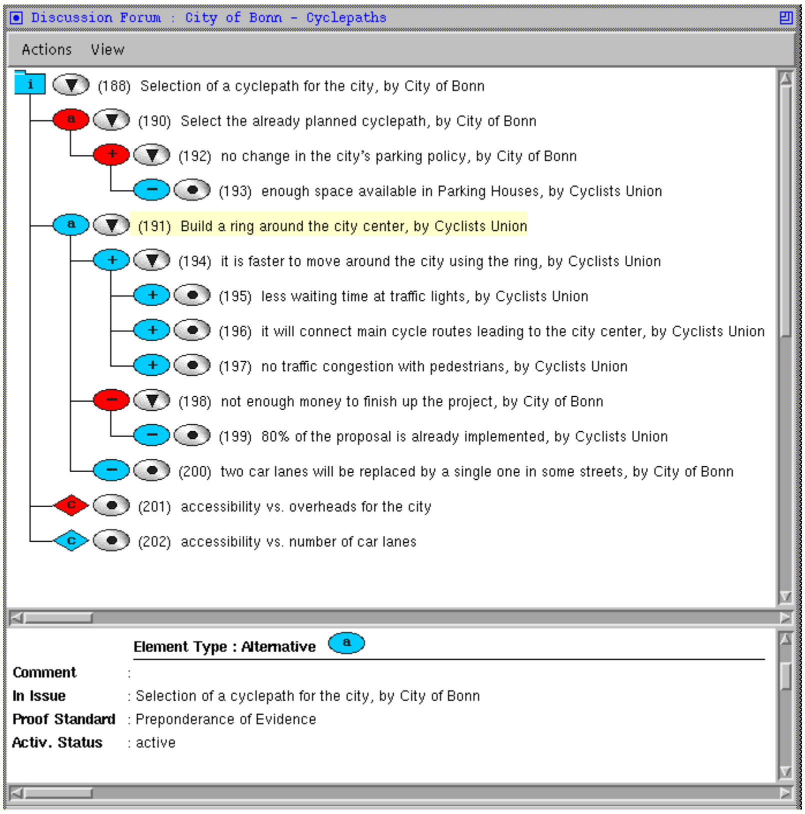

Figure 1: *An instance of the Hermes Discussion Forum*

rests upon the absence of deception, and appears fragile in the presence of mutual misunderstanding. The work of Cohen and Levesque [1990] and of Smith and Cohen [1996] is very similar to Sidner's work, but relies in addition on the primitive notion of *joint goals*. Based on Searle's idea [Searle, 1969] that *requesting* something means that one is attempting to get an agent to perform an action, they define all *illocutionary acts* in terms of agent's mental states (illocutionary is an act performed as the result of a speaker making an utterance; the effect is called a *perlocutionary act*).

Core and Allen [1997] have introduced a scheme for annotating communication acts in dialogue; this scheme ignores the formation of opinions by hearers about speakers, and gives a single coding for each utterance. It is generally the case, however, that utterances can and should be considered to perform multiple functions.

We argue that an understanding of the implications in the CDM process requires a model of the *mental attitudes* of the agents involved (their beliefs, desires, intentions, goals, etc.) as they pertain to the task at hand (see also [Jennings, 1993], [Grosz and Sidner, 1990]). Further, it requires a model of the particular form of *discourse acts* that agents use to communicate their attitudes to each other, and affect the attitudes of others. In addition, it requires a model of the actions that relate to the argument process itself (what we shall refer to as the *internal acts*). The goal of this paper is to propose an acceptable model for these cases. The various approaches described above all take this *rational agent* approach, as do we. The model presented here, however, is oriented explicitly towards CDM.

3 A Model of Discourse Acts in Collaborative Decision Making

Collaborative decision making generally involves much debate between the participants, with negotiations and the formation of power blocks and voting cells (subgroups of individuals who act together with a common strategy or vote as an individual). Conflicts of opinion and interest are inevitable, and people use differing strategies to resolve these conflicts (see [Merin, 1997]). Generally, it is presumed that all participants are being cooperative and honest. Agents act optimally with respect to the information at hand, and do not consider how others might interpret their actions (they do not work to "please the boss").

3.1 Objects and Relations, States and Actions

The first question to consider is the primitive components of the model. This includes objects of discourse such as the alternatives among which we must choose, the criteria for evaluating these alternatives, and the method for applying those criteria (decision function). The participants in the decision process are also "objects" since we must model the interaction between them. We must also allow comparisons between criteria and alternatives along numerical scales, so it must be possible to represent notions such as *"cost is more important than speed"* or *"the total cost must be less than 5,000"* in a car purchase discourse. The basic language that we propose to use is a sorted first-order predicate calculus with extensions for numerical comparison. We will use terms such "*agt1*" or "*agtN*" to denote individual participants, and "*group*" to denote them all.

To understand the dynamics and evolution of a decision, we must have notions of time and states, and of actions that change states. *States* represent a coherent situation. They may be already past or current. In order to consider alternatives to the existing state of affairs, we introduce the notion of a hypothesis, which is an artificial state of the world that may not exist, and may not be possible. It provides a framework for hypothetical reasoning by an agent. If agent *agt1* hypothesizes the state `S1`, then we will write this as:

(HYP agt1 `S1`*)*

Actual states, future states, hypothetical states and temporal intervals are reified objects in our proposal, and all propositions must have them; however, for simplicity, they are only included in the examples here when pertinent.

Actions are defined in terms of the changes that they evoke in states. The simplest acts in our system are the actions of telling something to an agent, and its complement of hearing what an agent is saying:

(TELL agt1 agt2 `P`*), (HEAR agt2 agt1* `P`*)*

In order to describe an action, we will talk about the *effects* it will have. These effects are the difference between a start state and the new state that the action produces. We represent that an act `A` in state `S0` results in state `S` as:

(EFFECT `A S0 S`*)*

States are typified by a non-exhaustive set of assertions, so an action such as turning a switch might be defined as:

(EFFECT Turn(switch) [is(switch,off)] [is(switch,on)]) $\vee$
(EFFECT Turn(switch) [is(switch,on)] [is(switch,off)])

3.2 Primitive Mental Attitudes

When agents interact with each other in a dialogue, there is a number of mental attitudes that dictate the form of the interaction as well as the long-term behaviour of the agents throughout the dialogue. The attitudes can concern states of the world or actions that effect the world.

3.2.1 Beliefs

The most basic of these is the attitude of belief. In the context of AI and in this article, belief is used as a global term that covers the notion of knowledge as well as the notion of information in which we do not have complete confidence. Presuming that this information can be expressed as a proposition in, say, a first-order predicate calculus, then belief can be considered to be a modal operator relating an agent to a belief (see [Ballim, 1992] and [Ballim and Wilks, 1991] for a more detailed description). So, for example, the belief held by the agent *agt1* that ISDN lines are fast might be expressed as:

(BEL agt1 $\forall$`x[ISDN(x)` $\rightarrow$ `fast(x)])`

3.2.2 Mutual Belief

It is often convenient to refer to some belief as being commonly held between a group of agents. Where `P` is such a belief, this will be expressed as:

(MB agt1 ... agtN `P`*)*

3.2.3 Desires

Agents act in a world that is not always the same as the world in which they would like to be. Desires are used to express the wishes of the agent about the state of the world. They may also be expressed as modal operators over propositions. Thus, the desire that MBONE software be used (for some purpose), might be expressed in the following way:

(DES agt1 $\exists$`x[use(x)` $\wedge$ `MBONE(x)])`

3.2.4 Goals

Although agents might desire a particular state of affairs to exist, they are not obliged to act upon those desires. For example, we might all desire a care-free life, but our responsibilities would stop us acting upon this desire by (for example) dropping out of society. State of affairs that we wish to exist, and, further, towards which we actively aspire are referred to as *goals.* If an agent had as a goal that ISDN lines be used in the context of a decision process, then this might be written as:

(GOAL agt1 $\exists$`x[use(x)` $\wedge$ `ISDN(x)])`

3.2.5 Intentions

The essential difference between desires and goals is that there is the notion of having an intention to act to achieve the a goal, while that is not necessarily the case for desires. While it might be useful to thus define *intention* with respect to states of world ("I will work to achieve a certain state of the world") and then define a goal as desiring a state and intending that state, in our framework it is more reasonable that intention is related to actions, so that we intend to perform an action. So, if an agent intends to call another agent, we might represent this as:

(INT agt1 `call(agt1,agt2))`

The predicate `call` above should be interpreted as an action. The relation between our goals and the methods of achieving these goals is a *plan.* A simple plan is a sequence of actions, but more complex plans can be defined which depend on contingencies and options.

3.2.6 Support

For our domain, it is necessary to consider the relationship that agents believe hold between propositions, so we introduce the notion of *support.* Agent *agt1* believes that P1 supports P2 will be written as:

$$(BEL\ agt1\ (SUPP\ \ P1\ \ P2))$$

3.2.7 Refute

The opposition of support is that a belief refutes another. Agent *agt1* believes that P1 disproves P2 will be written as:

$$(BEL\ agt1\ \ (REF\ \ P1\ \ P2))$$

Such definitions are common in AI. While incomplete, they are sufficient to allow us now to describe the model of dialogue and internal acts in collaborative decision making.

3.3 Dialogue Acts

The interactions between agents in a collaborative decision making process are codified using *dialogue acts*. These can be used to interpret the discourse occurring between agents during the decision process, as well as to make inferences about their attitudes and to predict their likely future behaviour. The model that we present here is not a complete model of human discourse, but an interesting subset which allows an analysis of the group decision process. In the following, we define necessary conditions for a dialogue act to have occurred. Multiple dialogue acts can be associated with a single utterance.

3.3.1 Consider

The start of any group decision process involves proposing a topic for consideration. To simplify matters, we will presume that the topic is always an action to be performed (e.g., buying a car, choosing between different video conferencing systems).

$$(CON\ agt1\ group\ A)\ |= (BEL\ agt1\ (EFFECT\ A\ \ S0\ \ S)) \wedge (HYP\ agt1\ S) \wedge (TELL\ agt1\ group\ A) \wedge (GOAL\ agt1\ (HYP\ group\ S))$$

3.3.2 Inform

Agent *agt1* says something to somebody that he believes to be true.

$$(INFORM\ agt1\ agt2\ P)\ |= (BEL\ agt1\ P) \wedge (TELL\ agt1\ agt2\ P)$$

3.3.3 Request

A general dialogue act is that of requesting something. We split up requesting into three sub-cases of agent *agt1* making a demand, and later we will explain more complex requesting in terms of these.

- additional information is requested concerning a belief P:

$$(ASKINFO\ agt1\ agt2\ P)$$

- an opinion is demanded with respect to a belief P:

$$(ASKOP\ agt1\ agt2\ P)$$

- an act A is requested concerning a belief P; for instance, *agt1* wants *agt2* to agree or disagree with a belief P:

$$(ASKACT\ agt1\ agt2\ A\ \ P)$$

In the last case, when *agt1* does not specify the act he wants *agt2* to perform (that is, requests all possible acts), we write: *(ASKACT agt1 agt2 P)*

3.3.4 Compare

It is often necessary to compare beliefs or to compare beliefs with values. This is necessary, for instance, for data consistency purposes. In the dialogue, an agent may declare that they believe one criteria to be more important than another, or that some criteria must have values in a particular range. As such cases are very frequent, we will introduce a *compare* dialogue act to treat them.

$$(COMP\ agt1\ agt2\ \Re\ B1\ \ B2)\ |= (BEL\ agt1\ (\Re\ B1\ \ B2)) \wedge (TELL\ agt1\ agt2\ (\Re\ B1\ \ B2))$$

where $\Re$ is a comparison relation between beliefs (e.g., "is more important than"). For values, we have

$$(COMP\ agt1\ agt2\ \Re\ C\ \ V)\ |= (BEL\ agt1\ (\Re\ C\ \ V)) \wedge (TELL\ agt1\ agt2\ (\Re\ C\ \ V))$$

where $\Re$ is a comparison of criteria (C) with value (V).

3.3.5 Propose

Agent *agt1* proposes that belief P be accepted by another agent.

$$(PROP\ agt1\ agt2\ P)\ |= (DES\ agt1\ (BEL\ agt2\ P)) \wedge (INFORM\ agt1\ agt2\ P)$$

3.3.6 Agree

Agent *agt1* express his agreement with the belief P that was proposed by *agt2*.

$$(AGR\ agt1\ agt2\ P)\ |= (PROP\ agt2\ agt1\ P) \wedge (INFORM\ agt1\ agt2\ P)$$

3.3.7 Acknowledge

Agent *agt1* accepts that belief P may be valid, but that he requires further proof before agreeing to accept it.

$$(ACK\ agt1\ agt2\ P)\ |= (PROP\ agt2\ agt1\ P) \wedge (ASKINFO\ agt1\ agt2\ P)$$

3.3.8 Disagree

Agent *agt1* expresses that he disagrees with a belief P.

$$(DISAGR\ agt1\ agt2\ P)\ |= (PROP\ agt2\ agt1\ P) \wedge (INFORM\ agt1\ agt2\ \neg P)$$

3.3.9 Corroborate

Agent *agt1* agrees with a belief $P1$ and wishes to give it further credence by proposing $P2$.

$$(CORR\ agt1\ group\ P1\ \ P2) \models (AGR\ agt1\ group\ P1) \wedge (INFORM\ agt1\ group\ (BEL\ agt1\ (SUPP\ P2\ \ P1)))$$

3.3.10 Challenge

Agent *agt1* disagrees with belief $P1$, and wishes to further undermine it by proposing $P2$.

$$(CHALL\ agt1\ group\ P1\ \ P2) \models (DISAGR\ agt1\ group\ P1) \wedge (INFORM\ agt1\ group\ (BEL\ agt1\ (REF\ P2\ \ P1)))$$

3.3.11 Discard

Proposal by agent *agt1* to another agent *agt2* to stop considering a belief P that has been proposed.

$$(DISCARD\ agt1\ agt2\ P) \models \neg(BEL\ agt1\ P) \wedge (INFORM\ agt1\ agt2\ (GOAL\ agt1\ \neg(HYP\ agt2\ [P])))$$

3.3.12 Clarify

Agent *agt1* proposes (to *agt2*) a replacement belief ($P1$) for consideration as a clarification and replacement for belief $P2$ which was previously proposed ($P2$ may have been proposed by any agent).

$$(CLA\ agt1\ agt2\ P1\ \ P2) \models (PROP\ agt1\ agt2\ P1) \wedge (INFORM\ agt1\ agt2\ (GOAL\ agt1\ \neg(HYP\ agt2\ [P1]))) \wedge (PROP\ agt1\ agt2\ P2)$$

3.3.13 Counter-offer

Agent *agt1* is not ready to accept the belief $P1$ proposed by *agt2* and, without explicitly disagreeing to $P1$, he proposes a belief $P2$.

$$(COFF\ agt1\ agt2\ P1\ \ P2) \models (PROP\ agt2\ agt1\ P1) \wedge (INFORM\ agt1\ agt2\ (GOAL\ agt1\ \neg(HYP\ agt2\ [P1]))) \wedge (PROP\ agt1\ agt2\ P2)$$

4 An Example Dialogue

Consider the discourse transcription illustrated in Figure 2, which took place among executives of a european research consortium and concerns the purchase of an appropriate videoconferencing tool for their needs. Communication was performed through electronic mail; each individual's message was delivered to all executives through an electronic mailing list. The example comprises portions of the overall discourse and serves the illustration of the computational model suggested in the previous section.

The segmentation of the e-mail messages exchanged, as appears in Figure 2, was made in a way to clearly present the different types of acts involved in such discourses. Messages have been very slightly edited to improve their comprehensibility, that is we almost quote here their most representative parts.

The links appearing in the figure simply denote a *follow up* relation and help the reader to comprehend the evolution of the discourse. In other words, the father node of such a link precedes (has been asserted before) a child node.

For instance, the A16 discourse portion follows up what has been declared in A15, which in turn follows up E4 and so on. Each discourse portion is accompanied by a header that denotes the agent who brought it up and the time order of the portion concerning this very agent (e.g., C3 should be interpreted as the third such portion expressed by agent C). Actually, according to the communication practice followed by the agents, sets of these portions happened to be included in the same e-mail message (e.g., B1, B2 and B3 composed a reply message of agent B to agent A).

Agent A initiates the discourse

A1: "I am writing to you about the choice of a video conferencing tool to be purchased for the purposes of our consortium",

remindseveryone of some conditions holding

A2: "I remind you that the budget is around 30 KECUs and that the choice has to be made by February 15, 1998),

provides a list of questions

A3: "Here is a list of questions I have in order to identify the needs in a more accurate way"

and potential products

A4: "Here is a list of potential products I have already identified", respectively).

and requests some acts from the other agents by a certain date

A4: "Please send your answers and comments before January 25, 1998".

Agents B, C, D and E then discuss the various choice criteria and alternatives initially suggested. Exhorted by the request of agent A for additional products

A9: "Could you please send me additional suggestions of products that either you have heard about or you have experimented yourself."

E brings up in the sequel of the discourse a new alternative

E4: "We have also some recent experience with videoconferencing tools from the MERCI suite",

as agent A also does later

A16: "We could also consider the use of a SMART Board".

In the rest of the section, we express these discourse portions according to the suggested model. When necessary, the expressions are further explained. Note that, whenever