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Computer supported argumentation and collaborative decision making: the HERMES system

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Abstract

Collaborative decision making problems can be addressed through argumentative discourse and collaboration among the users involved. Consensus is achieved through the process of collaboratively considering alternative understandings of the problem, competing interests, priorities and constraints. The application of formal modeling and analysis tools to solve the related processes is impossible before the problem can be articulated in a concise and agreed upon manner. This paper describes HERMES, a system that augments classical decision making approaches by supporting argumentative discourse among decision makers. It is fully implemented in Java and runs on the Web, thus providing relatively inexpensive access to a broad public. Using an illustrative example, we present the argumentation elements, discourse acts and reasoning mechanisms involved in HERMES. We also describe the integration of advanced features to the system; these enable users to retrieve data stored in remote databases in order to further warrant their arguments, and stimulate them to perform acts that best reflect their interests and intentions. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Collaborative decision support systems (CDSSs) can be defined as interactive computer-based systems, which facilitate the solution of ill-structured problems by a set of decision makers working together as a team [1]. The main objective of a CDSS is to augment the effectiveness of decision groups through the interactive sharing of information between group members and the computer. This can be achieved by removing

communication impediments, and providing techniques for structuring the decision analysis and systematically directing the pattern, timing, or content of the related discussions. Major issues arising during the development of such a system are the effective work organization, in order to improve coordination, and the use of communication technology, to make decision making more efficient. Provision of rules and procedures for achieving consistency and automation of data processing, especially in data intensive decision making situations, are also of high importance.

Usually, collaborative decision making (CDM) is performed through debates and negotiations among a group of people. Conflicts of interest are

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inevitable and support for achieving consensus and compromise is required. Each decision maker may adopt and, consequently, suggest his/her own strategy that fulfills some goals at a specific level. Opinions may differ about the relevance or value of a position when deciding an issue. Decision makers may have arguments supporting or against alternative solutions. In addition, they have to confront the existence of insufficient or too much information. In other words, for some parts of the problem, relevant information that would be useful for making a decision is missing, whereas for others, the time needed for the retrieval and comprehension of the existing volume of information is prohibitive.

Furthermore, factual knowledge is not always sufficient for making a decision. Value judgments, depending on the role and the goals of each decision maker, are among the critical issues requiring attention. A CDSS should provide users with appropriate means to assert their preferences, which often are expressed in qualitative terms. Finally, decision makers are not necessarily proficient in computer science and information technology. They need appropriate tools in order to easily follow and participate in the associated processes. Such tools should stimulate their participation giving them an *active* role. This is in accordance with the vision of the DSS community's pioneers: by supporting and not replacing human judgment, the system comes in second and the users first.

This paper describes HERMES, a system developed to address the above issues. HERMES aims at augmenting classical decision making approaches by supporting argumentative discourse among decision makers [2]. It is implemented in Java (applets) and runs on the Web, using any standard browser. The system can be used for distributed, asynchronous collaboration, allowing users to surpass the requirements of being in the same place and working at the same time.

The remainder of the paper is structured as follows: Section 2 outlines the related research work and comments on the role of argumentation in CDM. Sections 3 and 4 describe the *argumentation elements* and the features of the system, respectively, through an illustrative example. Representative *discourse acts* are presented in

Section 5, while tools that provide additional functionality to the system are discussed in Section 6. Finally, evaluation results and concluding remarks are given in Sections 7 and 8, respectively.

2. Argumentation and collaborative decision making

CDM admittedly falls in the category of *wicked* problems [3,4], a class of problems that can be addressed through argumentative discourse and collaboration among the users involved. In such a case, consensus emerges through the process of collaboratively considering alternative understandings of the problem, competing interests, priorities and constraints (see, for instance [5,6]). The application of more formal modeling and analysis tools is impossible before the problem can be articulated in a concise and agreed upon manner.

Research on argumentative discourse has been performed through various viewpoints such as *philosophical*, where argumentation is considered as a way of theory formation [7], *linguistic*, inspired by speech act theory and discourse analysis [8], *rhetorical*, where argumentation is studied primarily as a form of manipulation through language [9], and *psychological*, where the relationships between arguments and cognitive processes are explored [10]. As comprehensively described in [11], most approaches follow two main methodologies, namely, formal and informal logic. According to the *formal perspective*, arguments are de-contextualized sets of sentences or symbols viewed in terms of their syntactic or semantic relationships. For instance, [12] reconstructed Rescher's theory of formal disputation [13], while Gordon's work [14], was based on Geffner and Pearl's concepts of conditional entailment [15].¹ On the other hand, *informal logic* views arguments as pragmatic, i.e., their meaning is a function of their purposive context.

In addition to argumentation theories, implementation of argumentation and decision rationale support systems for different types of groups

¹ A discussion on the use of alternative logics in argumentative discourse can be found in [47].

and application areas has been receiving growing interest in the last few years. Such systems address the needs of a user to interpret and reason about knowledge during a discourse. For instance, *QuestMap* [16] 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 are placed on the “whiteboard”, and the relationships between them are graphically displayed. Users end up with a “map” that shows the history of an on-line conversation that led to key decisions and plans. *QuestMap* has been based on the *gIBIS* hypertext groupware tool [17], which aimed at capturing the rationale of a design process. *Euclid* [18] is another system of this category, which provides a graphical representation language for generic argumentation. Moreover, *JANUS* [19] is based on acts of critiquing existing knowledge in order to foster the understanding of design knowledge. *SEPIA* [20] is a knowledge-based authoring and idea processing tool for creating and revising hyper-documents that views authoring as a design process. Questions, options and criteria (QOC) is another interesting model to represent the rationale of reasoning in a decision making process [21,22], in that it provides users the means to represent and integrate rationale of varying degrees of stability, at different stages in a design process. Finally, *Belvedere* [23], originally designed to support students engaged in critical discussion of science issues, uses a rich graphical language to represent different logical and rhetorical relations within a debate. Although this category of systems provides a cognitive argumentation environment that stimulates discussion among participants, it lacks decision making capabilities.

In the same context, *REMAP* [24] is a conceptual model used to capture deliberations during requirements analysis, which relates process knowledge to the objects that are created during the requirements engineering process. It embodies the *IBIS* model of argumentation [3,4] and is supported by a system based on the *Telos* language [25]. *REMAP* is useful in capturing deliberations and knowledge when transforming requirements into design and enhances previous approaches by adding explicit representation of

decisions, constraints and assumptions, and by introducing knowledge process components. However, the model is not generic, in that it cannot efficiently capture and represent process knowledge across various phases of systems development. Interesting automated rationale based techniques in requirements engineering have been also proposed by Robinson and his colleagues [26,27]. Their *Oz* prototype automates the generation of resolutions in conflicts arising during the integration of multi-user requirements. Using planning techniques (such as back-propagation), *Oz* can detect conflicts and generate compromise resolutions through a requirements restructuring model. Once again, it is our belief that their approach is not generic enough to address alternative decision making environments; as also admitted in [27], requirements need always to be formally represented, and there are open issues concerning coverage of the restructuring methods and their controlling heuristics.

SIBYL [28] is another tool for managing group decision rationale, which has also been viewed as an extension of *gIBIS*; while the latter is mainly a hypertext system whose services focus on the representation of a discourse structure (with the purpose to make it easy for people to see the discourse’s rationale), *SIBYL* is rather a knowledge-based system that provides services for the management of dependency, uncertainty, viewpoints and precedents. *SIBYL* implements decision representation language (DRL) that supports among others goals, alternatives, claims and relations among them. In addition, the tool makes people articulate and become aware of the objectives against which alternatives are evaluated, thus targeting to an explicit representation of goals. However, decision making in *SIBYL* is only performed through simple decision matrices, where users evaluate alternatives with respect to the goals specified; arguments in favor or against an alternative are to be considered by the users before they submit their evaluation.

Increasing interest also develops in implementing Web-based conferencing systems, such as *AltaVista Forum Center*, *Open Meeting*, *NetForum* and *UK Web’s Focus*, to mention some. Such systems exploit the platform-independent commu-

nication framework of the Web, as well as its associated facilities for data representation, transmission and access. They usually provide means for discussion structuring and user administration tools, while the more sophisticated ones allow for sharing of documents, on-line calendars, embedded e-mail and chat tools, etc. Discussion is structured via a variety of links, such as simple *responses* or different *comment types* (e.g., *qualify*, *agree*, *example* in *Open Meeting*) to a previous message. However, the above systems merely provide threaded discussion forums, where messages are linked *passively*; this usually leads to an unsorted collection of vaguely associated comments. As pointed out by the developers of *Open Meeting*, there is a lack of consensus seeking abilities and decision making methods [29].

Contrary to the above systems, our approach focuses on aiding decision makers reach a decision, not only by efficiently structuring the discussion, but also by providing reasoning mechanisms for it. Our primary goal in HERMES was to develop a generic *active* system that efficiently captures users' rationale, stimulates knowledge elicitation and argumentation on the issues under consideration, while it constantly (and automatically) checks for inconsistencies among users preferences and considers the whole set of the argumentation items asserted to update the discourse status. In other words (following Conklin's terminology), the system not only "captures the informal organizational memory" embodied in such environments [30], but also helps the users during the decision making process *per se* by integrating features based on concepts from well-established areas such as Decision Theory, non-monotonic reasoning, constraint satisfaction, truth maintenance and information retrieval. As comprehensively described in the next sections, the reasoning mechanisms of the system can efficiently handle qualitative data and are automatically triggered each time a user inserts a new item in the discourse graph (insertion of a new item may change the status of numerous existing items and make another alternative look as more promising). As a last note, it should be noted here 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 users [31].

3. Argumentation elements

The argumentation framework of HERMES is an extension of ZENO [32], which in turn has its roots to the informal IBIS model of argumentation [3,4]. The basic argumentation elements in HERMES are *issues*, *alternatives*, *positions*, and *constraints* representing *preference relations*.²

Throughout this paper, we use a real example from the medical decision making domain about the appropriate treatment for a patient case. Three medical doctors participate in the discussion, namely Dr. Brown, Dr. Clark and Dr. Wadder; they bring up the necessary argumentation in order to express their interests and perspectives. Fig. 1 illustrates an instance of the corresponding HERMES *Discussion Forum*. As shown, our approach maps a multi-agent decision making process to a discussion graph with a hierarchical structure (upper pane). Each entry in the Forum corresponds to an argumentation element. In the applet window of Fig. 1, each element is accompanied by two icons, one that indicates the element type and another serving for folding/unfolding purposes. Moreover, the numbers shown in parentheses (next to the icons) correspond to a unique ID of the element in the database (IDs are automatically assigned). Finally, each entry in the Forum may contain the username of the user who submitted it and the date of submission (alternative forms of each entry can be obtained through options provided under the **View** menu). The lower pane of the applet window provides all necessary information about a selected entry of the discussion graph (users can select an entry by clicking on it; for instance, **position-11** has been selected in Fig. 1).

Issues correspond to decisions to be made, or goals to be achieved (e.g., **issue-1**: "Prolactinoma case of patient CD-5687-98; what's the appro-

²The IBIS model has as elements issues, positions and arguments; Conklin's variant uses the same set of elements under the terms questions, ideas, pros and cons [4].

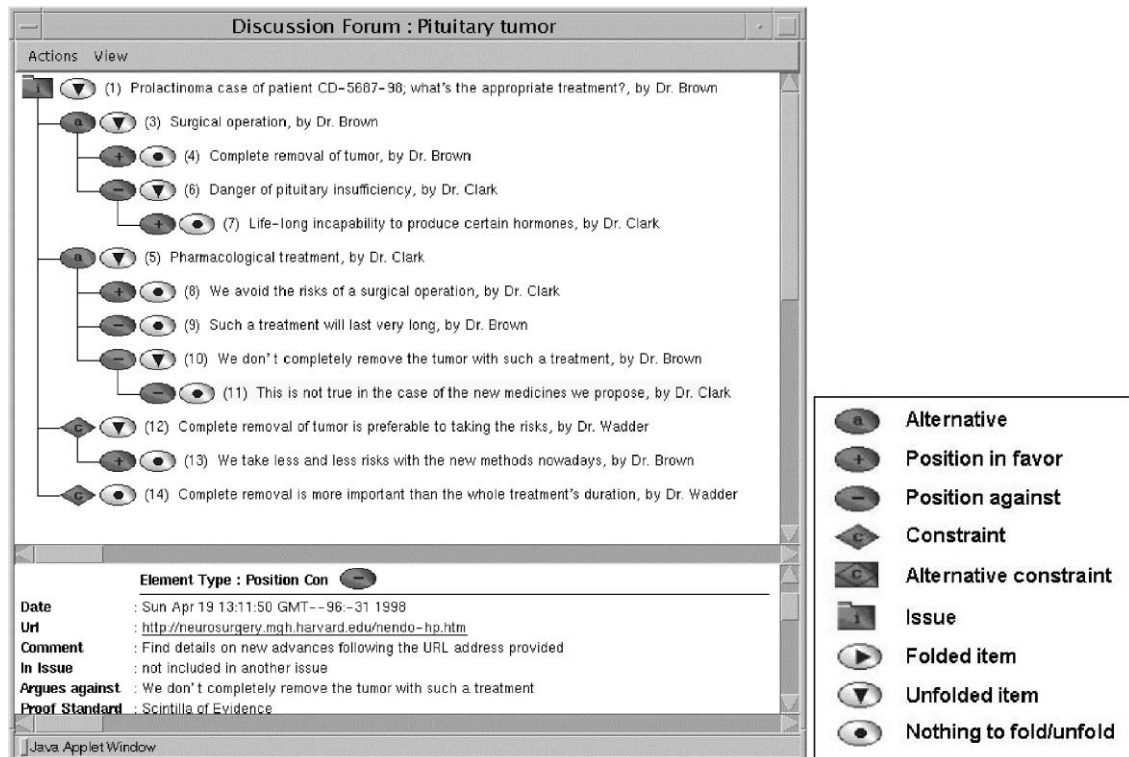


Fig. 1. An instance of the HERMES discussion forum (left) and an explanation of the full notation used in the system (right).

priate treatment?"). They are brought up by users and are open to dispute (the root entity of a Discussion Forum has always to be an issue). Issues consist of a set of *alternatives* that correspond to potential choices (e.g., **alternative-3**: "Surgical operation", and **alternative-5**: "Pharmacological treatment" both belong to **issue-1**, and have been proposed by Dr. Brown and Dr. Clark, respectively).

An issue can be also "inside" another issue, in cases where some alternatives need to be grouped together. For instance, assume that there were two alternative pharmacological treatments, say an ordinary and an innovative one. Fig. 2 shows the structure of the Discussion Forum in such a case. **Alternative-5**: "Ordinary pharmacological treatment" and **alternative-7**: "Innovative pharmacological treatment" have been put together in an internal *subissue* (**issue-6**: "Selection of the appropriate pharmacological

treatment"). During the discourse, the selected (best) alternative of **issue-6** is compared to **alternative-3**.

Positions are asserted in order to support the selection of a specific course of action (alternative), or avert the users' interest from it by expressing some objection. For instance, in Fig. 1, **position-4**: "Complete removal of tumor" has been asserted to support **alternative-3**, while **position-9**: "Such a treatment will last very long" to express Dr. Brown's objection to **alternative-5**. Positions may also refer to some other position in order to provide additional information about it, e.g., **position-11**: "This is not true in the case of the new medicines we propose" (arguing *against* **position-10**), and **position-7**: "Life-long incapability to produce certain hormones" (arguing *in favor* of **position-6**). A position *refers to* a single other position or alternative, while an alternative is always *in* a single issue.

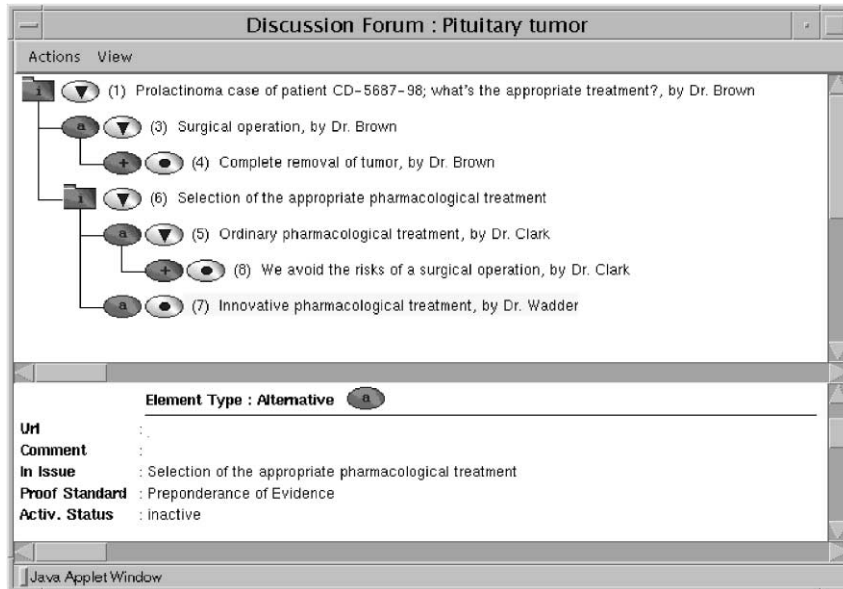


Fig. 2. Subissues.

In decision making environments, one has often to define priorities among actions and weigh different criteria. Well-defined utility and probability functions regarding properties or attributes of alternatives (used in traditional approaches, see for instance [33]), as well as complete ordering of these properties are usually absent. Furthermore, it has been extensively argued that such approaches are impractical for the majority of decision making tasks that involve common sense knowledge and reasoning [34]. In argumentation studies, subjects like *priority relationships* and *preference orders* between arguments have been mostly handled through quantitative approaches [35,36].

In HERMES, *constraints* provide a qualitative way to weigh reasons for and against the selection of a certain course of action. A constraint is a tuple of the form (position, preference_relation, position), where the preference relation can be *more (less) important than* or *of equal importance to*. Constraints refer to an issue (or an internal subissue) and may give various levels of importance to alternatives. Like the other argumentation elements, they are subject to discussion; therefore, they may be “linked” with positions supporting or

challenging them. In Fig. 1, constraint-12: “Complete removal of tumor is preferable to taking the risks” expresses the preference relation “position-4 is more important than position-8”, refers to issue-1 and is supported by position-13.

More specifically, two types of preferences can be expressed by the system:

- *Local*, when a constraint refers to a position, or another constraint. In this case, the positions that constitute the constraint must refer to the same element (i.e., have the same father). In the example shown in Fig. 1, a preference of this type could be expressed by the constraint “position-7 is less important than position-99”, assuming that position-99 has been inserted and refers to position-6. Note that a constraint of the form “position-9 is less important than position-11” is not permitted, since the positions compared through the constraint (called *constituent positions* hereafter) do not refer to the same father element.
- *Non-local*, when a constraint refers to an issue. In this case, its constituent positions must refer to alternatives (not necessarily the same one) of

this very issue (both constraint-12 and constraint-14 fall in this category).

4. System features

This section describes the reasoning mechanisms integrated in the system. Without resorting to formal approaches (such as qualitative probabilistic knowledge [37] and logic of argumentation [38]), such mechanisms determine the appropriate labeling for each entry of the discussion graph, the aim being to keep users aware of the discourse status. As highlighted in Sections 1 and 2 of the paper, the features illustrated here provide the basis for an efficient interworking of multi-agent argumentation and decision making.

4.1. Proof standards

Alternatives, positions and constraints have an *activation label* indicating their current status (they can be *active* or *inactive*). This label is calculated according to the argumentation underneath and the *type of evidence* specified for them. Activation in HERMES is a recursive procedure; a change of the activation label of an element (alternative, position or constraint) is propagated upwards in the discussion graph. For instance, when an alternative is affected during the discussion, the issue it belongs to should be updated since a new choice may be made.

In general, different elements of the argumentation, even in the same debate, do not necessarily need the same type of evidence. Quoting the well-used legal domain example, the arguments required to indict someone need not be as convincing as those needed to convict him [39]. Therefore, a generic argumentation system requires different *proof standards* (work on AI and Law uses the term *burdens of proof*). In the sequel, we describe the ones implemented in HERMES (the names have the same interpretation as in the legal domain). We do not claim that the list is exhaustive; however, other standards, which match specific application needs, can be easily incorporated to the system.

- *Scintilla of evidence* (SoE): According to this proof standard, a position p_i is active, if at least one active position argues in favor of it: $active(p_i) \Leftrightarrow \exists p_j (active(p_j) \wedge in_favor(p_j, p_i))$.
- *Beyond reasonable doubt* (BRD): According to BRD, a position p_i is active if there are not any active positions that speak against it: $active(p_i) \Leftrightarrow \neg \exists p_j (active(p_j) \wedge against(p_j, p_i))$.

In the case of the third proof standard, each position has a $weight = (max_weight + min_weight)/2$, while an alternative with no positions linked underneath has a $weight = min_weight$. Both max_weight and min_weight are initialized to some predefined values (in the following, we assume that initially $min_weight = 0$ and $max_weight = 10$; this may be changed by preference constraints). The *score* of an argumentation element e_i is used to compute its *activation label*. If an element does not have any arguments, its score is equal to its weight; otherwise, the score is calculated from the weights of the active positions that refer to it:

$$score(e_i) = \sum_{\substack{in_favor(p_j, e_i) \wedge \\ active(p_j)}} weight(p_j) - \sum_{\substack{against(p_k, e_i) \wedge \\ active(p_k)}} weight(p_k)$$

- *Preponderance of evidence* (PoE): According to this standard, a position is *active* when the active positions that support it outweigh those that speak against it: $active(p_i) \Leftrightarrow score(p_i) \geq 0$. Concerning alternatives, PoE will produce positive activation label for an alternative a_i when there are no alternatives with larger score in the same issue: $active(a_i) \Leftrightarrow \forall a_j in_issue(a_i), score(a_j) \leq score(a_i)$. Note that, according to the above, more than one alternative can be active at a discussion instance (e.g., consider a case where three alternatives a_1 , a_2 and a_3 have scores 8, 5 and 8, respectively; a_1 and a_3 are both active, while a_2 is inactive).

In the discussion instance of Fig. 1, it has been assumed that the proof standard is SoE for all positions and PoE for alternatives (for more on the selection of a proof standard, see Section 5). **Position-10** is inactive (in the system's interface windows, the accompanying icons of inactive items appear in red color) since **position-11** is active and

speaks against it (note that, according to the definition of SoE, **position-10** needs an active position that will argue in favor of it in order to become active again). On the contrary, **position-6** is active (in the system's interface windows, the accompanying icons of active items appear in blue color) since there is at least one active position (**position-7**) that speaks in favor of it (similarly to the above, **position-6** will become inactive if a new position will argue against **position-7**). Active positions are considered "accepted" due to discussion underneath (e.g., strong supporting arguments, no counter-arguments), while inactive positions are (temporarily) considered as "discarded" or "rejected".

Similarly, active alternatives correspond to "recommended" choices, i.e., choices that are the strongest among the alternatives in their issue. Note that both alternatives are actually (at the discussion instance shown in Fig. 1) linked with a position in favor and a position against them (concerning **alternative-5**, the second position against it, namely **position-10**, is inactive). If there were not any constraints, the two alternatives would receive the same score. The insertion of **constraint-12** and **constraint-14** renders a higher score to **alternative-3** (calculation of scores is described in detail in Section 4.3), hence this is the solution currently indicated by the system.

The activation label of constraints is decided by two factors: the discussion underneath (similarly to what happens with positions) and the activation label of their constituent positions. In Fig. 1, both constraints have BRD as proof standard; therefore, they are currently active. If during the evolution of the discussion, a new position inactivates **position-4**, this will result in the inactivation of both constraints, since **position-4** is one of their constituent positions (assuming that nothing else related to them changes). In such a case, the two alternatives will receive again the same score.

4.2. Detecting conflicts and inconsistencies

Apart from an activation label, each constraint has a *consistency label*, which can be *consistent* or

inconsistent. Every time a constraint is inserted in the discussion graph, the system checks if both constituent positions of the new constraint exist in another, previously inserted, constraint. If yes, the new constraint is considered either *redundant*, if it also has the same preference relation, or *conflicting*, otherwise. A redundant constraint is ignored, while a conflicting one is grouped together with the previously inserted constraint in an issue automatically created by the system, the rationale being to gather together conflicting constraints and stimulate further argumentation on them until only one becomes active. It should be noted here that both constituent positions of a new constraint have been already inserted in the discussion graph; thus, whenever a user is about to insert a new constraint, the system provides him/her with a list of all possible combinations to select from (see Fig. 7 and the related discussion in the next section).

To illustrate the above, recall that in the discussion instance shown in Fig. 1, **issue-1** contains two constraints, namely **constraint-12** and **constraint-14**. The latter has been asserted by Dr. Wadder and expresses the preference relation "**position-4** is more important than **position-9**". Assume now that Dr. Clark has another opinion on this relation believing that "**position-4** is less important than **position-9**". Fig. 3 depicts the Discussion Forum applet window after the submission of the corresponding constraint by Dr. Clark (**constraint-16**: "Complete removal is less important than the whole treatment's duration"). Note that the icons of the two associated constraints have been changed now (these icons correspond to what we call *alternative constraints*). A new issue (**issue-15**) has been also (automatically) brought up, which consists of these two constraints. The subject of such an issue is standard, namely "issue contains alternative (inconsistent) constraints". Alternative constraints are obviously open to discussion; users may submit appropriate argumentation items to speak in favor or against them (actually, constraints are now handled as proper alternatives; in other words, the system calculates their scores taking into account the weights of the active positions that argue in favor or against them). In Fig. 3, the

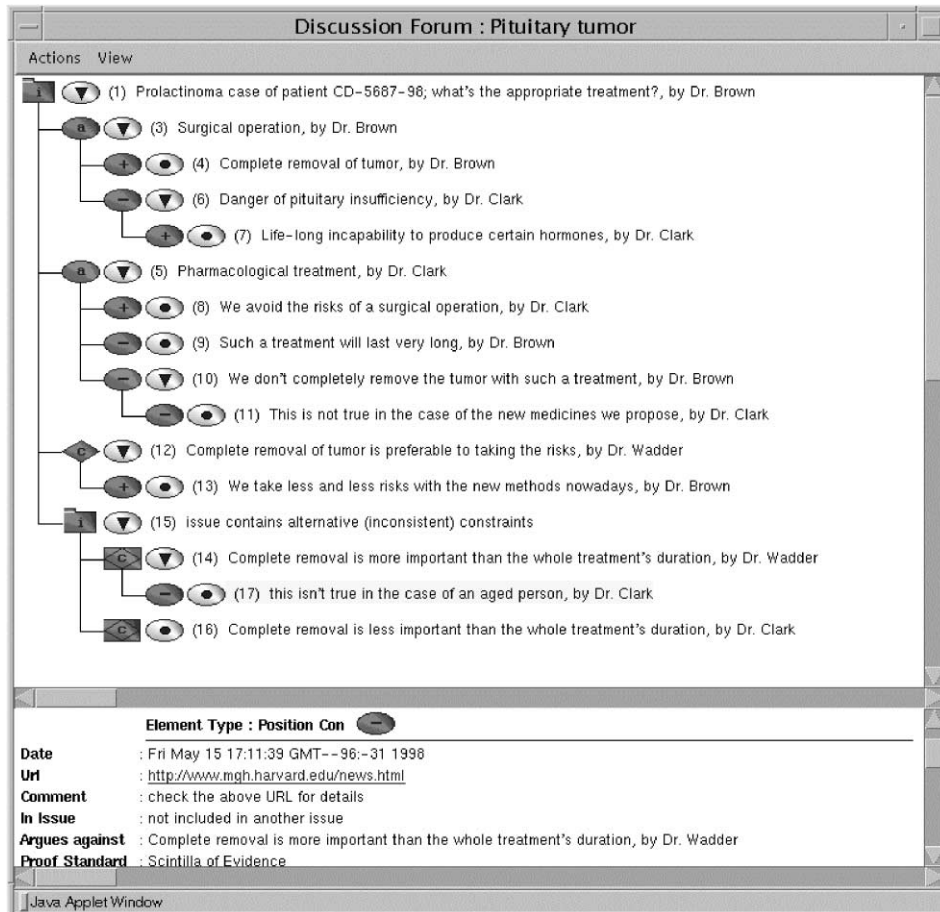


Fig. 3. Detecting inconsistent constraints.

insertion of position-17: “this is not true in the case of an aged person” has resulted to the inactivation of constraint-14 (since constraint-16 has a larger score); therefore, issue-15 is “resolved”, by proposing constraint-16 (issue resolution is performed through the weighting mechanism, which is comprehensively described in the next section). In turn, constraint-12 and constraint-16 are now the ones taken into account for the resolution (selection of the best alternative) of issue-1.

If both positions of the new constraint do not exist in a previously inserted constraint, its consistency is checked against previous active and consistent constraints referring to the same

element (or belonging to the same issue). Consider for instance a situation, where there exist two constraints “position-x is more important than position-y” and “position-y is more important than position-z”. A new constraint “position-z is more important than position-x” would be inconsistent with respect to the first two ones, although it is not directly conflicting with either one. Inconsistency checking is performed through a polynomial ($O(N^3)$, N the number of the associated positions) *path consistency* algorithm [40]. Although path consistency, as most discourse acts described in the sequel, interacts with the database where the discussion graph is stored (the “public-domain” *mSQL* is used), the algorithm is efficient;

even for non-local preferences involving issues with numerous alternatives and positions linked to them, execution time is negligible compared to communication delay.

4.3. The weighting mechanism

Active and consistent constraints participate in the weighting mechanism (only **constraint-12** and **constraint-16** in the example of Fig. 3). In order to demonstrate how the algorithm for altering weights works, we use the example of Fig. 4. There exist five positions and four constraints that relate them as illustrated in Fig. 4a. The arrowed lines correspond to the “more important than” ($>$) relation (e.g., $p_1 > p_2$) and the dotted line to the “equally important to” ($=$) relation (e.g., $p_3 = p_4$). Initially (with no constraints inserted in the system), each position would have a $weight = (-max_weight + min_weight)/2 = 5$ (as stated in Section 4.1, we have assumed that $max_weight = 10$ and $min_weight = 0$). *Topological sort* [41] is applied twice to compute the possible maximum and minimum weights for each position (Fig. 4b). The new weight of each position (having taken all constraints into account) is the average of its new max_weight and min_weight . More specifically, it is: $weight(p_1) = 6$, $weight(p_2) = 4.5$, $weight(p_3) = 5$, $weight(p_4) = 5$ and $weight(p_5) = 4$.

For instance, the scores of **alternative-3** and **alternative-5** in Fig. 3 are 0 and -2 , respectively, since **position-4**, **position-6**, **position-8**, and **position-9** have scores 5, 5, 4 and 6, respectively (**position-10** is inactive). Therefore, **alternative-3** is active and recommended by the system. If **position-9** were also inactive (assuming that nothing

else had changed), the scores of the above two alternatives would be 0 and 4. In this case, **alternative-5** would be the recommended one.

The basic idea behind the above mechanism is that the weight of a position is increased every time the position is more important than another one (and decreased when it is less important), the aim being to extract a total order of alternatives. Since only partial information may be given, the choice of the initial maximum and minimum weights may affect the system’s recommendation. Furthermore, this weighting scheme is not the only solution; alternative schemes, based on different algorithms, are under implementation.

5. Discourse acts

Argumentation in our framework is performed through a variety of *discourse acts*. These acts may have different functions and roles in the argumentative discourse. We classify them in two major categories: *agent acts* and *internal (system) acts*.

5.1. Agent acts

Agent acts concern user actions and correspond to functions directly supported by the user interface. Such functions include the opening of an issue, insertion of a new alternative to an issue, addition of a new alternative to an existing alternative, insertion of a new position in favor or against an existing position/constraint/alternative, and insertion of a new constraint to an existing issue. There is also another agent act, which is not immediately connected to the

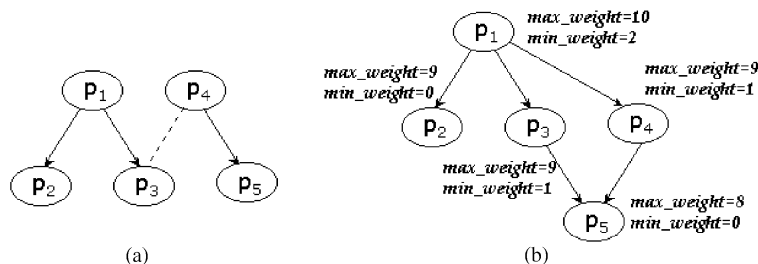


Fig. 4. The weighting mechanism.

Discussion Forum, that allows users to ask the system's database queries of the form “give me all messages by a *specific user* on an *issue*” or “what was the recommended solution on a *given date*”. In the sequel, we present the pseudo-code for a few representative agent acts:

```

add_Altern..to_Issue (altern. alt, issue iss) {
    ln(alt) = iss; /* alt is attached in iss */
    update(iss); }

add_Altern..to_Altern. (altern. alti, altern. altj) {
    issj = ln(altj);
    create new issue issi;
    ln(issi) = issj;
    ln(alti) = ln(altj) = issi;
    update(issi); }

```

The applet window for adding a new alternative to an existing issue is shown in Fig. 5. When an alternative alt_i is added to another alt_j (and not directly to the issue iss_j where alt_j belongs), a new issue iss_i is automatically created inside iss_j . Both alt_i and alt_j are now put inside the new issue and compared through $update(iss_i)$. $Update(iss_i)$ will be called from $update(iss_j)$ and the recommended choice between alt_i and alt_j will be compared against the other alternatives of the external (initial) issue. Note that in Fig. 5, users can give a *subject* (title) of the new alternative, but also provide more details about their entry through the URL pane. More specifically, they can fill in a web address that corresponds to a file with multimedia content. In such a way, they actually “attach” to their elements

Fig. 5. Adding a new alternative.

Fig. 6. Adding a new position.

larger pieces of text, images, figures, sound, etc., thus providing the extra information needed.

The applet window for adding a new position is shown in Fig. 6. The *father* element can be an alternative, another position, or a constraint. In addition to the “Add a new alternative” applet window, users have to specify here the *type of link* (*argues for* or *argues against*) and the *proof standard* they prefer (depending on the discussion context, this option may be inactivated; that is, the same proof standard is used for all positions). The purpose of the **Consult Database** button will be discussed in the next section.

Fig. 7 illustrates the applet window for adding a new constraint to an issue. Depending on the argumentation element selected for its insertion, the *pair of items* pane provides users a menu with all valid pairs (combinations) of positions, preventing users from making errors in expressing a preference. The *relation type* menu includes the preference relations *more (less) important than* and *equally important to*. The pseudo-code for adding a constraint to an issue is as follows:

```

add_Constraint_to_Issue (constraint con, issue iss) {
    if (redundant(con)) return; /* ignore */
    refersTo(con) = iss;
    for all constraints coni that refer to iss
        if (conflicting(conj, con))
        {
            create new issue issn;
            ln(conj) = issn;
            ln(con) = issn;
        }
}

```

Constraint

Java Applet Window

Add a new Constraint

The new constraint will be included in the issue below.

In Issue : Prolactinoma case of patient CD-5687-98; what's the appropriate treatment?

Add information about the new constraint below.

Subject : Complete removal of tumor is preferable to taking the risks

Preference

Pair of Items : (4) Complete removal of tumor vs. (8) We avoid the risks of a surgical operation

Relation Type : first item is more important than the second one

Proof Standard : Beyond Reasonable Doubt

URL : <http://www.unil.ch/med/surgical/reports/A175.htm>

Comments : Justification about my preference can be found in a previous report available at the URL address I provide. We should certainly pay much attention to the particularities of the patient's case

Submit **Clear** **Cancel**

Fig. 7. Adding a new constraint.

```

update(issn);
return; }
if (contains_inactive(con))  $\neg$  active(con);
else { active(con);
      if ( $\neg$  consistent_with_previous}(con))
           $\neg$  consistent(con);
      else { consistent(con);
            update(iss); }}}

```

Redundant and conflicting constraints were discussed in the previous section. **Contains_inactive** (*con*) checks whether one or both constituent positions are *inactive*, in which case *con* becomes *inactive*. The justification is that it does not make sense to argue about the relevant importance of positions that are rejected (*con* will be activated automatically when the constituent positions get activated—see **activate** (*position pos*)). If *con* does not **contains_inactive**, then it is checked for consistency. Only if it is found consistent, the position that it refers to is updated, since inconsistent constraints do not participate in the weighting scheme.

5.2. Internal acts

Internal acts are functions performed by the system in order to check consistency, update the discussion status and recommend solutions. These functions are automatically triggered by the agent acts (that is, whenever a new item is added in the

discourse graph) and are hidden from the end user. For instance, **consistent_with_previous** (*con*), called by **add_Constraint_to_Issue**, constructs a graph similar to Fig. 4 and applies path consistency. In the rest of this section, we present the pseudo-code and an analysis of the most representative internal acts:

```

boolean compute_activation(position pos) {
boolean  $\neg$  status_changed, old_activation = activation(pos);
switch Proof_Standard(pos) {
case Scintilla of Evidence {
 $\neg$  activation(pos);
for all positions posj that refer to pos
if (active(posj)  $\wedge$  in_favor(posj, pos))
{ activation(pos);
break ; } }
case Beyond Reasonable Doubt {
activation(pos);
for all positions posj that refer to pos
if (active(posj)  $\wedge$  against(posj, pos))
{  $\neg$  activation(pos);
break ; } }
case Preponderance of Evidence {
score(pos) = 0;
calculate_weights(pos);
for all positions posj that refer to pos
if (active(posj)  $\wedge$  in_favor(posj, pos))
score(pos) + = weight(posj);
else if (active(posj)  $\wedge$  against(posj, pos))
score(pos) - = weight(posj);
if (score(pos)  $\geq$  0) activation(pos);
else  $\neg$  activation(pos) } }
}

```

```
if (old_activation != activation(pos)) status_changed;
return status_changed; }
```

Compute_activation returns *status_changed*, which is *true* if the activation label of the position changed. Activation is calculated according to the proof standard used. Proof standards are a straightforward implementation of the definitions given in Section 4.1. In case of PoE, **calculate_weights(pos)** calls topological sort to compute the weights of the positions in favor and against *pos*.

```
update(position pos) {
  if (compute_activation(pos)) {
    if (active(pos)) activate(pos);
    else inactivate(pos);
  }
  update(RefersTo(pos)); } } /* propagate upwards */
```

Update calls **compute_activation** to check whether activation label has changed. If this is the case, **activate** (see below) or **inactivate** are called and the change is propagated upwards. Note that **update** is automatically called and executed by the system each time a user adds a new item (i.e., alternative, position, constraint) in the discourse graph.

```
activate(position pos) {
  posj = refersTo(pos);
  for all constraints conj that refer to posj
    if (¬ active(conj) ∧ conj has a preference relation on pos)
      if (compute_activation(conj)) {
        if (consistent_with_previous(conj)
            consistent(conj);
        else ¬ consistent(conj); } }
```

Activation of position *pos* involves the retrieval of the constraints where *pos* appears (that is, the constraints whose one of the constituent parts is the position *pos*) and a check as to whether they can now become *active* and *consistent*. Inactivation of positions is similar, in the sense that when a position becomes inactive, the system searches for the constraints where the position appears and inactivates them as well. This may cause some other inconsistent constraints to become consistent, so consistency check is performed again for the related constraints.

In addition to the above, other internal acts have been implemented for the activation/inactivation of constraints and the update of issues (in which case there is only PoE). The procedures described in this section, although only a subset of the whole set of functions performed by the system, give an indication of its dynamic structure. A single insertion in the discussion graph may update a large portion of the tree. Every time there is a change, the status of the argumentation elements is recorded in the database that keeps track of the discourse.

6. System enhancements

This section describes the integration of additional features to HERMES. Having as ultimate goal the development of an advanced system for real CDM applications, we aim at providing users efficient means to further assist them during argumentation-based decision making processes.

6.1. The information retrieval tool

In order to reach understanding, negotiate and resolve conflicts, users may use various types of information to warrant their arguments towards the selection or rejection of a statement or action. Such information may be stored either in the system's proprietary database, or in external, remote ones consisting of legacy data. The information retrieval tool (IRT) allows users to ask queries regarding an ongoing discussion. Each time users want to add a position in the discussion graph, they can use IRT to retrieve auxiliary information from a pre-specified set of databases (the tool provides easy addition or removal of a database from this set).

Fig. 6 illustrates the applet window for adding a new position in favor of position-4: "Complete removal of tumor" (see again the example given in Section 4). This act can correspond to Dr. Brown's wish to further support position-4 by bringing up information concerning previous cases. Clicking on the **Consult Database** button, a new window applet appears; one can then select the database

and which of its tables he/she wants to consult, and then submit a query. Fig. 8 illustrates such a query to a remote medical database. Note that this applet window is dynamically created, depending on the database and table selected by the user (this is achieved by exploiting *metadata* about the structure of each database). Also, depending on the contents of a database's table, the appropriate *selection menu buttons* for each entry will be placed (upon the data type of each field of the selected table). For instance, a selection menu with the options {before, after, is, is not} will be attached next to a date-type entry; a different one, with the options {contains, does not contain, is, is not}, next to a string-type entry, and so on. In the example shown in Fig. 8, the user looks for patient

cases where their examination date is after 01/01/97, morbidity contains the word “tumor”, diagnostic contains the word “prolactinoma”, the patient age (at the examination date) is larger than 50 years, and so on. Fig. 9 depicts the applet window with the results of the query shown in Fig. 8.

Communication with a set of remote databases is achieved through the common object request broker architecture (CORBA) protocol, which has become a standard for interoperability in heterogeneous computing environments. The *Visigenic's "VisiBroker for Java"* environment has been used in our implementation; it is a complete CORBA 2.0 ORB environment for building, deploying and managing distributed Java applications that interoperate across multiple platforms. For instance, in the example discussed in this paper, the users could consult a *MS Access* medical database, running on a PC platform, and an *Oracle* one, on Unix.

6.2. The argument builder tool

Ongoing work is being performed towards the development of an argument builder tool (ABT), which aims at assisting users to construct robust arguments. The tool basically deals with perusal of a discussion, in order to suggest the appropriate acts to be (individually) followed. It will extensively be interworking with IRT; having retrieved the required information, ABT will help decision makers to “wrap” these data with the appropriate discourse acts, to be then submitted to the corresponding discourse graph. The tool relies on a set of rules, concerning the *grammar* and *syntax* of CDM-related discussions. It comprises methods

Fig. 8. Consulting a remote database.

Result of the Query												
patient ID	age	emergency	exam. da...	morbidity	requester	origin	endoscopy	diagnostic	history	chapter No	scenario ...	doctor ID
CD-123...	55	high	23/04/98	tumor	Muller	Germany	NULL	prolactin...	NULL	3	87	GP-123
CD-765...	63	normal	12/01/97	tumor pi...	Martin	Switzerla...	PR-DA-23	prolactin...	NULL	2	65	GP-124
CD-443...	51	normal	25/03/98	tumor	Allaf	Lebanon	NULL	prolactin...	NULL	5	87	GP-123

Fig. 9. The query results.

that, at any time, try to match *patterns* of an ongoing discussion with pre-specified ones (topological matching). For instance, if one's position is supported by only one piece of evidence, it will suggest him/her to take the appropriate actions to further support it; in cases of conflicts between users (see previous section about conflicting constraints), it will advise them on actions for conflict resolution (such actions intend to achieve a deeper understanding of the issue to be solved). Note that, in any case, users are free to adopt or discard such suggestions. In addition, by exploiting case-based reasoning (CBR) techniques, the tool will provoke the submission of the appropriate queries to the related databases and point out discourse acts that successfully reflect the interests and intentions of the parties involved (some preliminary work is presented in [42]). Such techniques have been particularly useful in the CDM domain, due to their resemblance to the way people evaluate a potential future action by using past experience, the scarcity (or even absence) of explicitly stated rules, and the ill-structured definitions of the associated problems [43].

Related work has been recently performed in the context of the *Belvedere* system [44] to address students' tasks to find and use information about a scientific controversy (note that, in *Belvedere*, the required information exists in a prepared, rather modest, domain-relevant database of HTML documents; on the contrary, as described above, HERMES is able to access any-platform, remote databases). Another interesting approach, based on an integration of CBR and multi-attribute utility theory (MAUT), is followed in PERSUADER [45] to provide conflict resolution and negotiation support in labor-management disputes. In general, keeping track of previous cases (in HERMES's proprietary database) can also increase the efficiency of the system, by reusing previous instances of similar argumentation; such cases can be also attached as warrants to one's arguments.

7. Evaluation results

HERMES has been evaluated by different types of users, such as high school and university students,

well-experienced computer science researchers, medical doctors, and civil and mechanical engineers. Evaluation has been conducted in three research labs (namely, FIT-KI at GMD-Sankt Augustin, Germany, AID at INRIA-Sophia Antipolis, France, and LITH at EPFL, Switzerland), a university department (Dept. of Mechanical Engineering, EPFL, with the participation of 3 professors and 46 undergraduate students) and a hospital (CHUV, Lausanne, Switzerland, with the participation of 12 medical doctors). The average number of users in each research lab was 9. Furthermore, 16 high school students were involved in the evaluation during two public demonstrations of the system in the second lab.

In all evaluation stages, users worked with individual computers and in different rooms. Even for inexperienced users, a system introduction of less than an hour was sufficient to get them acquainted with HERMES. A human moderator supervised the argumentation and assisted the users whenever needed. The role of the supervisor was similar to that of a system's administrator, i.e., to provide access rights, make sure that elements were inserted to the right position in the discussion graph, etc.

During the early evaluation phases, we asked for feedback concerning the usability of the model, the discourse structure, and the functionality of the user interface. Setting up various pilot discussions and by applying their individual way of argumentation, users contributed significantly in what the system looks like today. Features like nested issues or the grouping of conflicting constraints in a separate issue resulted from various suggestions at this stage.

In the sequel, the system was evaluated through two real application projects. The first concerned an instructional environment for Mechanical Engineering undergraduate students, which use the system to solve a problem given by their supervisor [46]. Students contemplate alternative solutions and argue on them linking their argumentation elements with existing electronic documents (supervisor's notes, papers, etc.). The second project was in the context of medical decision making; more specifically, it concerned the appropriateness of certain medical and surgical

procedures for patients with various tumor-related symptoms (the examples used in this paper have been extracted from this project). The objective was the achievement of consensus as to whether a medical treatment or an operation is appropriate. Doctors used the system from remote machines, mostly in an asynchronous way, to express and validate their proposals and argue on those of the others. This particular application motivated us to enhance HERMES with IRT (due to the practices followed in real life and the numerous medical databases available).

Each discussion in the first real application project involved 3–6 users, depending on the problem under consideration (12 different discussions were constructed). A supervisor and some students were using the system for a period of one academic semester. In some problems, argumentation was quite lengthy, with more than 3–5 argumentation items submitted. As far as the second application is concerned, discussions lasted from 2 weeks to 5 months, with the participation of 3–5 medical doctors (the system was tested in 7 different discussions). In one case, the related Discussion Forum consisted of more than 80 argumentation items (5 users, about 4 months

long), while most discussions comprised 20–40 items. In all cases, the system was properly performing (negligible execution time), indicating that HERMES can efficiently handle long argumentation processes.

Two series of questionnaires were distributed to all users involved in these two projects (61 in total: 3 professors, 46 undergraduate students, 12 medical doctors). We received feedback from 50 of them (3 professors, 35 undergraduate students, 12 medical doctors). The objective of the first questionnaire was to evaluate the users' overall opinion about the system. Users were asked whether HERMES is easy and enjoyable to use, provides efficient support to organize an electronic discourse, and stimulates discussion. Also, whether the time spent working with it was worthy and they intend to use it again in the future. To fill the questionnaire in, users had to give an answer from the (strongly agree, agree, neutral, disagree, strongly disagree) scale (results are given in Fig. 10). The objective of the second questionnaire was to get users' assessments about the effectiveness of the proposed CDM environment. More specifically, users had to evaluate the levels of interaction (answering whether what they

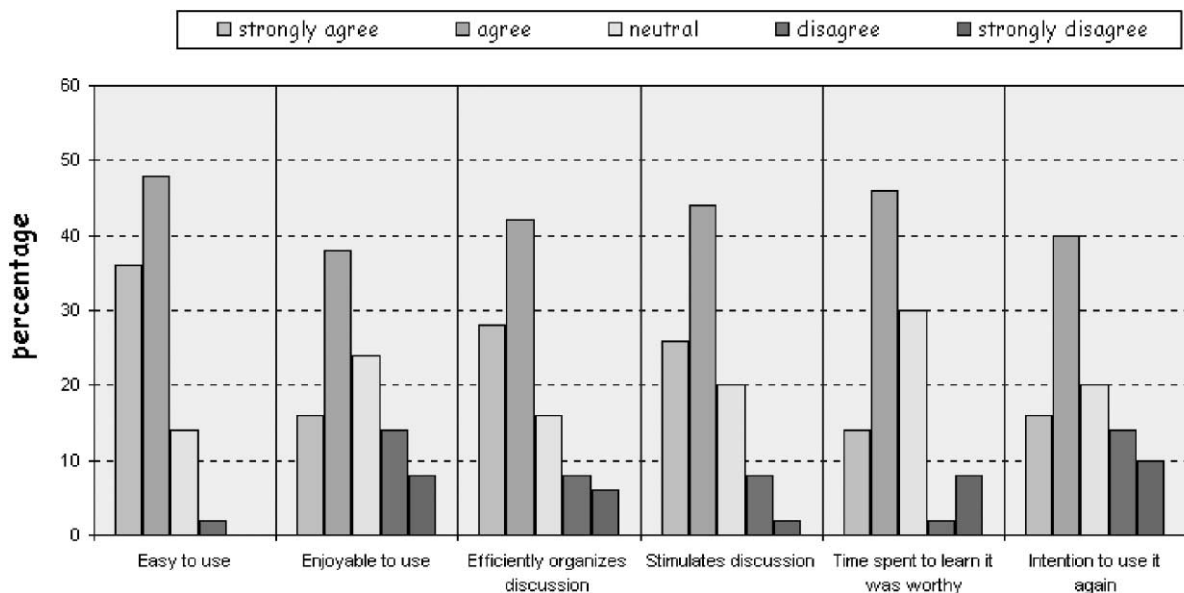


Fig. 10. Evaluation data—Questionnaire I.

had to do and had achieved using the system was clear, the content level was right and challenging, and the presentation was sufficiently informative), interfaces (answering whether windows are easy to read, terms and procedures for navigation are consistent, and functions, menus and icons provided are easy to understand) and navigation offered (answering whether it was easy to find out what they had already completed and what is still to be done, and what options were available). For all these issues, users had the (agree, neutral, disagree) choices to select from (results are given in Fig. 11).

The feedback we received was certainly encouraging. In all issues raised in the first questionnaire, the percentage of the positive answers (sum of the strongly agree and agree percentages) was over 54% (note that it was 84% for the “easy to use” issue). Very positive results came also out of the second questionnaire; the percentage of the positive answers (agree) was in the range 48–78%, the users being more skeptical on the “right and challenging content level” issue. Having further elaborated their answers to this very issue, we concluded that this was due to the change of the way they were accustomed to work. However, the majority of the users was convinced that the appropriate integration of web-based tools in a

CDM environment has a high potential to enhance its effectiveness.

8. Conclusion

We have presented HERMES, a system that aids decision makers reach a decision, not only by efficiently structuring the discussion rationale, but also by providing reasoning mechanisms that constantly update the discourse status in order to recommend the most backed-up alternative. Our primary goal was to develop an *active* system, which not only “captures the informal organizational memory” embodied in decision making settings, but also helps the users during the decision making process *per se*. We view human intervention as necessary to determine certain instances of the argumentation items being asserted and the relations holding between them. HERMES acts as an *assistant* and *advisor*, by facilitating communication and recommending solutions, but leaving the final enforcement of decisions and actions to the decision makers involved. Exploiting the system’s features, users can better understand the arguments of their fellow decision makers, and advance more pointed argumentation of their own.

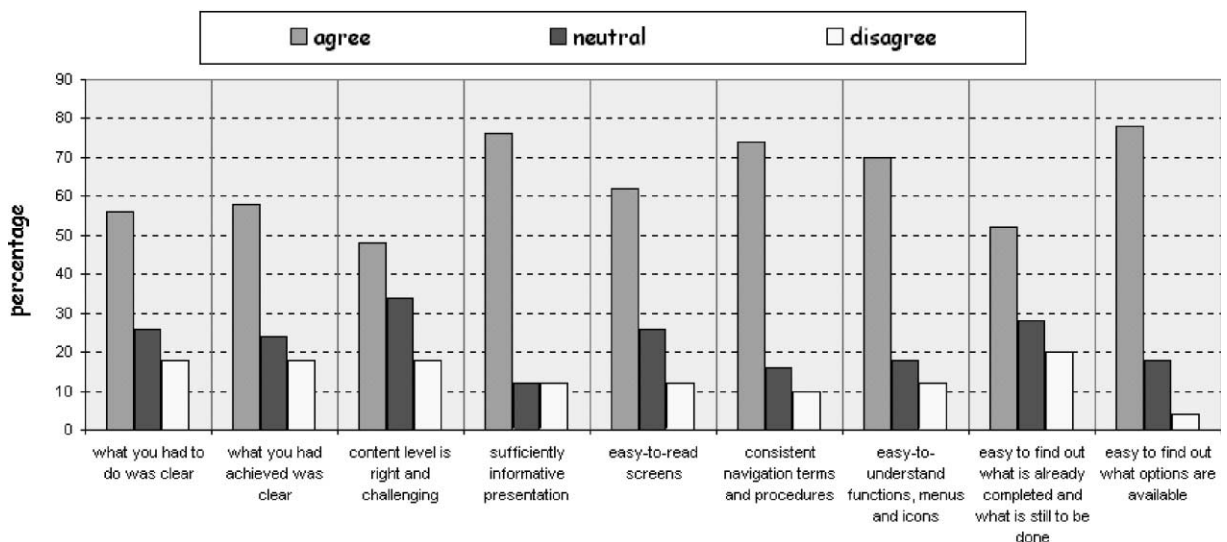


Fig. 11. Evaluation data—Questionnaire II.

It is our belief that the integration of the system modules discussed in this paper with a properly specified model of discourse acts is the most reasonable way to cross the divide between, on the one hand, the simple systems for remote CDM that provide no more than a communication channel and archiving facility between participants (e.g., newsgroups and web forums) and, on the other hand, fully-blown reasoning systems that attempt to automatically solve the decision making problem. This latter approach appears to us to be infeasible at the moment. However, the mix of human and machine reasoning, that forms the basis of our framework, appears to be feasible.

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