CBR and Argument Schemes for Collaborative Decision Making

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Abstract.
In this paper we present a novel approach for combining Case-Based Reasoning (CBR) and Argumentation. This approach involves 1) the use of CBR for evaluating the arguments submitted by agents in collaborative decision making dialogs, and 2) the use of Argument Schemes and Critical Questions to organize the CBR memory space. The former involves use of past cases to resolve conflicts among newly submitted arguments by assigning them a strength, and possibly submitting additional arguments deemed relevant in similar past deliberations. The latter enables use of agents’ submitted arguments instantiating Argument Schemes and Critical Questions, to assess the similarity among cases. Hence, a case is simply defined as a placeholder for the available data related to an experience, and it is the submitted arguments associated with each experience that provide means for comparing cases. This use of CBR and argumentation is formulated with the ProCLAIM model, which features a Mediator Agent that directs proponent agents in their deliberation and subsequently evaluates their submitted arguments so as to conclude whether a proposed decision is valid. To motivate and substantiate the practical value of this approach, we illustrate its application in the human organ transplantation field.

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1. Introduction

In many domains decisions are made following established guidelines that guarantee their correctness and/or safety in the case of safety-critical domains. However, there are circumstances in which decisions that deviate from the guidelines are justified. In this paper we present a model – ProCLAIM - that provides a setting for proponent agents to argue over the validity of their intended decisions. The model features a Mediator Agent (MA) that directs the proponent agents in their deliberation and subsequently evaluates the submitted arguments so as to conclude whether a proposed decision is valid. The MA

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will generally accept as valid only those decisions that, in light of the given arguments, comply with the guidelines. However, the MA may exceptionally be persuaded to accept (resp. reject) proposed decisions whose supporting and attacking arguments indicate that, although they do not comply (resp. do comply) with the guidelines, there is evidential basis to accept (resp. reject) them.

Hence, ProCLAIM defines a Case-Based Reasoning component/engine (CBRe) for evaluating, in light of the arguments used in the current and previous deliberations, whether there is sufficient evidence to accept or reject a proposed decision. To enable this functionality, the CBRe’s memory space is organized using a structured set of Argument Schemes and Critical Questions [16]. This provides the CBRe with the means to compare cases on the basis of arguments used in each deliberation. Broadly speaking, two cases are similar if the submitted arguments, associated to these cases, are similar.

From an argumentation perspective, a proposed decision is itself represented by an argument that is attacked and reinstated by the submitted arguments organized into a graph of interacting arguments. Assessing the validity of a proposed decision thus amounts to determining the dialectical status of the argument representing the decision. To do so may require establishing a preference between arguments that attack each other, based on the relative strength of the mutually attacking arguments. The role of the CBRe is to use past cases in order to assign these strengths, as well as possibly submitting additional arguments deemed relevant in similar past deliberations.

To illustrate the practical value of ProCLAIM and in particular of the CBRe, we apply the model in a transplant scenario [14]. In the following section we describe the ProCLAIM model. In §3 we introduce the transplant scenario, and in §4 we show how the CBRe makes use of arguments to compare cases and how cases can be used to resolve conflicts among arguments. Finally, §5 concludes with a discussion and programme for future work.

2. The ProCLAIM Model

Broadly construed, the ProCLAIM model consist of a mediator agent, MA, directing proponent agents in an argument based collaborative decision making dialog, in which the final decision must comply with certain domain dependent guidelines. The arguments submitted by the proponent agents may also persuade the MA to accept decisions that deviate from the guidelines. For example, the MA may be able to reason that the submitted arguments supporting an alternative decision have proven to be correct in previous similar deliberations.

We believe that ProCLAIM is of particular value in safety-critical domains (although the scope of domain may well be wider) where the consequences ensuing from a wrong decision may be catastrophic. Guidelines in such sensitive environments usually exist and are created in an attempt to minimize hazardous decisions. Nonetheless, there are circumstances in which a decision is appropriate despite violating established guidelines. Moreover, in such environments, arguments supported by empirical evidence are somewhat more persuasive.

ProCLAIM defines three main tasks for the MA: 1) Inform the proponent agents as to what are their dialectical possible moves at each stage of the deliberation; 2) Ensure that the submitted arguments are relevant (i.e., comply with the guidelines), and 3) Eval-
uate the submitted arguments in order to identify the winning arguments and thus determine whether a proposed decision is valid. This last task may require the assignment of strengths to the given arguments and possibly submission of additional arguments. In order to undertake these tasks, \( MA \) makes use of four knowledge resources (see fig. 1):

- **Argument Scheme Repository (ASR):** In order to direct the proponent agents in their deliberation the \( MA \) makes use of a repository of argument schemes and their associated critical questions formalized in a way that defines a protocol based exchange of arguments (e.g. given a submitted argument \( A \) instantiating a scheme of ASR, the \( MA \) can reference the ASR in order to identify the schemes that, if effectively instantiated, constitute an attack on \( A \)). As we will see in §4, the ASR also structures the CBRe’s memory space.
- **Guideline Knowledge (GK):** This component enables the \( MA \) to check whether the arguments comply with the established knowledge, by checking what are the valid instantiations of the schemes in ASR (the ASR can thus be regarded as an abstraction of the GK).
- **Case-Based Reasoning Engine (CBRe):** This component enables \( MA \) to assign strengths to the submitted arguments on the basis of their associated evidence, as well as provide additional arguments deemed relevant in previous similar situations.
- **Argument Source Manager ASM:** Depending on the source from whom, or where, the arguments are submitted, the strengths of these arguments may be readjusted by the \( MA \). Thus, this component manages the knowledge related to the agents’ roles and/or reputations, and/or the types of certificates, or references, that may empower agents to undertake some exceptional decision.

The agents’ argument construction is based on a first order logic programming language described in [10]. This work also defines the conflict based interaction between arguments. Given the constructed arguments and their interactions we apply Dung’s seminal calculus of opposition [7] to determine the justified or winning arguments. However, determining the winning arguments may require the \( MA \) to assign strengths to the submitted arguments and possibly the submission of additional arguments. This is further discussed and illustrated in sections 3 and 4. The agents’ dialog and in particular, the role of the \( MA \) in directing the deliberation by referencing the ASR is defined in [15]. Agents construct and submit arguments by instantiating the schemes and critical questions in the
ASR. The MA’s task is then to determine which are the winning arguments in order to conclude whether the proposed decision complies with the GK. This may involve referencing the CBRe to access similar past experiences and arguments given to support an undertaken decision not compliant with the GK, but which proved to have a successful outcome. This may also involve referencing past experiences in order to resolve mutually attacking arguments by assigning relative strengths to these arguments. These roles of the CBRe are further developed in §4. We now introduce the transplant scenario in order to illustrate the practical value of ProCLAIM, and in particular the value of Case-Based Reasoning in resolving conflicting arguments and the use of arguments for comparing cases.

3. The Transplant Scenario

Human organ transplantation constitutes the only effective therapy for many life-threatening diseases. However, while the increasing success of transplants has led to increase in demand, the lack of a concomitant increase in donor organ availability has led to a growing disparity between supply and demand [9]. In spite of this, an important percentage of human organs available for transplantation are discarded as being deemed non-viable for that purpose.

The human organ selection process illustrates the ubiquity of disagreement and conflict of opinion in the medical domain. What may be a sufficient reason for discarding an organ for some qualified professionals may not be for others. Different policies in different hospitals and regions exist, and a consensus among medical professionals is not always feasible. Hence, contradictory conclusions may be derived from the same set of facts. For example, suppose a donor with a smoking history of more than 20-30 packs a year and no history of chronic obstructive pulmonary disease (COPD). The medical guidelines indicate that a donor’s smoking history is a sufficient reason for deeming a donor’s lung as non-viable [11]. However, there are qualified physicians that reason that the donor’s lung is viable given that there is no history of COPD [9]. Similarly, the guidelines suggest discarding the kidney of a donor whose cause of death was streptococcus viridans endocarditis (sve) [11]. However, some reason that by administrating penicillin to the recipient the kidney can safely be transplanted [5].

The transplant scenario begins when a potential donor becomes available. The donor’s organs deemed non-viable by the Transplant Coordinator (which we name the Donor Agent, DA) are discarded, whereas the organs deemed viable are offered via a third-party (Transplant Organization) in a queue of Transplant Units, (which we name Recipient Agents) that may be located in different hospitals. These Recipient Agents, RA1, ..., RAn, to which the organ may eventually be offered may accept it, in which case they may attempt to implant it to a potential recipient they are responsible for. Or, if every RAj fails to accept the organ, it is discarded, i.e. not extracted from the donor.

A DA’s decision to not offer an organ which he believes to be non-viable prevents other RAj’s from having the opportunity to make use of that organ. The human organ selection process is described in more detail in [14] where an alternative selection process is proposed to be managed by CARREL, an agent-based organization designed to improve the overall transplant process. In this alternative process a DAi that detects a potential donor offers all the potentially transplantable organs irrespective of whether he
believes the organs to be viable or non-viable. CARREL then distributes the offer to the appropriate RAs. Together with an organ offer, the DA_i has to provide the arguments that support his assessment over the organ’s viability. In that way, a RA_j will be able to counter-argue DA_i’s assessment when there is disagreement. The DA_i, in turn, will have the chance to counter-argue, and so on. Thus an argument-based dialog may take place between DA_i and RA_j. In particular, a DA_i’s arguments for the non-viability of an organ may now be defeated by the RA_j’s arguments for viability, and thus, RA_j may have the opportunity to make use of that organ. In the same way, DA_i’s arguments for the viability of the offered organ may be stronger than those of a RA_j for non-viability. This will result in committing RA_j to transplant the offered organ as his decision for not transplanting it would be deemed unjustified.

Therefore, the ProCLAIM model is instantiated in order to extend the CARREL System so as to support the new selection process which we believe has the potential to increase the number of organs current selection processes make available. In particular, the proponent agents are the DA_i and RA_j, the GK is instantiated by the Acceptability Criteria Knowledge Base (ACKB) that encodes the criteria the medical doctors should refer to when deciding the organs’ viability. The Argument Source Manager relates to the agents’ reputation. Namely, the MA may deem as stronger the arguments submitted by agents with good reputation (e.g. a RA_j that have in the past successfully transplanted those organs which he claimed to be viable). Finally, the CBRe allows the MA to evaluate the submitted arguments on the basis of past transplantation experiences. For example, if an agent argues that the lung of a donor with a smoking history can safely be transplanted because he did not have COPD, the MA references the CBRe in order to evaluate this argument’s evidential support. Note that at the same time, the submitted arguments highlight what are the relevant factors for deciding a case. Namely, the argument graphs highlight the relevant attributes for assessing the similarity among cases.

As we will see in §4, the stage in the transplant experience in which arguments are submitted have associated different evidential weight. Arguments submitted before an organ is extracted are referred to as phase 1 arguments and have associated weaker evidential weight. If an organ is deemed viable for a RA_j, the organ is extracted. At this time, new evidence may indicate that the organ is in fact non-viable, and so it is discarded. The RA_j is then obliged to provide CARREL with the new arguments (capturing the new evidence) as to why the organ is non-viable. These are referred to as phase 2 (post-extraction/pre-transplantation) arguments. If complications arise after transplantation, then RA_j provides CARREL with arguments justifying (explaining) how the complications resulted in failure (eventually making the organ non-viable), or, conversely, arguments explaining how the complications were overcome so as to result in a successful transplant (eventually making the organ viable). These are referred to as phase 3 (post-transplant) arguments and are deemed as providing stronger evidence. Hence, phase 1 arguments are presumptive, submitted prior to undertaking any decision, whereas, phase 2 and 3 arguments are submitted once the consequences of the decision is known, and so they are conclusive or explanatory arguments. We now give a short example of phase 1 arguments.

Figure 2a. captures the schemes used by the agents in order to argue over the viability of an offered kidney of a donor d whose cause of death was sev. The argument graph that may result from such deliberation is illustrated in figure 2b. A deliberation must begin with the instantiation of the scheme that captures the decision under debate, the topic
of the deliberation. In this case, the instantiation of the Viability Scheme (\(A1\) in fig. 2b.). The later submitted arguments will attack \(A1\) or reinstate it (see [15] for a more detailed description of the dialog process). Note that in fig. 2b. arguments \(A5\) and \(A4\) mutually attack each other. This is because the claim of \(A5\) –Recipient \(r\) will not result in having \(sve\) as a consequence of donor \(d\) having \(sve\)– is in contradiction with the statement in \(A4\) –\(r\) may result in having \(sve\)–. Intuitively, it remains a moot point as to whether administering penicillin is a sufficiently efficacious action for preventing \(sve\) in \(r\) (\(A5\) wins out over \(A4\)) or not (\(A4\) wins out over \(A5\)). Therefore, it cannot be concluded whether the kidney is viable or not. Applying Dung’s calculus of opposition to the fig. 2b. graph only \(A7\) is evaluated as winning. However, if we take \(A5\) to asymmetrically defeat \(A4\) (succeeds in its attack at the expense of \(A4\)’s attack on \(A5\)) then Dung’s winning arguments are \(A5\), \(A3\) and \(A1\). Thus, the organ would be deemed viable. But if \(A4\) defeats \(A5\), then \(A4\) and \(A2\) win and the organ would be deemed non-viable. In order to resolve this impasse in the argument evaluation, the \(MA\) makes use of the three knowledge resources: ACKB, the agents’ reputation and the CBRs. Supposing penicillin is a novel treatment for preventing \(sve\), the ACKB would not value argument \(A5\) as reliable, and so the \(MA\) would derive that \(A4\) defeats \(A5\). However, supposing the agent submitting argument \(A5\) has good reputation, \(A5\) may be deemed stronger than \(A4\), hence the \(MA\) would conclude that the kidney is viable\(^1\). We now describe the CBR role in resolving conflicting arguments and the ASR structure the case base.

4. The Case-Based Reasoning Engine

Case Based Reasoning (CBR) has proven to be an appropriate reasoning and learning approach for ill-structured domains, where capturing experts’ knowledge is difficult and/or the domain theory is weak or incomplete. However, CBR developers still have to face problems such as having to decide how to represent a case, what are the relevant factors for comparing them and how to retain new cases that encode, in a useful way, both the

\(^1\) It is beyond the scope of this paper to discuss the conflict resolution based on the other knowledge resources.
success and failure of the cases’ proposed solutions. On the other hand, argumentation has proven to be a suitable approach for reasoning under uncertainty, with inconsistent knowledge sources, and in dialog based communication. However, one unresolved issue in argumentation is how to reuse the knowledge encoded in the arguments used in previous dialogs. A few approaches (see [12] and [8]) address this issue by providing support to end users for accessing or retrieving previous stored dialogs. On the other hand, [4] formalizes the way in which arguments used in previous legal cases can be integrated into the current dialog, also represented as a Dung’s argument graph.

In this section we propose the use of CBR together with argumentation to: 1) make use of previous resolved deliberations for evaluating the argument graph resulting from a new deliberation. This amounts to assigning a strength to the submitted arguments and possibly submitting additional arguments deemed relevant in previous similar deliberations; and 2) organize the case memory by making use of the structure of argument schemes and critical questions encoded in the ASR. We show that in this way, a case can simply be defined as a placeholder for the available data in an experience (e.g. a transplant experience) together with the agents’ submitted arguments; and that it is these argument graphs associated with each case that provide the means for case comparison. Moreover, these argument graphs represent two aspects of an experience. In the first case they capture the arguments exchanged by the proponent agents in arriving at a decision; thus presumptive arguments (phase 1 arguments). In the second case they capture the downstream outcome of actions taken as a result of the decision arrived at in the first case; thus conclusive or explanatory arguments (phase 2 and 3 arguments). In this way, the appropriateness of the decision is fed back into the argument graph associated with the case. Hence, the success and failure of a case’s proposed solution is given by the dialectical status of the argument representing the decision.

4.1. Cases and Argument-Graphs Representation

Each (transplant) experience constitutes a case. The textual (medical) information describing an experience - the case description - along with the graph of (presumptive and explanatory) arguments submitted by the agents capture the case’s features. In different experiences the arguments given by the agents may be the same, i.e. different cases may share the same graph (see fig.3). Each argument graph has an associated evidential support represented by a tuple of natural numbers \((F, K)\). \(F\) indicates the degree of certainty in the decision’s correctness and \(K\) is the number of cases that share the argument graph. Thus, graphs with bigger \(F\) and \(K\) provide stronger evidence. Note that graphs representing cases with no feedback on the decisions’ correctness have a more presumptive nature (smaller \(F\)) than those whose decision is supported or attacked by factual evidence (bigger \(F\)) which are more conclusive, or explanatory in nature. In the transplant scenario this accounts for \(F\) being 1, 2 or 3 according to the phase in which the transplant experience was resolved. An argument graph may be deemed as having sufficient evidential support, when the evidential support is bigger than a given threshold (e.g. \(K > 5\)).

As described in §3, it may be that the argument graph \(G\) of a new case may have nodes connected by bi-directional links, i.e., arguments \(A\) and \(A'\) mutually attack. One of the CBR tasks is to decide, on the basis of argument graphs associated with past experiences, whether \(A\) defeats \(A'\) or vice versa, and thus help establish whether a decision should be accepted (e.g. whether the organ being decided over in the new case is viable
3. Case and Argument Graph Representation. Although, for readability purposes, we depict graphs as trees, with the argument for viability as the root, a child node may have more than one parent.

or not). Referring to the example in §3, this would involve determining whether the evidence represented by past cases indicates that penicillin is (A5 defeats A4) or is not (A4 defeats A5) effective in preventing the recipient from contracting svi. Another example would be the use of evidence to determine whether or not lung transplants are successful where the donor had smoking history but no COPD. In the next subsection we describe the CBRe’s reasoning cycle [1]. That is, the four processes: retrieve, reuse, revise and retain, that enable CBRe to carry out its task. As we will also see, these processes assume an organization in the case-base memory space given by the ASR.

4.2. The CBRe Reasoning Cycle

Retrieval: We describe in some detail the first reasoning process in which, given a target problem, the relevant cases for solving it are retrieved from the memory. The relevant cases will be represented by their associated argument graphs. The relevant graphs to retrieve are those that apply to the new situation and have sufficient evidential support. 

The memory from which the relevant argument graphs are retrieved is a set $M$ of directed graphs whose nodes are instantiated argument schemes or critical questions of the ASR, and whose edges represent attacks or defeats between arguments that are allowed by the ASR. Also, every graph $G_i \in M$ contains a single node that captures the topic under debate. In the transplant scenario this account only for the Viability Scheme. In order to facilitate the retrieval process, the memory space is organized on the basis of three partial orderings:

Definition 1 Let $S$ be defined as the memory space $M$ and let $S'$ be equal to $S$ (containing the ‘same’ graphs) except that in $S'$ the edges are not directional and nodes are the identifiers of the schemes or critical questions of ASR. Thus, if for example, VS(donor,organ,recipient) is a node of a graph in $S$ its correspondent node in $S'$ is VS$^2$. Let $p_S$ be the canonical projection function from $S$ into $S'$. Given $G_1, G_2 \in S$, we say that $G_2$ structurally contains $G_1$, $G_1 \preceq_S G_2$, if and only if the graph $p_S(G_1)$ is a subgraph of $p_S(G_2)$.

2 Graphs in $S'$ ignore both, edges’ direction and schemes’ instantiation.
Given a new target problem with an associated graph $G$, the CBR system first identifies those graphs in its memory $M$ that structurally contain $G$, i.e., the set $\{G_1, \ldots, G_n\} \subseteq M$ such that for $i = 1 \ldots n$, $G \precsim_S G_i$ (where the set $S$ of Definition 1 is $M \cup \{G\}$). The instantiation of schemes in $G_i$ may differ from the instantiations in $G$. We wish to retrieve only those $G_i$ whose instantiations are related to that of $G$ as determined by an ontological hierarchy of instantiating terms.

**Definition 2** Let $O$ be the ontology whose terms instantiate the argument schemes of ASR, where $O$ is expressed as an ordering $\prec_T$ on terms, and $\prec_T$ is interpreted as ‘more specific than’ (e.g., $\text{svi} \prec_T \text{bacterial_infection}$).

We are only interested in those $G_i$ related to $G$, where the degree of similarity, or the *distance* between them, falls below a given threshold. To evaluate this, we use the distance between terms in $O$, denoted as $\delta_O$ (e.g., $\delta_O(\text{infection}, \text{svi}) = 2$), to determine a distance $\delta_{sch}$ between scheme instantiations, and so a distance between graphs that share the same structure.

**Definition 3** Let $G_1, G_2 \in M$ such that $G_1 \precsim_S G_2$ (i.e., $p_S(G_1) = p_S(G_2)$) and $sch_1 \ldots sch_m$ be the nodes of both $p_S(G_1)$ and $p_S(G_2)$. That is, for $j = 1 \ldots m$, $sch_j(x_1, \ldots, x_n)$ is a node in $G_1$ iff $sch_j(y_1, \ldots, y_n)$ is a node in $G_2$. Then the *distance* between $G_1$ and $G_2$ is given by: $\delta(G_1, G_2) = \max_{j=1}^m (\delta_{sch}(sch_j(x_1, \ldots, x_n), sch_j(y_1, \ldots, y_n)))$, where $\delta_{sch}(sch_j(x_1, \ldots, x_n), sch_j(y_1, \ldots, y_n)) = \max_{j=1}^m (\delta_O(x_1, y_1))$.

We then state a threshold $k$ such that the CBRe retains only those $G_i$ such that $\delta(G, G_i) < k$. To summarize, given a target graph $G$, CBRe retrieves the set $R_i = \{G_1 \ldots G_n\}$ such that for $i = 1 \ldots n$, $G \precsim_{D_k} G_i$ (step 2 of fig. 4), where $\precsim_{D_k}$ is defined as follows:

**Definition 4** Let $G_1, G_2 \in M$ such that for some sub-graph $G_3$ of $G_2$, $G_1 \precsim_S G_3$ (hence $G_1 \precsim_S G_2$). Then, $G_1 \precsim_{D_k} G_2$ if $\delta(G_1, G_3) < k$.

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3Note that these are labelled graphs, moreover they all have a single node representing the topic under debate (e.g. Viability Scheme), hence, the graph comparison does not result in a computational overhead.

4Note that the donors and recipients are not relevant for the graph comparison, thus $\delta_O(d, d') = 0$ and $\delta_O(r, r') = 0$ for every two donors $d$ and $d'$ and recipients $r$ and $r'$. 

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Figure 4. The Retrieval Process: steps 1 until 4. The Reuse Process, step 5.
From $R_1$, the CBRe excludes the graphs that have arguments that are not applicable in the target case, resulting in the set $R_2$ (step 3 of fig. 4). For example, a graph $G_x$ in $R_1$ will not be retained in $R_2$ if $G_x$ has an argument $A_x$ that assumes the donor has property $X$ which is not true in the target case. This process implies searching for property $X$ on the donor in the target case’s description. Note that if this property is actually found in the case’s description $G_x$ will remain in $R_2$ and thus argument $A_x$. Although no belonging to the target graph it may be deemed relevant for resolving the target case. From

the resulting set $R_2$, the CBRe selects the graphs with sufficient evidential support (see sub§4.1), resulting in $R_3$. At this stage (step 4 of fig. 4), each $G_i \in R_3$ is an argument graph that is applicable to the new case’s situation, taking into account all the submitted arguments, and such that it has sufficient evidential support. Therefore, each argument in $G_i$ is relevant.

**Reusing:** The aim of this process is to map $R_3$ to a solution for the target graph $G$. All the argument graphs in $R_3$ are merged into a single graph $G_R$ such that it contains all the arguments in all graphs in $R_3$, and therefore in $G$ (step 5 of fig.4), i.e. $G_R$ is the minimal graph such that $G_i \leq_{D_{k}} G_R, G_i \in R_3$. Note that in merging the graphs it may be that there are $G_1, G_2 \in R_3$ such that an argument $A$ asymmetrically defeats $A'$ in $G_1$ but $A'$ asymmetrically defeats $A$ in $G_2$. We thus must decide the direction of the defeat (the edge direction) in $G_R$. Recalling the mutually attacking arguments $A4$ and $A5$ in the target graph shown in fig.2b), this amounts to deciding which argument asymmetrically defeats the other given the previous graphs $G_1$ and $G_2$, (where $A4 = A$ and $A5 = A'$).

Suppose that for each edge connecting arguments $A$ and $A'$ of $G_i \in R_3$ such that $A$ asymmetrically defeats $A'$ we associate the evidential support of $G_i$, writing $ES(G_i, A, A') = (F, K)$. Whereas if $A$ does not asymmetrically defeat $A'$ then $ES(G_i, A, A') = (0, 0)$. Now, for every two connected arguments $A, A'$ in $G_R$, if $max_{G_i \in R_3}(ES(G_i, A, A'))$ is sufficiently greater\(^5\) than $max_{G_i \in R_3}(ES(G_i, A', A))$, then the edge in $G_R$ will go from $A$ to $A'$ indicating that $A$ defeats $A'$. Otherwise, $A$ and $A'$ will remain connected by a bi-directional edge in $G_R$ indicating a mutual attack, which means there is no sufficient evidence to resolve the conflicting arguments.

Thus, $G_R$ is the CBRe proposed solution, where, as described above, evidential supports are used to determine defeats and so a winning argument for viable or non-viable as described in §3. However, $G_R$ can also determine the decision’s validity given additional arguments in $G$ that are not in $G$. $G_R$ may identify additional arguments, not

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\(^5\)The definition of ‘sufficiently greater’ is domain dependent. We can say that $(F_1, K_1)$ is sufficiently greater than $(F_2, K_2)$ if: a) $F_1 > F_2$, or b) $F_1 = F_2$ and $F_1 > 1$, $F_2 > 1$, and $K_1 * 0.6 > K_2$. 

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*Figure 5. Smoking history example illustrating the CBRe reasoning cycle*
in $G$, that are applicable to the target case and belonging to a graph with sufficient evidential support. Thus, these additional argument may identify new relevant factors for deciding the target problem which were not taken into account initially in $G$. Recall also that $G$ will be a graph constructed from presumptive arguments (phase 1 arguments), whereas $G_R$ may also contain conclusive arguments (phases 2 and 3 arguments). As described at the end of §3, phase 2 arguments in $G_R$ may provide conclusive evidence supporting a final decision for non-viability. Phase 3 arguments may provide conclusive evidence supporting a final decision for non-viability or viability (e.g., arguments describing post-transplant procedures that unsuccessfully, respectively successfully, dealt with post-transplant complications). To summarize, $G_R$ provides: 1) evidential support to determine defeats amongst arguments in $G$ and so determine the decision’s validity; 2) new arguments for determining the decision’s viability; 3) additional arguments that may serve, for example, as guidance to the $RA_j$ for post-transplant management of patients.

**Revising**: The solution $G_R$ must be tested in the real world, and if necessary, revised. This is achieved by requiring the agents to continue submitting arguments to $G_R$ until the (transplant) experience ends. For example, if in the smoking history example the lung is deemed viable in $G_R$ (see fig.5) but there is a graft failure the reasons for the failure will be submitted as new argument $A4$, that will reinstate the argument for non-viability. The resulting updated argument graph $G'_R$ will then be stored in the case base.

**Retain**: The aim is to store the possibly updated $G'_R$ as a new graph in the memory. Hence, when a (transplant) experience finishes, the case describing this experience is retained by the CBRe. If there already exists an argument graph $G_M$ in the memory such that $G'_R = D_k G_M$ and the edges directions coincide, then the case is associated with $G_M$ increasing $G_M$’s evidential support. Otherwise, the target case is retained as associated to $G'_R$ which is added as a new argument graph to $M$.

5. Conclusions and Future Work

In this paper we have proposed 1) the use of CBR in order to evaluate the evidential support (and thus relative strength) of the agents’ submitted arguments, which helps to resolve the impasse of having arguments that mutually attack each other; and 2) the use of argument schemes and critical questions to organize the CBR’s memory space, which enables comparison of cases on the basis of the submitted arguments.

This use of CBR is described as part of the ProCLAIM model intended for agents to argue over the validity of their intended decisions. We have shown its practical value in assessing the viability of organs for transplantation. The work described furthers are eventual objective [14], viz.a.vie. to increase the number of human organs current selection processes make available for transplantation.

Other works that have combined argumentation with cases can be found in the legal domain, particularly in the context of the Common law system, a legal system based on unwritten laws developed through judicial decisions that create binding precedent. The inherent argumentative nature of the legal domain and the particular features of the Common law system provide a scenario for developing models and systems for reasoning and arguing with precedents, i.e. past cases. Exponents of this works are systems such as CATO [2], HYPO[3] and CABARET [13] which assist users in constructing arguments from cases. Intended for the same purposes is the extension to the HERMES System
proposed in [8] that aims to support human agents involved in group decision making processes to retrieve, adapt and re-use past cases.

We are currently prototyping the CBRe so as to extend an existing prototype of the logical argumentation model described in [10]. This work is intended as a precursor to development of a robust large scale demonstrator with embedded argumentation components developed by the EU 6th framework project ASPIC (Argumentation Services Platform with Integrated Components) (see www.argumentation.org). Future work will focus on extending the retrieval process so as to address adaptation of previous cases in order to increase the scope of the relevant cases. Another future line of work is use of the case base for searching patterns in order to propose new arguments, i.e. to propose new instantiations of argument schemes (e.g. relating a donor condition $x$ with unsuccessful transplants: $\text{NVS}_1(d,x,\text{organ})$).

The transplant scenario serves to illustrate ProCLAIM’s practical value. We believe ProCLAIM, and in particular the CBRe, may also prove to be useful in other safety-related environments. We are currently investigating the application of ProCLAIM as an extension to DAI-DEPUR [6], a decision support systems for Wastewater Treatment Plants (wwtp). In this scenario, the proponent agents would represent the wwtp operators, the Argument Source Manager would relate to the operators’ hierarchy within the plant and the GK would be instantiated by the guidelines encoding compliance with the environmental legislations. The CBRe will help to establish on an evidential basis, indicating whether the operators’ decisions are appropriate and thus environmentally safe, in light of their given arguments.

References