Enhanced Case-Based Reasoning through Use of Argumentation and Numerical Taxonomy

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Abstract

Cases as used in case-based reasoning (CBR) typically record experts' steps of reasoning and action, but not the arguments an expert may consider during the problem-solving. Knowledge that can improve the quality of performance of CBR is therefore lost. The paper describes an approach that tackles this problem by representing arguments in a simple form and treating them, along with the traditional information contained in cases, as case properties. These properties are processed according to methods of numerical taxonomy when similarities between cases are being computed. The cases themselves are structured according to a model (CommonKADS) familiar in knowledge engineering but seldom applied to CBR and argumentation.

Introduction

An expert interpretation is not simply a conclusion drawn from observed facts. The expert's reasoning usually involves a sequence of arguments regarding relevant parts of the problem, with associated justifications for interpretations. We are investigating these problem-solving activities by exploiting the way that experts apply their knowledge and experience when they find it most natural to base their interpretations on previous analysed cases. The aim of this work is to offer an approach to integrating case-based reasoning (CBR) and argumentation characteristics, where enhanced interpretation cases are constructed from both facts and arguments.

The approach is being developed with the help of an application to shortwave radio-frequency spectrum management. The shortwave radio problem is the allocation of frequencies for reliable and interference-free (as far as possible) reception of shortwave radio broadcasting. The results of radio-frequency allocation interpretations are recommendation reports about the quality of the allocation arrangements. There are no formalized theories for performing these expert-based qualitative recommendations. They are developed in a case-based manner, where solutions are proposed on the grounds of facts, their relationships, semantics, and related conceptual information arising from both relevant maps of frequency propagation/attenuation and the quality obtained in previous radio-frequency allocations. To approach this problem, an expert in the field is being asked to provide cases of radio-frequency allocation. He was invited to slow down his problem-solving analysis, and then to describe factual characteristics, as well as the pro and con arguments that emerge *during* the main steps of inference of the problem.

The expert arguments, usually lost in the customary case representations in CBR, are acquired with the use of reasoning templates from knowledge engineering methodology (Schreiber et al. 2000). The components of the enhanced case structure are the factual characteristics, which were already there in the traditional case representation, along with problem-solving inferences from the reasoning template and their related arguments. As a way of both integrating factual and argumentation characteristics and constructing similarity metrics, our approach proposes to exploit these enhanced cases via techniques of numerical taxonomy (Sneath and Sokal 1973) – the name for the grouping of numerical techniques for systematically investigating classification problems. Despite previous work (Campbell 2004) in establishing similarity metrics from factual characteristics only, which were exploited by different agents when negotiating case-based radio-frequency recommendations, there is no explicit treatment of numerical techniques of taxonomy (as far as we know) in combining factual and argumentation properties while establishing similarity metrics for CBR and argumentation systems.

In using techniques of numerical taxonomy, we expect that one can investigate the amalgamation of properties from facts and arguments by means of a classification framework. We test the effectiveness of this integration approach by comparing the CBR results with actual past data on radio-frequency allocation. We have not tried to generate arguments during the process, but in principle a generative approach could also be useful, as mentioned in (Bruninghaus and Ashley 2003).

Case representation: acquiring and grounding arguments on reasoning templates

According to (Aamodt and Plaza 1994), primary problems of case representation in CBR are deciding what to store in a case and finding structure for describing case contents. As a means of acquiring and representing expert knowledge in cases, we are taking advantage of a set of inference templates of knowledge models from the CommonKADS methodology (Schreiber et al. 2000). As described in (Trott and Leng 1997), the modeling elements from this methodology have already been used once in collecting and representing expert knowledge in CBR. In our approach, however, we focus on reasoning templates – where reasoning is described in an abstract and reusable way – in guiding the collection and representation of *argumentation* information for CBR.

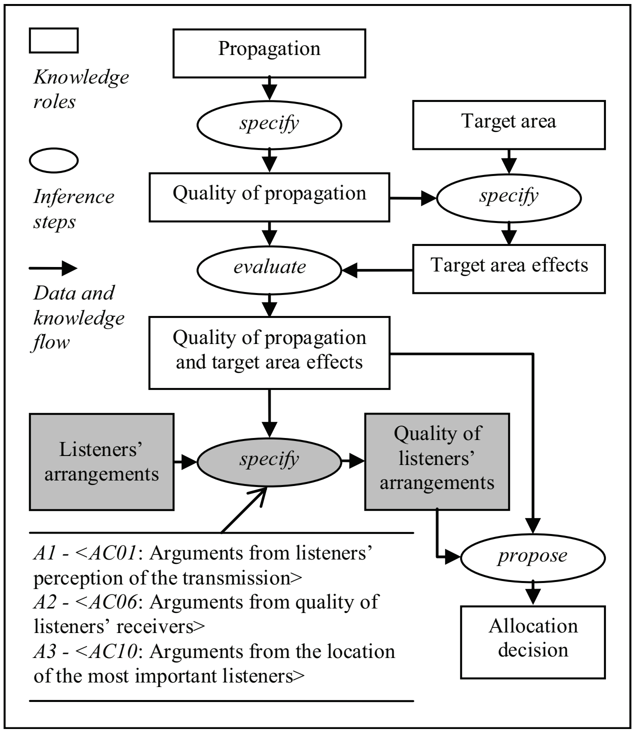

Figure 1: The radio-frequency allocation template

With the help of the expert, the process of case representation starts by choosing the most appropriate inference template (or a set of them) from a library (in this project, task-oriented templates from the CommonKADS catalog). After discussion with the expert about which template is the best with respect to a representative group of cases (or taking more than one template in parallel until agreement about the best one is achieved), the preferred template is adapted to the requirements and assumptions of the application. Template libraries, e.g. for CommonKADS, exist already, but there are enough varieties in expert problem-solving methods that there is still room for them to expand. For instance, our application has aspects of both "assessment" and "assignment" that are not expressed by existing templates of either type, and these aspects are by no means peculiar to radio.

Once a tailored inference template for describing the main aspects of the reasoning about the problem has been obtained, this inference structure guides the expert in later explicit verbalization of the problem-solving analysis, and the pro and con arguments for discussing the inference steps, in each new case. The inference steps also act as grounding places for attaching the acquired arguments, and organizing the argumentation knowledge at the relevant place(s) in the case structure. In effect, these grounding places are knowledge repositories – places where arguments should be attached within the inference structure – defined in relation to argumentation-based inferences about the problem, e.g. inferences such as "quality of listeners' arrangements" and "propagation" of target radio stations and others that may interfere with their reception.

In Figure 1, some types of listener's arguments are attached to the "listeners' arrangements" inference. In effect, an argumentation sequence is attached to this inference, where each sequence discusses aspects involved in the decision/outcome of the inference. Once these enhanced cases are available, the set of factual properties originally kept there along with the combination of arguments plus their grounding inferences can be exploited most simply when numerical taxonomy is applied to assist CBR.

Argumentation characteristics as sources of taxonomic properties in practice

While the relationship between CBR and argumentation is not new (Karacapilidis, Trousse, and Papadias 1997; Tolchinsky et al. 2006) but oriented most towards modeling case-based legal reasoning techniques (Skalak and Rissland 1992; Ashley 1991; Aleven 2003), our approach takes advantage of numerical taxonomy when investigating how the similarity between taxonomic entities can be measured more efficiently (in the present work, the taxonomic entities whose similarities are estimated are the augmented cases themselves). It is because the underlying format of numerical taxonomy describes a systematic sequence of steps – basically: i) observation and coding of entity properties, ii) construction and evaluation of similarity metrics and resemblance matrices, iii) determination and presentation of clustering results, and iv) establishment of taxonomy: details about these steps can be found in (Sneath and Sokal 1973) – that we can get detailed trace information when assessing taxonomic aspects of the combination of factual and argumentation characteristics.

The basic aim in describing argumentation characteristics as sources of taxonomic properties is the observation and coding of properties from arguments and argumentation episodes. The nature of these properties allows the proposal and testing of metrics for measuring how similar (or different) two arguments are. We now give an example of the kinds of characteristics of arguments that can be used in taxonomic treatment of cases that contain them.

We start by saying that a concept along with a piece of text is enough to describe an argument. In argumentation and qualitative methods of decision-making (Fox and Parsons 1998), qualitative signs (e.g.: +, ++, 0, –, – –, ?) are usually linked to these arguments. For example: <++;

beam_direction: “signal from potentially interfering station X is beamed well away from the target location Y”>. When recorded in an enhanced case, such an argument states that “beam direction” provides strong positive support for allocating a radio frequency. This piece of knowledge might be present in an inference from case A and not in the same inference in case B. Then, even mere presence/absence characteristics of these qualitative arguments can be exploited as a taxonomically significant property when assessing the similarities of enhanced cases.

Based on the presence/absence of argumentation features (where these features are captured from a set of questions along with “yes”, “no” and “not applicable” answers), early work involving the classification of legal cases has been developed (Popple 1993). Although this approach has not endured in law because its limitations where normative explanation is concerned, classification and explanation can go together, as demonstrated in (Sneath and Sokal 1973) by the use of taxonomic treatment of fossil data to generate and/or confirm possible evolutionary “family trees”. Current case-based legal argumentation research focuses on a different meaning of “explanation”, but the two can coexist. In particular, recent argumentation formalisms (Bex et al. 2003) admit semantic features, in addition to factual data, which can be used as characteristics (coordinates in a metric) in a taxonomic treatment.

Typically, an argument is represented by premises and conclusion. For example: premises: i) <“the signal of station X is beamed to target location Y”> and ii) <“the signal of allocated station K is beamed to target location Z”> and iii) <“that the signal of allocated station K beamed to a target location Z is well away from the target location Y indicates that there is no interference from allocated station K at target location Y”>, then conclusion: <“there is no interference from allocated station K at the target location Y”>. Using this argument as source of study, one can make high-level analogies in terms of similarities of premises and conclusion, or taking both together as a single modeling concept, in helping to establish a distance function between arguments.

A structure due to Toulmin (Toulmin 1958) – data, claim, warrant, backing, qualifier and rebuttal – is by far the most investigated formalism for the representation of arguments. For example: data: <“the frequency of station X is Fx kHz”> and <“the frequency of station Y is Fx +/– 5 kHz”>, claim: <“the interference from station Y on station X is on Fx +/– 5 kHz (i.e. sidebands) only”>, qualifier: <is>, and warrant: <“that the frequency of station Y is +/– 5 kHz from station X indicates that the interference from station Y on station X is on sidebands only”>. As one can appreciate, these elements and their many possible refinements are rich sources of taxonomic properties for investigating analogies between arguments. Guided by the elements of Toulmin’s representation, the presence, type, role, etc of warrants, for example, are just some possible characteristics that one can employ in distinguishing features of argumentation in cases enhanced by arguments. When the expert can organize these features in a precise and reliable way, one can establish distance functions based on preference relations among them. Toulmin’s formalism has the advantage of being detailed enough to capture relevant aspects of the problem. Indeed, while we have noted the expert saying “you’re asking for too much detail in the description of the problem using this kind of representation”, we have not yet heard any complaint that prompts or slots for information have been missing.

By taking advantage of Toulmin’s representation, argumentation episodes can also be represented in abstract forms such as diagrams (Reed and Rowe 2005; Bex et al. 2003). The structural properties of arguments can be read off from such diagrams, provided their steps of construction are controlled systematically. As an example of these properties, one can employ long argumentation trees as indications of higher levels of complexity in cases. Based on this simple structural observation, a two-part distance function can be established to respect the following: a1) short argumentation sequences: low values of structural complexity in the distance function which compares two cases, and a2) long argumentation sequences: high values of structural complexity in the same distance function, where b) the second part of this distance function can be computed from factual values. In effect, the function then expresses degrees of similarity between argumentation facts and argumentation structures.

Not only can an individual argument be represented, but also the structure of argumentation episodes (e.g., dialogical situations such as discussions). For example: <“the interference from station Y on station X is on sidebands only”> is_supported_by <“station Y can make heavy sideband interference with power P”>. This support relationship might be understood as a rebuttal between arguments put forwarded by different agents. Further, the final status of a discussion may indicate what interpretation remains at some point, and what taxonomic properties can be derived from it. As an example, two arguments may obtain some of their rating of similarity because they are both “winners” at some point of a discussion.

Argumentation schemes (Bex et al. 2003) are another source of taxonomic properties. The nature of these schemes, which represent stereotypical patterns of human reasoning as argument forms, and how one can apply them in real-life applications, are still under investigation. Simple instances of them are common in cases of radio-frequency allocation. An instance of “arguments from sign”, which is one standard scheme in interpretation of visual material such as, for example, maps of frequency propagation/attenuation, can be described as <“the signs of *high-gradient contours* are there *in the relevant maps of frequency propagation/attenuation*; this indicates that *disturbances in the signal propagation may occur*”>. In this scheme, *…* can be replaced by any other set of facts in the application domain. Analogies among argumentation schemes can make use of two-part distance functions again, where one part denotes similarities arising from the presence of the scheme in the case and the other part from the domain elements of the scheme, indicated by the *…*.

Last but not least, argumentation systems are usually shaped by other descriptive features, such as “issues”, “factors”, and choices, as in legal applications (Ashley 1991; Aleven 2003). For example: <issue: interference; “the interference from station Y on station X is on sidebands only”>. The explicit representation of such features can discriminate better between arguments as well as between problem-solving episodes, which is demonstrated empirically in (Bruninghaus and Ashley 2003). Analogies among arguments can be made by just referring to the “issues” and “factors” that the case arguments are discussing, which are exploited in this way by moves of argumentation within legal cases (Ashley 1991; Aleven 2003), for instance. Although these argumentation features offer relevant taxonomic characteristics, non-legal applications do not routinely contain them as well-defined explanatory concepts.

In conclusion, some pragmatic rules for selecting and using argumentation formalisms are worth following:

- The best argumentation formalisms should be the simplest ones. Although the modeling of formal argumentation features is quite relevant to the study of different applications, in a context where cases are needed primarily, the simplest argumentation characteristics are the easiest to translate to numerical formats (or preference relations), and then to provide relevant enhancements in relation to the use of traditional factual properties;
- A combination of argumentation features should be investigated. That is what people trying to characterize new specimens of animal do, for instance, where the main goal in taxonomy is to exploit as many different features of the specimens as possible, where specimens are here represented by enhanced cases;
- Sets of potential taxonomic items should be chosen to avoid deductive dependencies which would lead to taxonomically erroneous double counting or overweighting of characteristics (Sneath and Sokal 1973). This consideration applies as well as to arguments as to factual data.

A form for describing arguments

Based on the argumentation characteristics discussed previously, we have developed an argument form for collecting argumentation knowledge. This form is well supported by qualitative aspects of reasoning (Forbus 1997), since the nature of the reasoning in radio-frequency allocation exhibits both qualitative and presumptive aspects. The components of the argument form are the following:

- A_i – Argument identifier in a sequence of arguments;
- St – Argument sentence: a textual description;
- AC_i – Application-related argument concept: it may be understood as an argumentation scheme, as exploited in the case-based argumentation approach of (Tolchinsky et al. 2006). The radio-frequency allocation model is currently supported by 25 different application-related argument concepts (e.g., AC01 in Figure 1);
- Mi – Main argument issue: the quality of radio-frequency allocation arrangements for the target station;
- Or – Argument orientation in relation to the main issue: “in favor”, “against” or “no orientation”;
- Si – Sub-issues: the input(s) and output(s) of an argument are represented in relation to two relevant sub-issues of the problem: i) what is the quality of the target radio-frequency allocation? (i.e. the propagation-related issue) and ii) what is the level of the interference in the target radio-frequency allocation? (i.e. the interference-related issue);
- In and Out ($in \Rightarrow out$) – Arguments regarding each sub-issue are described using the set of qualitative input and output signs {+, ++, 0, –, – –, ?}, indicating the strength of evidence for the labels and/or values that they modify. These labels, chosen with the expert, are used as the input(s) and output(s) of the arguments. Examples from labels referring to levels of interference on the frequency being considered for target allocation are: V: slight (encoded by a value 5.0), N: nuisance (value 6.0) and P: problem (value 7.0). Signs along with the labels help in describing more precisely what the expert states as input/output of the argument: for instance, an interference-related description such as ++N = 6.5, while 0N = 6.0, where the present scale varies in steps of 0.25. To sum up, an argument example is shown in Example 1.

A2: <St: “Listeners’ equipment will not be state-of-the-art, which means that the stronger station is likely to blot out the weaker interfering one when they are listening”; AC06: “Argument from the quality of listeners’ receivers”; Mi: “Target allocation issue”; Or: “In favor of the target allocation”; Si: “Interference-related issue”; In: “+N, 0P”; Out: “+V, –N, – –P”>

Example 1

In dealing with the radio-frequency allocation problem, we are taking advantage of the characteristics of these arguments when assessing the similarity of augmented cases. Although we present this argument form by using examples from the radio-frequency allocation problem, the proposed argument representation is intended to be general, i.e. not limited to our application domain.

Assessing enhanced cases through numerical taxonomy: a first experiment

The current version of the software implementing our approach contains all the main elements of a taxonomic structure. In particular, it uses a K-nearest-neighbor clustering method (with K = 1), which can be presented in a dendrogram format. Details about such taxonomic techniques can be found in (Sneath and Sokal 1973).

The illustration refers to a set of 21 cases of radio-frequency allocation which have been provided by the expert. Figure 2 presents a dendrogram (using the distance scale as a reference) derived from factual values of the radio-frequency allocation cases (using a multidimensional Euclidian space, where key facts are the dimensions). Notice that argumentation features were *not* considered when generating the clustering results in Figure 2.

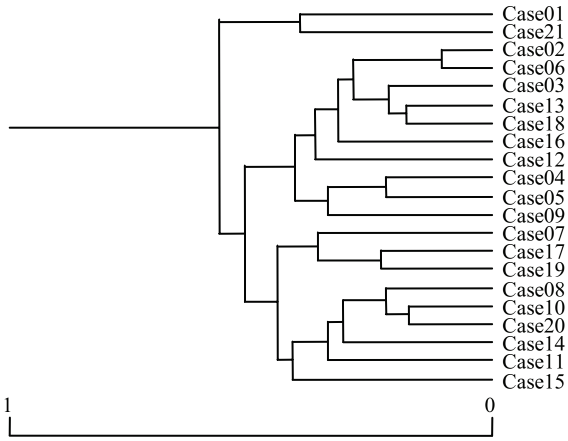

Figure 2: Clustering results from factual properties

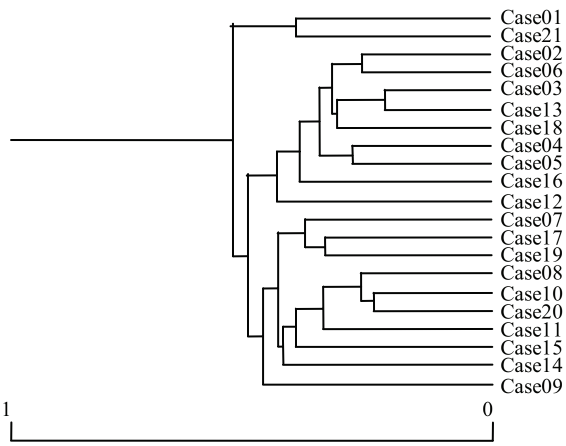

Figure 3: Clustering results from factual and argumentation properties

Figure 3 presents a dendrogram derived from factual and argumentation properties of augmented cases, i.e. cases represented in terms of their traditional CBR properties along with recorded sequence of arguments. The similarity between augmented cases is calculated by measuring the similarity of each case inference separately. In doing so, each inference has its set of argumentation features, as exemplified here by the listeners' arrangements inference (see Table 1 and Figure 4).

The distance metric between cases in the listeners' arrangements inference is based on the combination of three argumentation features: a) the presence of the argument in the inference, b) the worst value that the arguments have as outcome in the interference-related issue, and c) both the presence of the argument and the output value are evaluated in relation to the orientation of the argument. As a conclusion, high values of similarity between two arguments are found when i) the same argument appears in an inference, ii) the arguments have similar interference-related outputs and iii) the arguments have the same orientation (in favor, against …) in the cases. In Table 1, the presence, orientation and the worst interference condition in the listeners' arrangements inference are displayed.

Table 1: A case inference and its argumentation features

***Inference:* Specify quality of listeners' arrangements**				
ACi	***AC01***	***AC06***	...	***AC10***
Type	***Arg_feature***	***Arg_feature***	...	***Arg_feature***
Weight	***Weight$_{01}$***	***Weight$_{06}$***	...	***Weight$_{10}$***
Case01	**?**	**In favor, ++N**	…	**Against, 0P**
Case02	**Against, +V**	**In favor, – –V**	…	**?**
…	**…**	**…**	…	**…**

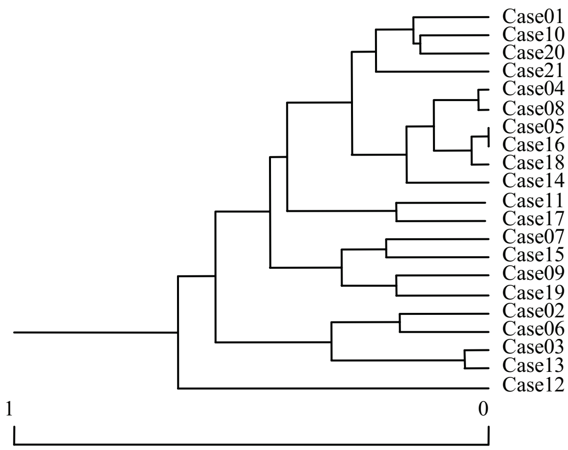

Figure 4: Clustering results from "listeners' arrangements" argumentation characteristics only

Figure 4 shows a dendrogram for the "listeners' arrangements" inference only. One of the advantages of measuring the case similarities via each of their inferences is to evaluate how the cases might be organized in these argumentation-related dimensions. Thus, different interpretations might emerge from this clustering structure, helping one in deciding how to weight similarities and differences during inference of augmented cases.

$$(D(a,b))^2 = \frac{\sum_{1\le i\le N} Wf_i * (Df_i(a,b))^2 + \sum_{1\le j\le K} Winf_j * (1 - Sinf_j(a,b))^2}{\sum_{1\le i\le N} Wf_i + \sum_{1\le j\le K} Winf_j}$$

Equation 1

Once the similarities of inferences between cases are computed, they are used together with information about similarities of facts in the cases, according to Equation 1. The meanings of terms there are: *D(a,b)* – distance between cases a and b, $Df_i(a,b)$ – factual distance between cases a and b, Wf_i – factual weight, $Winf_j$ – inference weight and $Sinf_j(a,b)$ – inference similarity between cases a and b, where N – number of facts and K – number of inferences. The overall distance between augmented cases is calculated from similarities that appear from argumentation-based inferences, which are taken as new case dimensions. Figure 4 shows the clusters generated from these cases.

We evaluated these preliminary clustering results qualitatively, where the expert was asked to interpret the clusters from Figures 2 and 3. According to the expert, both sets of clusters show already-expected groups. Their structures were also said to be qualitatively similar and satisfactory, whether facts alone or facts plus arguments were used. There were small differences between the dendrograms in the two situations, which the expert found to be convincing after considering how the changes in the clustering when arguments were taken into account could be interpreted. In particular, he stated that the dendrograms changed his perception of some aspects of interpretation, which needed further thought. That is, the computations were realistic enough to cause him to reconsider and make notes on some of the organization of his own knowledge.

Overall validation for a larger set of cases will involve confrontation between ratings of assignments A (the source of our case base) taken from a 2003 international radio database (Magne 2003) and information about the presence/absence of A from the 2004 database after expert weeding to remove differences (e.g. political, budget-driven) unrelated to pure radio propagation issues. While work is continuing on detailed improvements to the software and testing on larger stocks of cases, we have also started to collect similarly enhanced cases with an expert in another application domain (the analysis of problems of authentication of paintings), as a test of the domain-independence of the approach we have described.

Concluding remark

There are three aspects to the project reported here: i) the use of knowledge acquisition templates to structure cases for CBR, ii) the emphasis on arguments as significant components of cases that embody expert-level reasoning, and iii) the use of numerical taxonomy to support the determination of similarity between factual and argumentation characteristics. Each one, and their combined use, has general significance for CBR and/or the capture of expertise that is expressed primarily through cases.

Acknowledgments

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