On Constructing the Right Sort of CBR Implementation*

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Abstract

Case based reasoning implementations as currently constructed tend to fit three general models, characterized by implementation constraints: *task-based* (task alone), *enterprise* (integrating databases), and *web-based* (integrating web representations). These implementations represent the targets for automatic system construction, and it is important to understand the strengths of each, how they are built, and how one may be constructed by transforming another. This paper describes a framework that relates the three types of CBR implementation, discusses their typical strengths and weaknesses, and describes practical methods for automating the construction of new CBR systems by transforming and synthesizing existing resources.

1 Introduction

CBR systems as currently constructed tend to fit three general implementation models, defined by broad implementation constraints on representation and process.

Traditionally, *task-based* implementations have addressed system goals based only on the constraints imposed by the reasoning task itself. Most research systems, for example, focus on particular (often idiosyncratic) methods and representations optimized to address a specific reasoning task, either to demonstrate the effectiveness of the method or to meet specific task goals.

Recently, there has been an increasing and successful trend of incorporating CBR into enterprise systems (e.g [Watson, 1997; Stolpmann and Wess, 1998]) to leverage corporate knowledge assets by knowledge management (e.g. [Becerra-Fernandez and Aha, 1999]). *Enterprise* implementations reflect the additional implementation constraints imposed on CBR systems as part of an overall enterprise architecture (see [Kitano and Shimazu, 1996]). In our view, the most important implementational constraint in this context is that typically such CBR integrations must operate in conjunction with database systems, the mainstay of corporate knowledge activity. This will usually mean inter-operation with the more prevalent relational database systems (e.g. [Gardingen and Watson, 1998; Kitano and Shimazu, 1996; Allen *et al.*, 1995]), but may also include object database systems (e.g. [Ellman, 1995]). Thus enterprise CBR implementations provide for and make use of database functionality. Note that not all "enterprise CBR systems" will have an enterprise implementation in this sense.

Currently, CBR systems are emerging that take advantage of recent developments in knowledge representation and sharing on the world-wide web (e.g. [Shimazu, 1998; Gardingen and Watson, 1998; Doyle *et al.*, 1998]). *Web-based* implementations reflect additional constraints imposed on CBR systems by conforming to structured document representation standards for web/network communication, in particular XML—Extensible Markup Language [Bray *et al.*, 1998]. Note that the distinction is based on the construction of the reasoning system itself, not on its presentation of information. Thus a task-based implementation might have a web interface, and a web-based implementation might not.

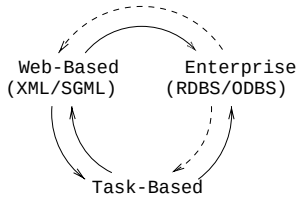

Figure 1: Relating CBR implementation types

The implementation characterizations—intended to be useful, not perfect—represent targets for automatic system construction, and varying task aspects and contexts may prefer one to another. Thus it is important to understand (1) how the models compare, (2) their individual construction, (3) their combination, and especially (4) how one may be constructed by transforming another. We view the framework of practical constructions and transformations outlined in this paper—

*The authors' research is supported in part by NASA under award No NCC 2-1035.

represented in figure 1—as a natural extension and generalization of mining databases to aid in system construction.

2 Implementation Models

The implementation characterizations can be applied at many levels of typical CBR systems. Here we find it useful to differentiate CBR process and representation. We also recognize the importance of object database models and Standard Generalized Markup Language (SGML, [ISO86, 1986]), but here we restrict our discussion to relational database models and XML.

Task-Based: Task-Based implementations account for the bulk of current CBR practice. These systems allow for highly tuned and efficient metrics and representations, but it may prove difficult to reuse them outside of the system context. Some efforts have used standardized representations to ameliorate these difficulties (e.g. [INRECA, 1994]), but this is not widespread.

Enterprise: Integrating CBR implementations with enterprise database systems imposes standardization constraints that are almost universal in the enterprise community. Representations must accord with the table model of relational database systems (RDBS), while process must adopt Structured Query Language (SQL) conventions. CBR systems gain the strengths of the underlying RDBS, such as security, concurrency control, backup/recovery, and scalability. Moreover, integration allows the use of enterprise data both for normal corporate tasks (e.g. reporting), as well as reasoning. SQL is limited in power, however, because it provides certain performance guarantees, so refined metrics may be difficult to construct. While complex cases are representable, they can be difficult to model in manual construction.

Web-based: XML is emerging as the vehicle for knowledge representation on the web. It provides a medium that allows (1) definition of customized representational markup languages and (2) application independent exchange of these complex hierarchical representations over existing web/network channels. XML also allows for customizable display of information using the associated Extensible Style Language[1]. While its use is now viable (e.g. for transfer and parsing), XML is a fairly new standard, so support (e.g. for browsing) is limited but growing, and its usability is still evolving fairly rapidly (e.g. [Hayes and Cunningham, 1999]). Benefits are immediately available for individual systems, but developing standard representations for community knowledge sharing will be crucial for the field. Since XML is a representation standard, it is not tightly coupled with process as in databases, so task-based applications are generally required for process. However, direct structured query mechanisms, analogous to SQL, are under development [Sengupta, 1998; W3C, 1998].

[1] http://www.w3.org/TR/1998/WD-xsl-19981216

3 Realizing Implementations

The realization of a framework for automatic implementation transformation involves outlining process and representation for each model, as well as defining and exemplifying the inter-model transformations.

3.1 Enterprise/RDBS

Constructing an enterprise implementation involves associating a case structure with a corresponding relational database schema. Figure 2 shows an Entity-Relationship (ER) model for typical CBR systems, where stored data represents cases (problems) which result in proposed decisions (solutions), and their outcomes (evaluations). This ER model can be fully implemented in a RDBS. The construction is straightforward for feature-vector case structures, where a single table row corresponds to a case. For more complex case structures, relational normalization techniques are used to model the data.

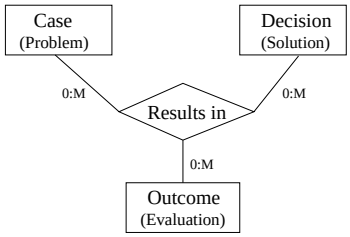

Figure 2: Entity Relationship diagram for a typical case-based reasoning process

Database systems can also be used for CBR process, for example by implementing k-nearest neighbor (k-nn) retrievals. A number of novel data structures have been proposed in the database literature for efficient implementation of k-nn algorithms (e.g. [Berchtold *et al.*, 1997]), but standard database systems do not currently offer such support. However, if the similarity metric can be expressed as a numeric-valued function, database cases can be retrieved as ordered by the similarity results. Thus we view database/CBR process as taking place on at least three levels:

1. *Simple Storage*: The database is used only as a storage medium. All cases are retrieved and processed by an external system. This combines the storage benefits of the database systems with task-based processing power, but requires a full task-based implementation. The basic query to the database in this case is:

   ```
   SELECT * FROM case_table
   ```

2. *Simple Retrieval*: A simple selection is performed based on conditions applied from the target, and the resulting subset is processed externally. This shifts part of the processing task to the database system, but may require considerable modeling effort to precompute similarity as in [Shimazu, 1998], or to relax query specifications as in [Gardingen and Watson,

1998; Daengdej and Lukose, 1997]. The basic query here is:

```
SELECT * FROM case_table WHERE conditions
```

3. *Metric Retrieval*: A metric function is used to order the rows based on a similarity value, `metric(c)`—a function of the target case c. This uses only the database system itself to perform a full k-nn analysis. This method is inefficient, since it must both compute and sort with every record and loses the efficiency of optimized database indexing. Thus it has been rejected in the past [Shimazu *et al.*, 1993], but could prove useful for some implementations, since it does not require additional processing for retrieval. We have used this method with good response time in a prototype application containing 4709 cases with 24 numeric-valued features. The basic query is:

```
SELECT * FROM case_table ORDER BY metric(k)
```

To take full advantage of database capabilities, a preselection of the cases in the case-base could be performed using simple retrieval before evaluating metric retrieval, to reduce (if possible by exact/ranged matching) the number of retrieved cases.

3.2 Web-based/XML

Based on the ER model of CBR in figure 2, we can also describe the structure of a full CBR system using an XML document type definition (DTD). Selected lines from the DTD are shown below:

```
<!ELEMENT CBR   (DATA, PROCESS?)>
...
<!ELEMENT DATA (PROBLEM, SOLUTION, EVAL?, RESULT?)>
<!ELEMENT PROBLEM (ATTRIBSET)>
<!ELEMENT ATTRIBSET (ATTRIB | ATTRIBSET)+>
...
<!ELEMENT PROCESS (METRIC+, ADAPT*)>
...
```

XML documents conforming to this CBR DTD describe the structure (i.e. meta-data) of particular CBR systems. Components of the case base are expressed as relations (attribute sets) and their constituent attributes. Complex hierarchies are supported by allowing sub-relations inside a relation (i.e., an ATTRIBSET inside another ATTRIBSET in the DTD). In contrast to other DTDs for CBR [Shimazu, 1998; Hayes *et al.*, 1998], we allow representation of both process (similarity, adaptation, evaluation) and case representation, together or individually. We are currently working on an implementation that incorporates MathML[2] to represent similarity metrics.

Using the XML model: An instance of the above DTD describes the actual case structure, which is used by a separate XML application to generate the proper structural definition (a separate DTD) of the case data. The actual case data can then be defined as conforming instances of the generated DTD. This two-step process has the following advantages:

1. *Consistency*: By generating the case data DTD from the CBR system markup, we ensure that no separate check is necessary to assert the consistency of the data with the reasoning system.
2. *Validation*: Document type definitions in which the system attributes are represented as generic identifiers (tags) instead of XML attributes allows the case data to be validated against its DTD to ensure its integrity.

While XML has no particular associated process for retrieval, evolving query language implementations such as DSQL in DocBase [Sengupta, 1998] and XML-QL [W3C, 1998] will enhance the applicability of XML as a web-based CBR implementation model.

4 Transforming Implementations

Perhaps as important as the implementations themselves is the transformation of one implementation to another. This is useful in two situations: When new task criteria prefer a model that differs from current implementation, and when differing implementation models are used in different aspects of a combined system (e.g. database storage, web communication, task-based front end). Here we outline the transformations in the framework.

4.1 Web-Based → Enterprise

An XML representation of case structure can be converted to a database system using an XML application that processes XML markup tags/content and generates appropriate Data Definition Language (DDL) statements to create tables in a relational database. Consider the following fragment of a CBR system description, containing a person/automobile relationship:

```
<ATTRIBSET NAME="Person">
  <ATTRIB ID="ID" REQD="REQD" TYPE="longint">SSN
  </ATTRIB>
  <ATTRIB TYPE="char" SIZE="20" REQD="REQD">Name
  </ATTRIB>
  <ATTRIBSET NAME="Auto">
    <ATTRIB TYPE="char">Make</ATTRIB>
    <ATTRIB TYPE="int">Year</ATTRIB>
  </ATTRIBSET>
</ATTRIBSET>
```

The above XML fragment is translated into the following relational DDL statements:

```
create table Person (SSN longint not null,
                     Name char(20) not null);
create table Auto (Person_SSN longint not null,
                   Make char(50), Year int);
```

For complex case structures, the application can adopt a simple foreign key strategy by augmenting a substructure with the key of the parent structure. In order to

[2] http://www.w3.org/TR/REC-MathML/

facilitate a possible future back-translation, this application should also update a database catalog (organized list) with the role of each table created in the CBR model. A similar transformation application can be used to transform XML case data to fill the generated tables.

4.2 Web-Based → Task-Based

The main task in transforming an XML implementation to a task-based implementation is to identify a mapping between XML and task-based structures. We assume that the user or developer of the task-based systems will have the necessary tools and information to create case data in the task-based model. Taking CASUEL [INRECA, 1994] as an example, an application like the one described in Web-Based→Enterprise can generate appropriate CASUEL declarations from the XML structure. This process is similar to the Web-Based→Enterprise generation process, except that the generated statements are in CASUEL instead of SQL.

4.3 Enterprise → Web-Based/Task-Based

Transforming an existing database model into a conforming XML model or task-based model is more involved. Because the database lacks explicit case structure (when using more than a single table), transformation applications need to understand the role of various database objects in the CBR representation. Maintaining a catalog of the database objects and their roles (as in Web-Based→Task-Based) should significantly reduce the amount of reasoning required prior to transformation. This process of role determination can be performed in several ways:

1. *Manual interaction:* The system may ask a user to assist in the process of determination of the roles of each of the objects,
2. *Catalog information:* The system may use a catalog that includes the roles of each of the objects,
3. *Mining:* The system may use data mining techniques to determine appropriate database objects and their roles.

The dashed lines in figure 1 represent the extra information requirements for these transformations.

4.4 Task-Based → Web-Based/Enterprise

Converting from task-based to an XML or database format also depends on the actual task-based model, and the availability of tools that can assist in such transformation. For example, cases represented using the CASUEL language can be mapped into the corresponding XML schema or a database format using an application built on top of a CASUEL parser.

5 Conclusion

We have presented a useful way of viewing current CBR implementation models, and how this view leads to practical support for automating the construction of the right sort of CBR implementations. We view these methods as a natural extension and generalization of mining databases to aid in system construction. Based on this framework, we present three challenges to the community: (1) to create community-standard XML representation specifications for CBR, (2) to build a set of standard methods/libraries for translating between XML and standard database representations, and (3) to develop standard CBR functionality within database systems. As CBR practice evolves, we expect the different implementation types to become increasingly integrated, and we hope to facilitate that transformation.

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