Fuzzy Logic in Case-Based Reasoning

C. Vasudevan† #, S.M. Smith#, K. Ganesan†

#Department of Ocean Engineering,
†Department of Computer Science and Engineering,
Florida Atlantic University, Boca Raton, FL 33431.
vasu@mystic.oe.fau.edu smith@alvin.oe.fau.edu ganesan@cse.fau.edu

Abstract

This paper presents a fuzzy logic approach to address the indexing problems in case-based reasoning paradigm. The relevance of representing case indices using fuzzy sets and a scheme for rating and ranking of candidate cases using fuzzy aggregation operators are discussed. We also suggest the prospects of employing case-based reasoning for learning in fuzzy systems. The proposed schemes are exemplified in the context of a hybrid reasoning system for reactive navigation of autonomous underwater vehicles.

1 Introduction

Case-Based Reasoning (CBR) is an actively pursued research domain with promising practical applications in planning, design, and decision making [Kol93]. Case-base is an episodic memory that represents past experience. The cases in this library are stored and accessed using specific indices derived from the salient features of the case, the type of problem, the failures encountered, and other related situation-specific details. When a new problem is presented, its relevant indices are derived by applying a set of indexing rules. These derived indices are then used to retrieve partially (or fully) matching cases from the case library. The candidate cases are then evaluated and the *best* one is selected. The selected case is modified to conform to the new situation using a set of *repair* rules that represent the domain models and heuristics. Finally, CBR has a learning phase which involves updating the case library with the modified case if it is found to be distinct and worthwhile.

The conventional approach to representation of indices in CBR systems is by specifying each index of each case as a specific value or an interval within which the observed value of the corresponding feature must lie. Successful matching of a selected index is an all or nothing affair. This approach poses difficulties because the intervals may be too small or specific resulting in no matches for a given observed feature set or else require a very large case library to cover the input space. Alternatively, the intervals may be too large leading to multiple dominant features and indistinguishable matches. System performance is overly sensitive to index interval specification. In this context, a major issue is to strike a balance between the two conflicting requirements that the indices should be general enough to make the cases useful for a variety of problems and at the same time, they should be specific enough to be recognizable in future situations. In this work, we propose to employ fuzzy logic techniques to address these indexing problems in CBR. One attempt in this direction is Cogitator [Bai93] - an expert system which computes the similarity between a query and an example case that produces similar outputs when posed with similar inputs. Here, we describe schemes to use fuzzy techniques to represent indices, evaluate cases, and aggregate multiple solutions.

2 Fuzzy Indexing

Case indices defined using fuzzy sets provide not only an interval within which matching occurs, but also, help to establish a preference within the interval as to the degree of match. Matching becomes graded instead of all-or-nothing. Overlapping the boundaries of the fuzzy indices allows multiple partial matches that can be aggregated, rated, and ranked. The case library can cover the input space with fewer cases and provides flexibility for tuning the performance by adjusting the fuzzy set membership functions. For example, in a case-based mission planning system, we employ fuzzy representation of case indices. Here, the cases typically represent different situations where particular navigational behaviors and behavioral parameters are applicable. Some examples of fuzzy indices for reactive navigation of autonomous underwater vehicles (AUVs) are shown in Table 1.

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Index Label	Values
obstacle bearing	zero, very small, small, large, very large
change in heading	zero, very small, small, medium, large
obstacle range	near, far, not seen
speed of water current	slow, medium, high, very high
clutter	open, sparse, cluttered

Table 1. Fuzzy Indices for Navigation Planning

3 Case Evaluation and Fusion

When there are multiple partially matching cases, they need to be graded before choosing the most appropriate one. This is a multi-criteria decision making problem. The primary complication with case-based reasoning is that the importance of various indices is case dependent. We propose a weighted hierarchical aggregation scheme in which the indices are classified into different groups each having a different type of aggregation operator.

If C_{ij} is the j^{th} index of the i^{th} case, then β_{ij}, the degree of match of the problem with case i may be expressed as

$\beta_{ij} = \mu_(C_{ij})(x'_j)$ where x'_j is the observed value of index x_j.

A weighted hierarchical aggregation involves individual weights w_{ij} for each of the indices and for each of the groups at different aggregating levels. If $*^k$ is the aggregating operator for group k, the degree of match of several indices in a particular group k could be expressed as

$$\beta_i^k = *^k([w_{i1}, \beta_{i1}], [w_{i2}, \beta_{i2}], \quad [w_{in}, \beta_{in}])$$

Finally, the degree of match of the new problem with case i is computed by aggregating the matches of individual groups of indices at different hierarchical levels in a similar fashion. Several different approaches to weighted aggregation exist such as simple weighted averaging, Yager's OWA operator, Zimmermann's γ-operator, etc., [Zim91, Yag88, DP88].

For real-time scenarios with dynamically varying outputs like in control applications, repairing and using a single case alone may not be desirable. Fuzzy techniques allow averaging or aggregation of multiple partially matching cases to produce a solution which may be better than any single one. For example, the navigational commands such as heading and speed may be aggregated to compute the final commanded values to the actuators. We have implemented fuzzy fusion of different navigational behaviors like *docking, cruising,* and *collision avoidance* using a weighted averaging scheme.

4 CBR for Learning in Fuzzy Logic Domain

An important benefit that can be realized by using a hybrid fuzzy-CBR scheme is the ability to add new cases into the casebase leading to incremental improvements in system performance. CBR can be employed to learn parameter values and coefficients in fuzzy functions which are appropriate in different contexts. An example is the weighted fusion of navigational command parameters prescribed by different behaviors. The weights to be attached to each of the behaviors are context dependent. These contexts and corresponding weights are stored as cases in the navigational system. The performance of such a system is modified by adding new cases or by modifying existing ones. We are currently investigating the issues in incremental learning in the context of fuzzy-CBR reasoning.

5 Conclusion

Identification of appropriate indices and matching them to suitable cases in the case library are of central concern in case-based reasoning. Fuzzy logic provides a suitable scheme for abstracting higher level symbolic information from surface features as well as for supporting inexact reasoning to manage the partial matches of cases. The proposed schemes are being implemented in a reactive navigation planning system for autonomous underwater vehicles. The symbiotic use of fuzzy logic and CBR techniques would lead to a more robust and efficient reasoning method than relying completely either on episodic knowledge of the conventional CBR approaches or preprocessed knowledge of the fuzzy domain.

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