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Emergent case-based reasoning applications

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Abstract

The basic principle underpinning case-based reasoning (CBR) is that new problems can be solved by reusing solutions to past problems. The generality of this idea means that CBR is finding application in a wide variety of areas. The special advantage of CBR is that a *case* can be a very convenient means of capturing knowledge, especially in *weak theory* domains where the relationship between causes and effects may not be well understood. Cases may embody more than problem-solving knowledge; the knowledge in a case may be a creative structure or a complex behavior pattern. The widespread applicability of this idea means that it has been exploited in a diverse range of areas across the arts and sciences. This article provides a brief summary of some of these applications.

1 Introduction

New CBR applications are starting to emerge and deserve attention. Because the CBR idea is so general, these new applications are emerging across a broad range of disciplines. The objective of this article is to provide an overview of these emergent applications. To do that, we organize our survey into applications in entertainment and the arts and applications in science.

2 Case-based reasoning in entertainment and the arts

A very representative emerging field is music. The first work that applied CBR to music is that of Arcos *et al*. (1998), which won the Best Paper Award at the 1997 International Computer Music Conference. In this work, the authors describe a system, called *SaxEx*, capable of synthesizing high-quality expressive tenor sax solo performances of jazz ballads based on cases representing human solo performances. Previous rule-based approaches to that problem could not deal with more than two expressive parameters (such as dynamics and rubato) because it is too difficult to find rules general enough to capture the variety present in expressive performances. Besides, the different expressive parameters interact with each other, making it even more difficult to find appropriate rules that account for these interactions. With CBR, the authors have shown that it is possible to deal with the five most important expressive parameters: dynamics, rubato, vibrato, articulation, and attack of the notes. To do so, SaxEx uses a case memory containing examples of human performances, analyzed by means of spectral modelling techniques and background musical knowledge. The score of the piece to be performed is also provided to the system. SaxEx's method analyzes each input note to determine its role in the musical phrase it belongs to, identify and

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retrieve (from the case base of human performances) notes with similar roles, and finally, transform the input node so that its expressive properties (dynamics, rubato, vibrato, articulation, and attack) match those of the most similar retrieved note. Each note in the case base is annotated with its role in the musical phrase it belongs to as well as with its expressive values. Furthermore, cases do not only contain information on each note; they also include contextual knowledge at the phrase level. Therefore, cases in this system have a complex object-centered representation. Although limited to monophonic performances, the results are very convincing and demonstrate that CBR can use the knowledge of a human performer that is implicit in played examples rather than trying to make this knowledge explicit by means of rules.

More recent papers by Arcos & López de Mántaras (2001) and by López de Mántaras and Arcos (2002) describe this system in great detail. Other applications of CBR to expressive music are described in (Suzuki *et al.,* 1999) and (Tobudic & Widmer, 2003). Suzuki *et al.* also use example cases of expressive performances to generate multiple performances of a given piece with varying musical expression. However, they deal only with two expressive parameters. Tobudic and Widmer apply instance-based learning (IBL) to the problem of generating expressive performances. The IBL approach is used to complement a note-level rule-based model with some predictive capability at the higher level of musical phrasing. More concretely, the IBL component recognizes performance patterns, of a concert pianist, at the phrase level and learns how to apply them to new pieces by analogy. The approach produced some interesting results but, as the authors recognize, was not very convincing due to the limitation of using an attribute-value representation for the phrases. Such a simple representation does not express relevant structural information of the piece, both at the sub-phrase level and at the interphrasal level. In a subsequent paper, Tobudic and Widmer (2004) succeeded in partly overcoming this limitation by using a relational phrase representation.

Another arts-related application is a system for poetry generation developed by Díaz-Agudo *et al.* (2002). Their system works by accepting a query consisting of a sequence of words. This query determines the indices for retrieving an existing poem in the case base and the adaptation step will substitute words of the retrieved poem with appropriate words from the query.

Perhaps the emerging application domain for CBR that is getting most attention at the moment is the area of computer games. This was the topic of a very successful workshop at the *International Conference on Case-Based Reasoning (ICCBR)* in Chicago in 2005 and is an area that will see much activity in the coming years. As Artificial Intelligence (AI) becomes an important differentiator in the marketing of computer games, it is clear that CBR has considerable potential for making games more intelligent. Ideas from CBR have been used to manage the scripting of story-based games (Fairclough & Cunningham, 2003). CBR ideas have been used in episodic memory in SOAR-5 to control a non-player character in the Quake II game (Laird, 2001). As game-worlds become more complex, planning becomes more difficult. Case-based planning has the potential to manage this complexity: indeed, the best paper award at the ICCBR 2005 conference went to a paper by Aha *et al.* (2005) on case-based planning in strategy games.

3 Case-based reasoning in the sciences

Another emergent field of application is molecular biology. Indeed, as it is pointed out in the paper by Jurisica *et al.* (2001), genomics projects are likely to produce hundreds of proteins for structural analysis every year. In order to use crystal X-ray diffraction to determine the protein structure, a process of crystal growth for proteins has to be carried out. The main goal of the research work of Jurisica *et al.* is to speed up the crystal growth process. An intelligent decision support system is being developed with this aim that contains a case-based reasoning component that provides support for the design of crystal growth experiments by retrieving previous similar cases and adapting them to solve the problem at hand. More concretely, the so-called precipitation index of a new protein is compared to the precipitation indices of all the proteins in the case base using a *k*-nearest neighbour approach. The crystallization plans of proteins with the most similar

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precipitation indices are retrieved and reused for planning the crystallization experiment of the new protein. Successful crystallizations are added to the case base for future use. Failed crystallizations are also kept since failures are useful to avoid repeating negative results. Other CBR systems have been developed to address other problems in molecular biology such as the problem of analyzing genomic sequences and determining the structure of proteins. See Jurisica & Glasgow (2004) for further information.

A significant emerging area in bioinformatics and medical informatics for CBR is the area of image analysis. As activity in these areas progresses, digital images are being produced from a variety of sources in volumes that cannot be analyzed by humans. Ideas from CBR are being applied in the annotation and classification of these types of images (Perner, 1999).

A final emerging field involving CBR concerns geographical information systems (GISs). The approach consists of combining CBR and GISs to solve spatial reasoning problems. The pioneering work in that field is by Holt & Benwell (1999). They apply CBR and GISs to the problem of soil classification, which is solved by searching the case base for spatial cases similar to the problem at hand. The authors conclude that the CBR approach has many advantages compared to previous methods used for soil classification.

4 Conclusion

It should be clear from this brief survey that the generality of the CBR idea has broad applicability. A case-based approach is often the only viable way to develop intelligent applications in complex domains. For this reason we can expect to see further CBR research in the areas discussed here and further emergent applications in other areas.

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