Applications of the CBR Methodology to Medicine

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Abstract

Case-Based Reasoning (CBR) means reasoning from experiences (old cases) in an effort to solve problems, critique solutions and explain anomalous situations. The CBR approach to problem-solving and learning has got a lot of attention within the Artificial Intelligence's community over the last few years, because as an intelligent-systems' method enables information managers to increase efficiency and reduce cost by substantially automating processes.

In the present paper we study the development of the CBR methodology in the area of Medicine and Bio-Medical Informatics, where one can find some of the most common and useful CBR applications. Summarizing first the benefits of using expert support systems (e.g. CBR systems) in healthcare, we present next characteristic applications of the CBR methodology in the Medicine domain and we discuss the knowledge engineering issues which are crucial in developing CBR systems for any healthcare task.

Keywords: *Cased-Based Reasoning, Analogical Reasoning, Problem-Solving, Machine Learning, Expert Systems, Knowledge Engineering, CBR Applications to Biomedical Informatics, Artificial Intelligence.*

1. Introduction

The *Case-Based Reasoning* (CBR) approach to problem-solving (PS) and learning has got a lot of attention within the Artificial Intelligence's (AI) community over the last few years [1], because as an intelligent-systems' method enables information managers to increase efficiency and reduce cost by substantially automating processes.

The target of the present paper is to study the development of the CBR methodology in the area of Medicine and Bio-Medical Informatics, where one can find some of the most common and useful CBR applications. The paper is organized as follows: In the next (second) section we summarize the benefits of using expert support systems (e.g. CBR systems) in healthcare. In section 3 we attempt a brief presentation of the general CBR methodology, while in section 4 we present characteristic applications of the CBR methodology in the Medicine domain. Further, in section 5 we discuss the knowledge engineering issues which are crucial in developing CBR systems for any healthcare task. Finally, in section 6, we state our conclusions.

2. Benefits of the Expert Support Systems to Healthcare

In AI an *expert system* is a computer program that simulates the decision-making ability and behavior of a human or an organization that has expert knowledge and experience in a particular field [2]. Typically, such a system includes a knowledge base containing accumulated experience and a set of rules for applying the knowledge base to each particular situation that is described to the program. Sophisticated expert systems can be enhanced with additions to the knowledge base or to the set of rules. Expert systems are designed to solve complex problems by reasoning about knowledge, represented primarily as if-then rules rather than through conventional procedural code. The first expert systems were created in the 1970's and then proliferated in the 1980's [3]. Expert systems were among the first truly successful forms of AI software.

The benefits of using expert support systems approach (e.g. CBR systems) in the healthcare sector are linked mainly with patients' treatment. We may enumerate several areas in which expert systems bring benefits, these are:

Treatment choice – may be easier with the use of if-then rules of an expert system; Following the rules, a physician is able to infer treatment adequate to symptoms and/or to a specific illness.

Diagnosis support – this comes both from rule-based systems as well from case based ones. If-then rules enable encoding of knowledge linking symptoms to illnesses, while case-based reasoning enables finding the illness by comparing patients' symptoms to these stored in case-based knowledge base;

Analysis of treatment options – rule-based knowledge enables a so-called what-if analysis: what is probable to happen if we use a specific treatment?

Keeping medical history – is easy with case-based expert systems, where individual patients' cases may be stored both for statistical purposes and for case-based reasoning.

3. The CBR methodology

CBR means reasoning from experiences (*old cases)* in an effort to solve problems, critique solutions, and explain anomalous situations [4]. A lawyer, who advocates a particular outcome in a trial based on legal precedents, or an auto mechanic, who fixes an engine by recalling another car that exhibited similar symptoms, or even a physician, who considers the diagnosis and treatment of a previous patient having similar symptoms, to determine the disease and treatment for the patient in front of him, are using CBR. In other words, CBR is an analogical reasoning technique providing both a methodology for PS and a cognitive model for people.

People tend to be comfortable using the CBR methodology for decision making, in dynamically changing situations and other situations were much is unknown and when solutions are not clear. The CBR systems' expertise is embodied in a collection (library) of past cases rather, than being encoded in classical rules. Each case typically contains a description of the problem plus a solution and/or the outcomes. The knowledge and reasoning process used by an expert to solve the problem is not recorded, but is implicit in the solution. A *case-library* can be a powerful corporate resource allowing everyone in an organization to tap in the corporate library, when handling a new problem. CBR allows the case-library to be developed incrementally, while its maintenance is relatively easy and can be carried out by domain experts.

The key difference between *CBR* and the classical *rule-induction algorithms,* which are procedures for learning rules for a given concept by generalizing from examples of that concept, lies in when the generalization is made. In fact, while CBR starts with a set of cases of training examples and forms generalizations of these examples by identifying commonalities between a retrieved case and the target problem, a rule-induction algorithm draws generalizations before the target problem is even known, i.e. it performs eager generalization.

CBR has been formalized for purposes of computer and human reasoning as a four step process, known as the *dynamic model of the CBR cycle* [5]. These steps involve the following actions:

- *Retrieve* the most similar to the new problem past case, or cases.
- *Reuse* the information and knowledge in that case to solve the problem.
- *Revise* the proposed solution.
- *Retain* the parts of this experience likely to be useful for future problem-solving.

The functional diagram of Figure 1 (where boxes represent process and ovals represent knowledge sources)

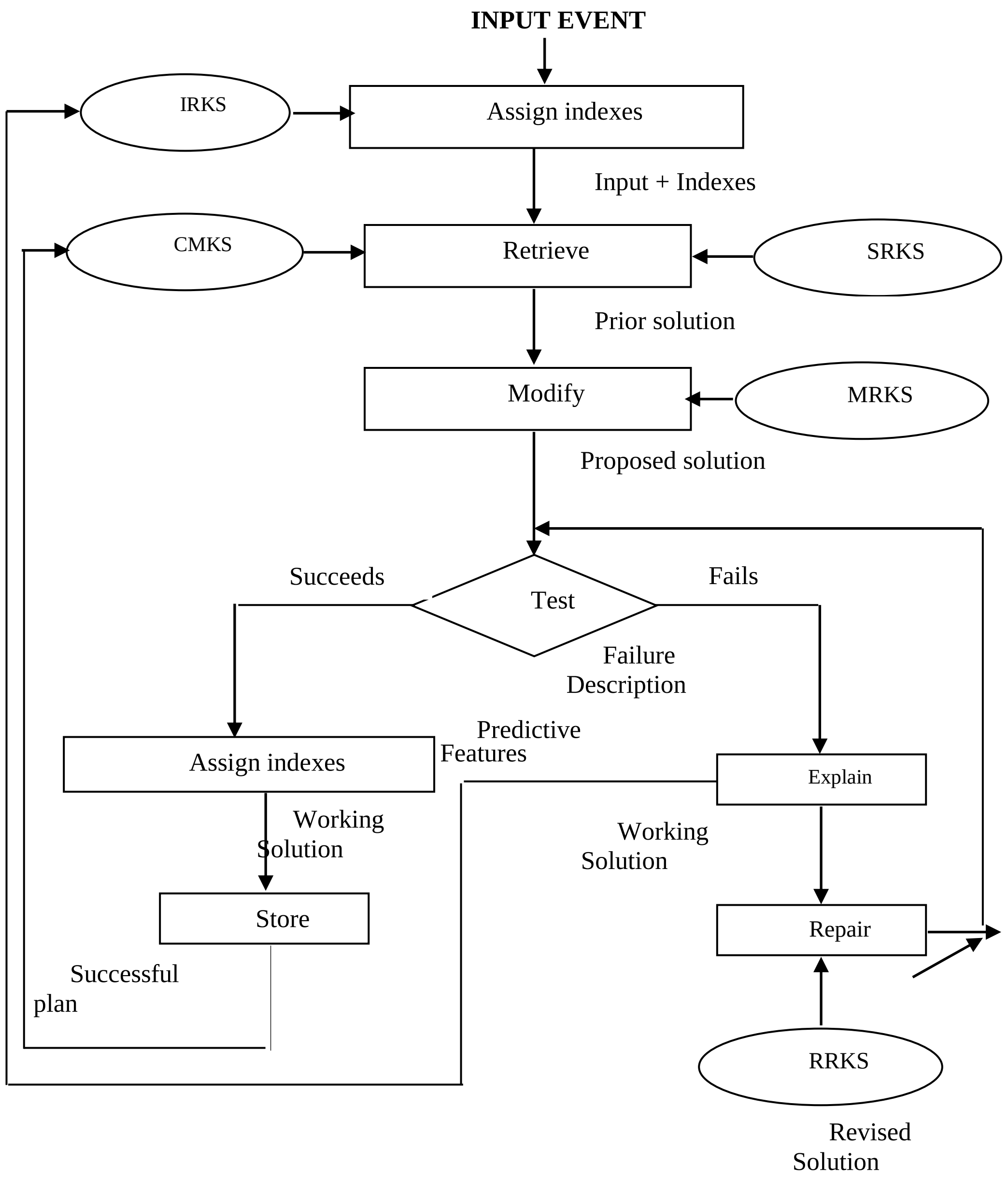

Fig. 1: A functional diagram of the CBR methodology

adapted from [3] and [6] and presented by Prof. Salem in his plenary lecture [7] at the 16th WSEAS International Conference on Computers (Kos island, Greece, July14-17, 2012), gives a graphical representation of the CBR methodology:

When a new problem is introduced in the system, the problem is indexed, and subsequently, the indexes are used to retrieve past cases from memory. These past cases lead to a set of prior solutions. Subsequently, the previous solutions are modified to adapt to the new situation. Then the proposed solution is tried out. If the solution succeeds, then it is stored as a working solution; if it fails, the working solution must be repaired and tested again.

Other flowcharts illustrating the basic steps of the CBR process were produced by Riesbeck and Bain [8], Slade [9], Lei et al. [10], Voskoglou [5], etc.

CBR's coupling to *learning* occurs as a natural by-product of PS. When a problem is successfully solved, the experience is retained in order to solve similar problems in future. When an attempt to solve a problem fails, the reason for the failure is identified and remembered in order to avoid the same mistake in future. Thus CBR is a cyclic and integrated process of solving a problem, learning from this experience, solving a new problem, etc.

CBR is often used where experts find it hard to articulate their thought processes when solving problems. This is because knowledge acquisition for a classical knowledge-based system would be extremely difficult in such domains, and is likely to produce incomplete or inaccurate results. When using CBR the need for knowledge acquisition can be limited to establishing how to characterize cases.

The main domains of the CBR applications include *diagnosis*, *help-desk*, *assessment*, *decision support*, *design*, etc. More explicitly:

CBR diagnostic systems try to retrieve past cases, whose symptom lists are similar in nature to that of the new case and suggest diagnoses based on the best matching retrieved

cases. CBR diagnostic systems are also used in the customer service area dealing with handling problems with a product or service (help-desk applications), e.g. Compaq SMART system [11].

In the assessment processes CBR systems are used to determine values for variables on comparing it to the known value of something similar. Assessment tasks are quite common in the finance and marketing domains.

In decision making, when faced with a complex problem, people often look for analogous problems for possible solutions. CBR systems have been developed to supporting this problem retrieval process to find relevant similar problems. CBR is particularly good at querying structured, modular and non-homogeneous documents.

Finally, systems to support human designers in architectural and industrial design have been developed. These systems assist the user in only one part of the design process, that of retrieving past cases, and would need to be combined with other forms of reasoning to support the full design process.

The driving force behind case-based methods has to a large extent come from the *machine learning* community, and CBR is regarded as a subfield of machine learning. In fact, the notion of CBR does not only denote a particular reasoning method, irrespective of how the cases are acquired, it also denotes a machine learning paradigm that enables sustained learning by updating the case base after a problem has been solved.

In concluding, the advantages and benefits of the CBR methodology can be summarized as follows:

- Can make use of background domain knowledge when available.
- It integrates symbolic and numeric techniques.
- It supports fuzzy quantities and queries.
- It offers rich indexing support.

- It uses known solutions to past experiences for solving a new problem whose solution is unknown.
- It combines the benefits of information retrieval and rule based reasoning.
- It copes with complex structured data

4. Applications of CBR in Medical Domain

4.1.1 CBR has already been applied in a number of different applications in medicine. Some CBR systems used in medical applications are: CASEY that gives a diagnosis for the heart disorders [4], GS.52 which is a diagnostic support system for dysmorphic syndromes, NIMON which is a renal function monitoring system, COSYL that gives a consultation for a liver transplanted patient [12], ICONS that presents a suitable calculated antibiotics therapy advise for intensive care patients [13], etc.

4.1.2 Here we present briefly two characteristic examples of CBR-based expert systems developed by Bio-Medical Informatics and Knowledge Engineering Labs at Artificial Intelligence Research Unit, Faculty of Computer and Information Sciences, Ain Shams University, Cairo, Egypt for medical applications:

I. CBR-based system for diagnosis of cancer diseases

Cancer is a group of more than 200 different diseases; it occurs when cells become abnormal and keep dividing and forming either benign or malignant tumors. Cancer has initial signs or symptoms if any is observed, the patient should perform complete blood count and other clinical examinations. Then to specify cancer type, patient needs to perform special lab-tests.

The main purpose of the system developed for diagnosis of cancer diseases is to serve as doctor diagnostic assistant. The system provides recommendation for controlling pain and providing symptom relief in advanced cancer. It can be used as a tool to aid and hopefully improve the quality of care given for those suffering intractable pain. The system is very useful in the management of the problem, and its task to aid the young physicians to check their diagnosis [14-15].

Figure 2 shows the architecture of the CBR-based system for cancer diagnosis.

The system's knowledge base is diverse and linked through a number of indices, frames and relationships. The bulk of this knowledge consists of actual case histories and includes 70 cancer patient cases; some are real Egyptian cases and some from virtual hospitals on the internet.

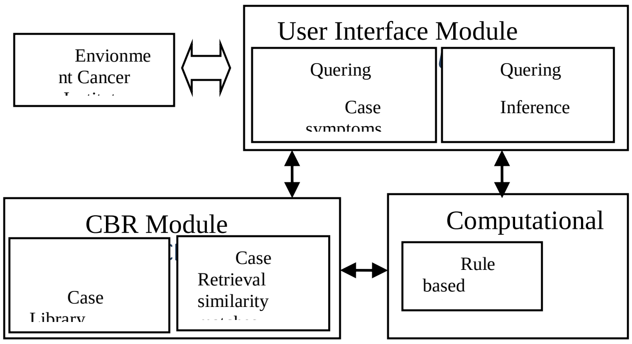

Fig.2: Architecture of the CBR-based system for cancer diagnosis

The system consists of three main modules; user interface, case base reasoning module and computational module; all are interacted with the main environment of cancer diseases. The user is a cancer expert doctor, the interaction is through menus and dialogues that simulate the patient text sheet containing symptoms and lab examinations. Computational model uses rule-based inference to give diagnostic decision and each new case is stored in case library. Patient cases are retrieved in dialogue with similarity matches using the nearest neighbor matching technique. The initial diagnostic process is done through firing of rules in the Rule-Based inference. These rules encode information about patient's symptoms and pathological examinations. Frames technique is used [16] for patient case indexing, storage and retrieval. The patient case will include age, sex

and weight occupation, pathologic, medical history family, physical exams and treatments. Below a typical example is given .of an Egyptian liver cancer case description of an old woman:

Patient: 65-years old female not working, with nausea and vomiting.
Medical History: Cancer head of pancreas
Physical Exam: Tender hepatomgaly liver, large amount of inflammatory about 3 liters, multiple liver pyogenic abscesses and large pancreatic head mass.
Laboratory Findings: Total bilrubin 1.3 mg/dl, direct bilrubin 0.4 mg/dl, sgot (ast) 28 IU/L, sgpt (alt) 26 IU/L.

II. CBR-based system for diagnosis of heart diseases

Heart disease is a vital health care problem affecting millions of people. Heart diseases are of 25 different ones; e.g. left-sided heart failure, right-sided heart failure, angina pectoris, myocardial infraction and essential hypertension. The system is able to give an appropriate diagnosis for the presented symptoms, signs and investigations done to a cardiac patient with the corresponding certainty factor. It can be used to serve as doctor diagnostic assistant and support the education for the undergraduate and postgraduate young physicians.

In this system the knowledge is represented in the form of frames and the case memory contains 110 cases for 4 heart diseases namely; mistral stenosis, left-sided heart failure, stable angina pectoris and essential hypertension. Each case contains 207 attributes concerning both demographic and clinical data. After removing the duplicate cases, the system has trained set of 42 cases for Egyptian cardiac patients. Statistical analysis has been done to determine the importance values of the case features. Two retrieval strategies were investigated namely; induction and nearest neighbor approaches. The results indicate that the nearest neighbor is better than the induction strategy. Cardiologists have evaluated the overall system performance where the system was able to give a correct diagnosis for thirteen new cases [17].

5. Knowledge Engineering Issues in Developing Bio-medical CBR Systems

Knowledge engineering (KE) was defined in 1983 by Feigenbaum and McCorduck [18] as follows: KE is an engineering discipline that involves integrating knowledge into computer systems in order to solve complex problems normally requiring a high level of human expertise

In what follows a brief discussion of the knowledge engineering issues which are crucial in developing CBR Systems for any healthcare task [18-19].

Case Representation: Determining the appropriate case features is the main knowledge engineering process in CBRS. The case is a list of features that lead to a particular outcome (e.g. the information on a patient history and the associated diagnosis). This process involves; (a) defining the terminology of the domain and (b) gathering representative examples of problem solving by the expert. Representations of cases can be in any of several forms; predicate representations, frame representations and representations resembling database entries.

Case Indexing Process: The CBR derives its power from its ability to retrieve relevant cases quickly and accurately from its memory. Figuring out when a case should be selected for retrieval in similar future situations is the goal of the case *indexing process*. Building a structure or process that will return the most appropriate case (from the case memory) is the goal of the *retrieval process*. Case indexing process usually falls into one of three approaches: nearest neighbor, inductive, and knowledge-guided or a combination of the three.

Case Memory Organization and Retrieval: Once cases are represented and indexed, they can be organized into an efficient structure for retrieval. Most case memory structures fall into a range between *purely associative retrieval*, where any or all of the features of a case are indexed independently of the other features and *purely hierarchical retrieval*, where case features are highly organized into a general-to-specific a concept structure. Nearest-neighbor matching techniques are considered associative because they have no real-memory organization. Discrimination nets are more of a cross between associative and hierarchical because they have some structure to the net but greater retrieval flexibility because they have a greater number of links between potential indexing features. Decision trees are an example of purely hierarchical memory organization.

Case Adaptation: It is difficult to define a single generically applicable approach to perform case adaptation, because adaptation tends to be problem specific. Most existing CBR systems achieve case adaptation for the specific problem domains they address by encoding adaptation knowledge in the form of a set of adaptation rules or domain model. Adaptation rules are then applied to a retrieved case to transform it into a new case that meets all of the input problem's constraints. More recent applications have successfully used pieces of existing cases in memory to perform adaptations.

Learning and Generalization: As cases accumulate, case generalization can be used to define prototypical cases that embody the major features of a group of specific cases, and those prototypical cases can be stored with the specific cases, improving the accuracy of the system in the long run.

CBR - Tools and Shells: The availability of a commercial CBR shells in the market helps the knowledge engineers to overcome some of the problems they currently face in designing and maintaining large knowledge-base learning systems using rule based tools [20-21].

6. Conclusions

The following conclusions can be drawn from the discussion developed in this paper:

i) CBR has blown a fresh wind and a well justified degree of optimism into AI in general, and knowledge based decision support systems in particular. The growing amount of on going CBR research has the potential of leading into significant breakthroughs of AI methods and applications.

ii) CBR is an appropriate methodology for all medical domains and tasks for the following reasons: cognitive adequateness, explicit experience, duality of objective and subjective knowledge, automatic acquisition of subjective knowledge, and system integration.

iii) CBR presents an essential technology of building intelligent CBR systems for medical diagnoses that can aid significantly in improving the decision making of the physicians. These systems help physicians and doctors to check, analyze and repair their solutions. The physician inputs a description of the domain situation and his (her) solution and the system can recalls cases with similar solutions and presents their outcomes to the student. Also he (she) attempts to analyze the outcomes to provide an accounting of why the proposed type of solution succeeded or failed.

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