An Overview on Recent Medical Case-Based Reasoning Systems

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Abstract

Case-based reasoning systems for medical application are increasingly applied to meet the challenges from the medical domain. This paper looks at the state of the art in case-based reasoning and some systems are classified in this respect. A survey is performed based on the recent publications and research projects in CBR in medicine. Also, the survey is based on e-mail questionnaire to the authors' to complete the missing property information. Some clear trends in recent projects/systems have been identified such as most of the systems are multi-modal, using a variety of different methods and techniques to serve multipurpose i.e. address more than one task.

1. Introduction

Learning from the past and solving new problems based on previously solved cases is the main approach of case-based reasoning (CBR). This approach is inspired by humans and how they sometimes reason when solving problems. CBR for health science is today both a recognized and well established method. The health science domain offers researchers in the CBR community worthy challenges driving the research area of CBR forward and at the same time enable researchers to develop methods and techniques in the medical domain previously difficult to solve with other methods and approaches. A number of interesting publications are looking at a CBR in health science and also number of influential CBR systems in health science (Gierl, and Schmidt, 1998; Schmidt et al. 2001; Holt et al. 2006; Bichindaritz and Marling 2006; Bichindaritz 2006; Montani 2008; Bichindaritz 2008).

Due to the area's fast and successful development and progress we recognize the need for a systematic survey capturing and indentifying recent trends in CBR for the health sciences. This paper contains a survey and investigation of the CBR in the medical domains between 2004 and 2008 following the same approach as (Nilsson and Sollenborn 2004) with a through literature search followed by an e-mail survey to the authors of the systems. A number of recent medical CBR systems development followed by the analysis of the properties and functionalities of such systems have been identified. Before going into the survey results we give a short summary and references of the systems included in the survey. If you are familiar with the area you may prefer to read the following section Assessment of Current Trends and use the following section Recent CBR Systems in the Health Sciences as reference section.

2. CBR Systems in the Health Sciences

An overview and status of medical CBR systems from 1999 to 2003 was done by Nilsson and Sollenborn (Nilsson and Sollenborn 2004) and before 1998 (Gierl and Schmidt 1998) published an overview. The overview presented in this paper reported systems developed between the years 2004 to date. The focus is on the progress and changes in the CBR systems in the health sciences. A number of specific prosperities, particularly the use of CBR systems and their changes in construction made to date are selected. The purpose of the systems follows the categories earlier identified by Gierl and Schmidt 1998 and Nilsson and Sollenborn 2004. The purpose Knowledge acquisition/management is used accordingly to (Watson 2001) where knowledge acquisition is labeled as a one of the activities of knowledge management. In medical domain, planning generally refers to treatment planning or therapy support. For instance, the RHENE system (Montani et al. 2006) provides planning expertise for the End Stage Renal Disease patients by monitoring and adjusting the treatment over time.

An effort has been made to include all of today's active systems in the area and considerable time has been spent on searching journals, conferences and workshops. Our aim is that this section gives sufficient information to trigger interest to systems not familiar to the reader and lead to exploration of the original publications. The following chapter narrates a number of major CBR systems/projects in the health sciences with the aim of assessing recent trends in CBR for health science. We have ranked the systems/projects' name in alphabetic order and then systems/projects (without name) are listed with their authors' name. Some systems with many purposes have been given longer explanations. In some system descriptions we also included brief summaries of issues not dealt with further in this survey but of interest out of a trend perspective, e.g. standardization efforts.

1. **CaseBook** (McSherry 2007) [*Purpose: Diagnosis, Classification*] is a hypothetico-deductive CBR system for classification and diagnosis that applies hypothetico-deductive reasoning (HDR) in conversational CBR systems. HDR facilitates to find the significant hypothesis

or to rule out a hypothesis proposed by a system or user while minimizing the number of tests required. The strategy is exemplified in recommending type of contact lenses in the contact lenses classification domain.

2. ExpressionCBR (De Paz et al. 2008) [*Purpose: Diagnosis, Classification*], is a decision support system for cancer diagnosis. The system classifies the Leukemia patients automatically from Exon array data and helps in diagnosis of patients with various cancer types. It uses a data filtering algorithm that deals with the dimensionality problem in data sets. Besides, a clustering algorithm for classification approach speeds up the process.

3. Fungi-PAD (Perner et al. 2006, Perner and Bühring 2004) [*Purpose: Classification, Knowledge acquisition/ management*] describes an object recognition method applying image processing and case-based reasoning to detect biomedical objects i.e. airborne fungal spores in a digital microscopic image. The appearance of fungal spores cannot be generalized to a model due to the large biological variation. The system uses a set of cases to explain the appearance of each object. It compares an object in the image to the original object. This original object is generated using a template which is a prototypical case produced by a semi-automatic process.

4. FrakaS (Cordier et al. 2007) [*Purpose: Diagnosis, Knowledge acquisition/ management*] is a prototype build in the domain of oncology using CBR. The paper emphasizes on the proper management of the domain knowledge to avoid wrong decisions in medical decision support system. Evolution of the domain knowledge is highlighted into the paper in a way when inconsistency between the domain and the expert knowledge is added as a new knowledge. These authors propose a conservative adaptation strategy for knowledge acquisition from experts.

5. GerAmi (Corchado, Bajo, and Abraham 2008) [*Purpose: Planning, Knowledge acquisition/ management*] 'Geriatric Ambient Intelligence' is an intelligent system that aims to support healthcare facilities for the elderly, Alzheimer's patients and people with other disabilities. This system mainly works as a multi-agent system and included CBR system to provide case-based planning mechanism. This helps to optimize work schedules and provide up-to-date patient data. The prototype system has been implemented at a care facility for Alzheimer patients in geriatric residences.

6. geneCBR (Glez-Peña et al. 2005; Díaz, Fdez-Riverola, and Corchado 2006) [*Purpose: Diagnosis, Classification*] is focusing on the classification of cancer, based on gene expression profile of microarray data. Each case contains 22,283 features. The system is aiming to deal with a common problem in bioinformatics i.e. to keep the original set of features as small as possible. Several AI techniques are combined to optimize the classification accuracy. Cases are represented using fuzzy sets, and fuzzy-prototype based retrieval is applied in the case retrieval. A set of rules helps to present an explanation of the provided solution. The patients are clustered into group of genetically similar patients using neural networks.

7. HEp2-PAD (Plata et al. 2008; Perner 2006a; Perner 1999) [*Purpose: Classification, Knowledge acquisition/ management*] addresses a novel case-based method for image segmentation in medical image diagnosis. The system combines CBR, image processing, feature extraction and data mining techniques to optimize image segmentation at low level unit. CBR performs the segmentation parameter selection mechanism based on current image characteristics. Cases are represented with image and non-image information. Similarity value is calculated from both the image and non-image information. This provides an image interpretation close to a human expert.

8. In the **ISOR** (Schmidt and Vorobieva 2006) [*Purpose: Diagnosis, Planning*], the authors address particularly the endocrine domain. The system identifies the causes of ineffective therapies and advises better recommendations to avoid inefficacy to support in long-term therapies. The system is exemplified in diagnosis and therapy recommendations of Hypothyroidism patients treated with hormonal therapy. The system is not only based on the case base but also on other knowledge components such as a knowledge base that represents the domain theory in a tree structure, prototypes i.e. generalized cases and medical histories of a patient. Information of these containers worked in a form of dialogue and key words are used for the case retrieval.

9. The **IPOS** (Begum et al. 2008) [*Purpose: Diagnosis*] project aims at proving a case-based decision support system to assist clinicians in diagnosing individual stress condition based on finger temperature measurements. The system uses calibration phase to generate an individual stress profile. Case-based reasoning is applied as the key methodology to facilitate experience reuse and decision explanation by retrieving previous similar temperature profiles. Further, fuzzy technique is incorporated into the CBR system to handle vagueness, uncertainty inherently existing in clinicians reasoning as well as imprecision of feature values. In addition, a hybrid CBR system is illustrated in (Ahmed et al. 2008a) dealing with combined time series signals and unstructured textual information for clinical decision support in stress medicine. The time series measurements and textual data capture different yet complementary aspects of a subject and they are desired to be tackled simultaneously for more comprehensive situation awareness and thereby more reliable diagnoses and decisions.

10. The **KASIMIR** project (D'Aquin, Lieber, and Napoli 2006) [*Purpose: Diagnosis, Classification, Knowledge acquisition/ management*], is an effort to provide decision support for the breast cancer treatment based on a protocol in Oncology. The adaptation of the protocol is an important issue handled here to provide therapeutic decisions for the cases those are out of the protocol. The system (Cordier et al. 2007) stresses particularly on the importance of the proper management of domain knowledge to avoid wrong decisions. The analysis of failure adds as a new dimension of knowledge into the domain knowledge enabling automatic evolution of this knowledge. Conservative protocol adaptation to a new case, depending on a revision operator provides a consistency between the domain knowledge and the target case.

11. The **Mémoire Project** (Bichindaritz 2006a) [*Purpose: Diagnosis, Planning, Knowledge acquisition/ management, Tutoring*], at the University of Washington, offers a framework to exchange case bases and the CBR systems in biology and medicine. It is an effort to apply semantic web approach in biomedical domain. Mémoire uses OWL representation language to make the case bases interoperable. A number of researches have been taken place (Bichindaritz 2008a; Bichindaritz 2007) in the Mémoire project to validate the different roles of prototypical cases. In (Bichindaritz 2007a) the author deals particularly with the prototypical cases, where the prototypical cases act as maintenance cases by keeping the knowledge up-to-date with the rapid development in the biomedical domain. The author argues that this maintenance prototypical case can be generated by mining from the medical literatures which could in turn lead to building and maintaining of case bases in an autonomous way in the medical domain. The project explores prototypical cases and how they can serve in various ways in a CBR system for example, maintenance of memory, maintenance of knowledge, management of reasoning and bootstrapping a case base. Bichindaritz have developed several other systems that addresses the issues related to prototypical cases in the biomedical domain such as, ProCaseMiner (Bichindaritz 2007) automatically builds initial case base.

12. RHENE (Montani et al. 2006; Montani et al. 2006a) [*Purpose: Classification, Planning, Knowledge acquisition/ management*], is a case-based system in the domain of nephrology for the management of end stage renal disease patients treated with hemodialysis. It mainly concentrates on the retrieval of patterns of failure over time and allows the physician to analyze the solution within and between the patients. RHENE assists to look for the consistency of a prescribed therapy plan to a proposed dialysis session and provides an assessment of the treatment efficacy. Each dialysis session is represented as a case in which static features characterize a patient and dynamic features are collected from the time series measurement. A case-based architecture is further described in (Leonardi et al. 2007) for parameter configuration of temporal abstractions on time-series data to reduce the dimensionality of the feature and is exploited into the RHENE system.

13. Somnus (Kwiatkowska and Atkins 2004) [*Purpose: Diagnosis, Planning, Tutoring*], is a prototype implemented in the domain of Obstructive Sleep Apnea (OSA). OSA is a respiratory disorder that causes sleeping problems in patients. The intention is to assist the respiratory therapy students in the sleep disorders clinic at the University College of the Cariboo. The students can analyze diagnosis and treatment process on a case by retrieving cases similar to a current case. The case base comprises three types of cases: *individual cases*- extracted from 37 OSA patients, *prototypical* and *exceptional cases* - collected manually with the help of a sleep specialist. Somnus is constructed as a combined framework in which fuzzy logic is applied for modeling of the case features and semiotic approach is used for the modeling of their measurements.

14. SISAIH (Lorenzi, Abel, and Ricci 2004) [*Purpose: Diagnosis*], is a decision support tool to assist in decision making process to the hospital admission authorities in the Brazilian health public system. The system attempts to manage admission of patients in hospital, handles patients billing error and medical procedures i.e. in general, managerial job. Expert knowledge to solve a problem i.e. an evaluation of hospital admission authorization (HAA) which decides whether to accept or reject a current HAA, is stored in each case. SISAIH simplifies the problematic manual knowledge acquisition process and utilizes the resources in a cost-effective way which in turn speeds-up and makes the process more accurate.

15. SIDSTOU (Ochoa et al. 2006) [*Purpose: Diagnosis, Planning, Tutoring*], is an intelligent tutoring CBR system for providing medical education on Tourette syndrome. It works as a tool for diagnosing Tourette syndrome and could minimize the need of Psychiatrist or Neurologist at the initial stage. The system can also learn automatically based on a number of defined predicting characteristics. An evaluation of the system comparing with the expert in the domain presents the reliability of the system.

16. Ahmed et al. (Ahmed 2008) [*Purpose: Planning*], proposes a three phase computer assisted sensor-based biofeedback decision support system to provide treatment for stress-related disorders. A CBR framework is deployed to classify a patient, estimate initial parameters and to make recommendations for biofeedback training. Fuzzy techniques are incorporated into the system to better accommodate uncertainty in clinicians reasoning as well as decision analysis. Biofeedback training is mostly guided by an experienced clinician and the results largely rely on the clinician's competence. The intention of the system is to enable a patient to train himself/herself without particular supervision.

17. Brien et al. (Brien 2005) [*Purpose: Classification, Knowledge acquisition/ management*], attempt to classify Attention-Deficit Hyperactivity disorder (ADHD) patients in the neuropsychiatric domain. The system is classifying a patient based on a hypothesis that the eye movement of a person i.e. altered control of saccadic eye movements contains significant information to diagnose ADHD which has not yet been established clinically. Nevertheless, the intention is to assist as a second option for the clinicians who have currently employed multi-source system to diagnose ADHD. The paper exploits an iterative refinement strategy during the knowledge acquisition step to achieve a satisfactory performance in terms of the case description and similarity assessment which can be applicable across other domains.

18. Doyle et al. (Doyle, Cunningham, and Walsh 2006) [*Purpose: Classification, Tutoring*], present a decision support system for Bronchiolitis treatment focusing on the explanation in decision making. The system provides recommendations based on precedent cases, beside this, explanatory text imparts the supporting and non-supporting aspects of a selected case as well as indicates the level of confidence in the prediction. The CBR system is evaluated at the Kern Medical Center and the result shows that the recommendation with explanation is rather useful for the medical professionals in making decision.

19. O'Sullivan et al. (O'Sullivan, Bertolotto, and Wilson 2006) [*Purpose: Diagnosis*], develops a case-based decision support system exploiting patients' electronic health records delivered by the wireless networks. It allows a user to electronically input and compare the patient records. The system facilitates knowledge sharing in the domain and allows 'remote-access health-care'. Cases are represented as multimedia data format containing patient information i.e. medical images, annotations, endoscopies, and physician's dictations. Contextual expert knowledge for the relevant cases is also stored into the case base of encapsulated patient cases. Cases contain the textual features and textual indices generated from each of the constituent features are used in the matching process. The system is evaluated using a dataset from 100 encapsulated patient profiles in the dermatology domain.

20. Marling et al. [*Purpose: Planning*], describes a case-based decision support system assisting daily management in patients with Type 1 diabetes on insulin pump therapy (Marling, Shubrook, and Schwartz 2008). It considers real-time monitor of patients' blood glucose level along with their life-style factors in adjusting patient-specific insulin dosage. It reduces the cumbersome manual review process for a physician in proving individual therapeutic recommendations. The best matching case is retrieved in two steps. First a subset with potential relevant cases is retrieved and then, from this subset, the most useful similar cases are retrieved using a standard nearest neighbor metric. An evaluation of the prototypical decision support system in the clinical context with 50 cases from the 20 patients articulates the potential applicability of CBR in managing diabetes on insulin pump therapy.

21. Song et al. [*Purpose: Planning*], proposes a system in radiotherapy for dose planning in prostate cancer (Song, Petrovic, and Sundar 2007). Their system is able to adjust the appropriate radiotherapy doses for an individual while, at the same time, reduces the risks of possible side effects of the treatment. The system is implemented in cooperation with the City Hospital at the Nottingham University Hospital. The matching between cases applies the fuzzy similarity measurement to incorporate the experts' knowledge in retrieving past similar experiences. Dempster-Shafer theory is introduced to fuse multiple cases to recommend a dose plan for a case, when in a real-world situation several retrieved similar cases provide different treatment solutions.

22. Wu et al. (Wu, Weber, and Abramson 2004) [*Purpose: Knowledge acquisition/ management, Planning*], present a CBR framework based on NutriGenomics knowledge considering person's genetic variation i.e. individual gene expression to provide personalized dietary counseling. Genetic variation of a person has an impact on person's response to diet. The system proposes a dietary strategy that influences individual gene expression and, as a consequence, facilitates to maintain health and prevent diseases. The NutriGenomics knowledge is collected applying the data mining technique and represented in form of ontologies. A distributed case base allows the system to save this knowledge, and generates new cases automatically if necessary, using a Case Builder based on this stored knowledge.

3. Assessment of Current Trends

The system properties are divided into two parts: purpose-oriented and construction-oriented properties. We have interpreted the purpose- properties as diagnosis, classification, tutoring, planning, based on previous surveys (Nilsson and Sollenborn 2004; Gierl and Schmidt 1998). Knowledge acquisition/management is one added purpose-oriented properties. Construction-oriented properties according to (Nilsson and Sollenborn 2004) are further investigated for the recent medical CBR systems (table 2). According to our survey, numerous systems are multipurpose-oriented and several other techniques are integrated into the CBR systems such as- Hypothetico-deductive reasoning (HDR), Rule-based reasoning (RBR), Knowledge management (KM) technique, Neural network (NN), Data mining etc.

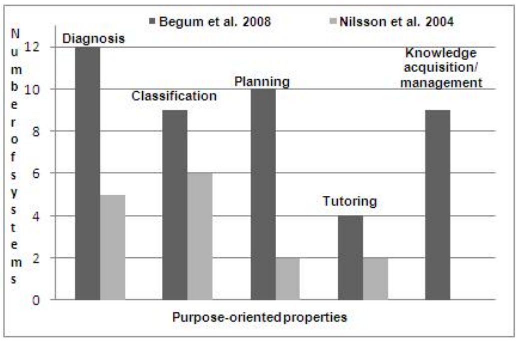

Figure 2: Number of systems belonging to each purpose-oriented category.

An interesting observation is how the purpose-oriented properties have changed and how they are combined in different systems. In figure 2 we see that besides a new category, knowledge acquisition/management, more systems address diagnosis and planning than in 2004 (Nilsson and Sollenborn 2004). Few systems address tutoring and the increase of classification systems is moderate. Nearly half of the system address planning and four systems are single purpose systems only addressing planning. This may be interpreted as planning in the medical domain offers interesting challenges to case based reasoning researcher and/or being an application where the case-based reasoning methodology may offer valuable progress and commercial applications (more than half of the systems in table 2 are aim at commercialization). Another interesting observation is that in 2004 only 2 (13%) of the evaluated systems where multipurpose systems while today 73% have two or more purposes (figure 2). Note that, Nilsson et al. investigated 15 CBR systems yet did not explicitly mention overlapping among their purpose-oriented properties.

3.1 Overall Trends

The majority of the recent CBR systems address more than one purpose-oriented category. The systems are not only concentrating on the diagnostics and treatment tasks as the early CBR systems. Recent CBR systems tend to support in other complex tasks in the health care domain. In particular, we can observe the use of CBR systems in Knowledge acquisition/management has attained increasing attention in recent years.

The wide range of application areas and a number of successfully implemented systems have proved that the interest of applying CBR in the health sciences is increasing. There is also an indication that the interest for applying CBR in the bioinformatics domain is increasing.

Majority of the health care domain requires pre-processing of datasets which leads to feature extraction or feature mining prior to the case representation. Also some of the systems/projects have successfully extracted features from multimedia data i.e. time series and images in a separate phase. Feature mining from multimedia data is a notable trend in health science domain which helps to represent cases with original implicit and complex features. Example of system focusing on feature mining is the dietary counseling system by Wu et al. 2004.

One of the identifiable achievements made in the medical CBR systems is that almost all that participated in the survey implemented their systems in a form of prototype. Only a few medical systems i.e. Perner 2006a and Corchado et al. 2008 showed successful commercialization of their systems. Several other projects which still are in the research phase, aim at commercial systems in future. Many of the systems have been successfully evalated in a clinical environment. But day-to-day use in clinical setting is not common.

Adaptation is often a challenging issue in the medical domain. Nevertheless, the survey shows that a number of recent medical CBR systems adopt and explore different automatic and semi-automatic adaptation strategies.

Indeed few systems depend only on CBR today; almost all medical CBR systems are combined more than one method and technique. In fact the multi-faced and complex nature of the medical domain leads to designing such multi-modal systems (Montani 2007; Nilsson and Sollenborn 2004). Integration of CBR and RBR was common in past CBR systems such as in CASEY (Koton 1988), FLORENCE (Bradburn 1994). Recent trends in hybrid CBR systems today are data mining, fuzzy logic and statistics.

4. Conclusions

This paper presents a recent survey of case-based reasoning systems in the medical domains. CBR has been demonstrated a powerful methodology for a class of problems and is increasingly applied in medical scenarios for decision support. We outline a number of medical CBR systems developed recently followed by analysis of properties and functionalities of such systems. We show in our survey that CBR is an increasingly popular methodology in many medical scenarios for various tasks such as diagnosis, classification, tutoring, treatment planning, as well as knowledge acquisition/ management. We also point out that hybridization of CBR with other AI techniques such as rule-based reasoning, data mining, fuzzy logic, as well as probabilistic and statistical computing exhibits promising opportunities to enhance CBR systems to scale up to increasingly large, complex, and uncertain data and information in clinical environments.

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