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APPLICATION OF A CASE-BASED EXPERT SYSTEM TO ORTHODONTIC DIAGNOSIS AND TREATMENT PLANNING: A REVIEW OF THE LITERATURE

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Computer expert systems are being utilised increasingly in medical fields to assist diagnosis and treatment planning. Traditional rule-based expert systems have some limitations when applied to orthodontic diagnosis and treatment planning. These limitations may be avoided by using a case-based system which is a particular type of expert system that uses a stored data bank of previously-treated cases to provide the knowledge for solving new treatment problems. This article reviews the use of expert systems for orthodontic diagnosis and treatment planning, outlines the rationale, processes and advantages of case-based systems, and gives examples of the application of this technology in medical fields.
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Introduction

For students and inexperienced practitioners in the medical fields, diagnosis and treatment planning can be very challenging. To improve the diagnostic decision making process, a class of computer systems has been developed. Known as 'expert systems', these knowledge-based computer programs are designed to represent the knowledge of specialists within a particular field, and to assist the practitioner by making this expertise available when required. Expert systems have been applied in a variety of medical fields and have been developed for orthodontic classification and treatment planning.[1,2,3] To date, these programs have been rule-based, decision-tree type expert systems. However, expert systems in which the knowledge is stored in a set of rules have limitations when dealing with complex problems. These limitations may be overcome using a type of expert system which utilises case-based reasoning, whereby knowledge is represented by complete cases rather than generalised rules. Case-based expert systems that have been developed for medical classification[4] and diagnosis[5] may present a more suitable means of classification and subsequent treatment planning in Orthodontics than rule-based systems.

Rule-Based Expert Systems

A rule-based system is a class of expert system that is designed to capture the problem solving and decision making skills of an expert. Problems solved by experts are used to generate production rules that are usually condition-action (if-then) rules. The rule-base is a list of rules reflecting know-how in a particular domain. Once the rules have been formulated they can be used to construct a decision-tree. In order to diagnose a new case, the system requests those attribute values which determine paths in the decision-tree leading to different outcomes.

Rule-based expert systems have been developed for classification and diagnosis and for treatment planning of malocclusions. Sims-Williams *et al* (1987)[2] developed a computer program to guide the general dental practitioner with limited orthodontic knowledge of the treatment of lower arch crowding. The evolution of this system was reported by the same group in 1991. The system was expanded to enable practitioners to identify Class II Division I cases which could be treated successfully using upper removable appliances alone. The authors pointed out two difficulties in the development of expert systems in Orthodontics: first, how to represent in a computer the important features of the patient's occlusion; and second, how to record the knowledge of the orthodontist and apply it to the representation of the patient's teeth.

Grant and Freer (1993)[1] used an expert system-shell to construct diagnostic trees capable of classifying malocclusions. This particular expert system utilised an induction algorithm to generate decision-trees which classified malocclusions according to Angle's classification and a subjective treatment priority score. The program performed with reasonable success; however, the database was found to be deficient in certain types of malocclusions that occur infrequently but that have high orthodontic interest. The comparative lack of information about the more unusual types of malocclusions produced

decision-trees which could not adequately cope with these cases.

The implementation of rule-based systems has led to the recognition of a number of fundamental developmental and maintenance limitations. In rule-based systems, the domain knowledge produces distinct rules that are combined to provide a solution; therefore, before building a rule-based system, the rules applicable to a given domain need to determined. This task, which on the surface appears simple, is in practice quite difficult. Even with careful rule determination, some knowledge is inevitably lost. To formulate the rules, knowledge must be taken out of its original context. However, Compton (1990),[6] looking at the philosophical basis for the acquisition of knowledge, claimed that it is important that knowledge not be generalised when it is acquired; it is in context that it has its closest link with insight and validity.

The difficulty of structuring rules into a working system also affects the long term costs of maintaining and updating the system. In a report on the four-year maintenance of R1 (an expert system which configures computers), the size of the technical group needed to maintain the system increased rather than decreased.[7] Compton *et al* (1988)[8] reported on the maintenance of GARVAN-ES1, a medical expert-system designed to give clinical interpretations of data from reports of thyroid cases. They found that it was necessary to increase the size of the knowledge base by 80 per cent over a three-year period by the addition of new rules or the modification of existing ones. Another shortcoming of rule-based systems is their limited ability to provide adequate explanations: the information provided by examples is distilled into rules. Therefore, a rule-based system can only report to the user the set of rules used, and since the new case must be shown to be an example of a concept that has been distilled into a set of rules, explanations involve a considerable amount of inference.

Case-Based Expert Systems

In many diagnostic processes there are so many exceptions and variations to any particular rule, that generalising a classification or diagnosis to conform to a set of rules will not serve every case. In an effort to overcome some of the limitations of rule-based systems, a new type of expert system based on cases rather than rules has been developed. In case-based systems, memory of relevant 'past' cases is used to interpret or to solve problems in a new case; rather than creating a solution from scratch, an operator recalls cases similar to the current case, and solves or interprets the problem by reference to past solutions or interpretations. Case-based systems acquire new knowledge by adding new cases, analysing them in the context of existing cases and thereby acquiring better indexing features.

When given a new case, the case-based system will search its memory for an existing case that matches the specifications of the new case. A case that exactly matches the input may be found and thus quickly provide a solution to a potentially complex problem. The likelihood of finding an exact match increases as new cases are added to the system. If no exact match is found, the system will retrieve a case that is similar to the input. If this does not provide an appropriate solution, small portions of the retrieved case that do not meet the input specifications can be identified and modified – either manually (by the user) or automatically.[9]

Case-based reasoning stems from the concept that a significant portion of human cognition and problem solving involves recalling entire experiences (in Orthodontics, entire cases) rather than just fragments of knowledge in the form of rules.[10] This idea is appealing because it is evident in many human problem solving tasks, particularly diagnosis and classification.[11] Case-based inferences are often employed by medical practitioners: when presented with an unusual combination of disorders, a doctor will use facts and knowledge of disease processes to generate a diagnosis; if such a novel combination is remembered, when encountered again it will be recognised and the difficult reasoning required originally for diagnosis may be avoided; in this way, a difficult problem is committed to memory so that it may be solved more easily in the future. Psychologists have discovered that when experts are making decisions, the use of individual cases is a far more important factor than the use of abstract principles or rules.[12] Importantly, case-based reasoning is invaluable when there is unknown or uncertain information,[13] or for the explanation of anomalous occurrences.[14] Orthodontics is one such field in which the rules of diagnosis are not always obvious: experienced practitioners often reason by referring to cases they have previously treated.

There are a number of basic steps involved in creating a case-based system: firstly, data must be collected and represented, examined and significant features identified; secondly, the cases must be indexed and an efficient retrieval system developed; and finally, the case selection, attributes and indexing scheme must be tested, evaluated and revised as required to improve the system's accuracy.

The foundation of a good case-based system is the collection of appropriate case data. This involves defining the terminology of the domain, gathering a representative and well distributed set of historical cases, and identifying the important features or attributes of those cases. Not every case encountered should necessarily be added to the case-base. It is important to distinguish which cases are worth recording. Grant and Freer (1993),[1] in discussing their rule-based expert system for orthodontic diagnosis, point out that a random selection of orthodontic cases would result in an oversupply of the more common types of malocclusions, and a relative scarcity of unusual cases or those with localised abnormalities. They proposed that case samples be engineered for a smaller, more efficient data base.

Each case may have a variable number of attributes and values. The attributes to be used must be chosen carefully if the most useful cases are to be recalled from the case library. Over the years, considerable effort has been employed to identify those attributes which are most useful for orthodontic diagnosis or classification. Numerous mathematical techniques have been used and a number of observations made which are relevant to case-based systems. Freer (1970),[15] attempting mathematically-based orthodontic classification, found that using a multitude of variables tended to merely flood the system with trivial information and that most of the useful information was contained in a limited number of attributes. This 'dilution' with increasing numbers of variables was also noted by Sanders (1994).[16] Trusler (1988)[17] found that model attributes were

more useful than cephalometric measures in determining clinical similarity. However, he also noted that cases that appear similar may not be treated the same, thereby implying that different attributes may be of importance in treatment planning compared with classification. Sanders (1994)[16] also noted this, and suggested, for example, that arch length discrepancy may provide a more discriminating value than incisor spacing or anterior irregularity.

The accuracy, precision, speed and efficiency of any system depend on its ability to recall a small set of cases that are similar to a new problem case. Depending on the capabilities of the tool, there are a number of methods by which cases may be organised or indexed. The nearest-neighbour matching method is used in a number of programs. This method of indexing and retrieval involves the use of an algorithm to find the closest matches to a new case, and uses a distance calculation that determines the 'similarity' of two cases by comparing their features. In general, each attribute of the new case is matched to its corresponding feature in the old case; comparisons may be qualitative or quantitative depending on the nature of the attribute. The degree of match based on the degree of importance given to each attribute is then computed and the products are added up to give an aggregate match score.[18] Nearest-neighbour indexing and retrieval may have some drawbacks when used exclusively: when weighting the features of each case, it can be very difficult to assign weights that will actively retrieve cases in all situations;[19] and feature weights for most problem domains are context-dependant: that is, firstly, depending on the values of the case's other features, a given feature may be more or less important in determining the appropriate case to retrieve; and secondly, nearest-neighbour algorithms are class 'blind' in that they are not effectual when cases from fundamentally different classes are compared.[11]

Case-based systems can effectively deal with some of the traditional limitations of rule-based systems. The ability to update without going back to the starting point is seen as their most important advantage in some applications.[20] As each new problem is solved, it can be added to the library of cases so that it can be used to solve similar problems in the future. The initial knowledge-acquisition stage is also easier than that of rule-based systems, since cases are easier to evaluate and examine than rules; as a result, case-based systems tend to be far easier to build than traditional ones. Goodman (1989)[21] reported on the construction of a case-based system which took two weeks to build in comparison with four months for the rule-based form. In another application, a rule-based system for diagnosis called CANASTA[22] took 960 days to complete; the cased-based version, CASCADE, required only 105 days. In addition, as illustrated by a system developed for autoclave curing which was in use with an initial case-base of only 20 cases, 20 case-based systems are useful from the earliest stages of their development.

Case-based systems can be maintained by a user without the assistance of an expert. To add more knowledge to a case-based system, new cases can be put into the system without major difficulties. In a rule-based system, the addition of new knowledge may involve recalculating the entire rule-tree.[18] In his comparison of CANASTA and CASCADE, Simoudis (1992)[22] points out that much time has been spent maintaining CANASTA, and that this will continue throughout the life of the system. CASCADE, on the other hand, needs almost no maintenance as the addition of cases to a case library requires little or no modification to the system. Case-based systems also satisfy the requirement of explanation by using previously learnt cases as models rather than abstract concepts. When classification cannot be made definitively, the user can look at real examples which may help make a final categorisation.

Case-Based Systems in Medicine

Although medical applications for case-based systems have been limited (due principally to the relative novelty of the technology), a number of medical diagnostic systems have been developed. CASEY,[5] a case-based technology which recalls problems it has seen previously, was designed for managing patients with cardiac diseases; it uses integrated case-based and causal reasoning techniques to provide a causal explanation of a patient's heart disease symptoms. It was found to be more efficient than its model-based predecessor.

PROTOS,[4] a case-based classification program, was designed for the diagnosis of hearing disorders and used their symptoms and test results as the data base. It was constructed with 200 cases and was found to be 100 per cent accurate when classifying 24 test cases. Interestingly, when the classification program ID3 (Quinlan, 1986)[23] was seeded with PROTOS 200 training cases and tested on its test cases, it was found to be less successful, especially in cases with many missing features. Methods like ID3 work best when examples are described with all the features of the domain; case-based methods can work with a limited selection of the available features.[18]

The utility of case-based systems in medical diagnosis was investigated by Ferrer-Salvans and Alonso-Valles in 1990.[24] They reported the development of a program in which the reasoning of clinical experts in a large group of actual cases was to be analysed. The methodology of the program aimed to combine Bayesian systems, expert systems, and other lines of research such as neural networks and case-based reasoning. It was hoped that the resultant expert system could be applied to most common pathologies. The program was only in the early stages of development.

FLORENCE was an expert system that advised on nursing care planning for a new client. Bradburn, Zeleznikow and Adams (1993)[25] described the data structures and reasoning methodologies of the system. It was primarily a case-based system but it also used ancillary model-based reasoning to advise on complex problems. They felt that the use of multiple reasoning methods allowed better simulation of the reasoning process of the expert clinician.

Tsukamoto (1993)[26] reported on the development of a case-based system for assistance in CT-image interpretation. The system used a key-word extraction method to evaluate reported similarities between a current case and all stored cases. The validity of the system was evaluated using forty-eight test cases. The matching ratio between diagnosis of the test cases and the most similar cases was 68.1 per cent. The ratio became higher with increasing numbers of stored cases. There has been no record in the literature of the use of case-based technology for dental applications.

Summary

Orthodontic diagnosis and treatment planning is complicated by the great variability and combination of attributes which may be present in any particular case. Rule-based expert systems have been developed for orthodontic diagnosis and treatment planning; however, because of the nature of the domain, such systems may have limitations in terms of the acquisition, maintenance and modification of knowledge.

Case-based systems, in which the knowledge is stored in the form of previously-treated cases, may be better suited to orthodontic diagnosis and treatment planning. These systems avoid the necessity for the generalisation of knowledge into rules and can be easily modified and updated. As experts often reason in terms of cases previously treated, the presentation of a treatment plan in the context of an actual case may be of more benefit than one formulated on the basis of rules alone.

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