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The Challenge of Modeling Decision Support Systems for Medical Problems Using Fuzzy Cognitive Maps: an Overview

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Abstract - The difficult and challenging problem of Medical Diagnosis using Decision Support Systems (DSS) is addressed from a system's point of view. The novel approach of Fuzzy Cognitive Maps (FCMs) as a computational modelling method has been used to tackle problem of DSS for medical problems. The FCM approach is used to address the Medical Decision Analysis and compare it with Decision Trees algorithms. Two medical problems, the bladder tumor grading and Radiotherapy are analyzed and studied using the proposed FCM approach. Simulation results been obtained previously are presented and discussed. The important contributions that have been made by using FCM in a number of medical applications are briefly discussed and future research directions are provided for the clinical use of the FCM methodology.

Index terms - fuzzy cognitive maps, decision support systems, medical diagnosis

I. INTRODUCTION

Complexity and large number of data characterize today's Medical Systems and their needs for making decisions continuously increase. New practices, models, methods and techniques have been emerging as complements to medical procedures and products. Meanwhile Decision Support Systems (DSS) in the field of Medicine, require flexibility, autonomy, intelligence, reliability but above all should be trusted by the physician-doctor. To fulfill all these diverse and difficult requirements physicians-doctors in close collaboration with scientists and engineers investigate new models and techniques that will integrate and combine known advanced theories and new techniques that will be the core of these sophisticated systems. At the same time, they seek to develop new models and software tools to address complicated issues of medical problems.

Modeling is the basis for effective knowledge representation from ancient times. It has become clear, the last 15 years that the requirements in modeling, analyzing and understanding medical problems cannot be handled only with the classical existing conventional methodologies and theories which have been developed and been used primarily by the specific scientific field of medicine. It is necessary to use methodologies and techniques from different scientific fields in an interdisciplinary manner. In addition it needs to investigate and use new models and methods that could exploit human experience, will have learning capabilities, will be equipped with failure detection and identification failures and that they can handle real medical problems been characterized with imprecision, uncertainty, complexity and at the same time are confronted with a large number of unsupervised medical data. The flourishing of new theories and techniques that different discipline fields provide such as, Fuzzy Logic, Neural Networks, Neutrosophic, Genetic Algorithms, Probabilistic Reasoning, Knowledge Based Systems (KBS), Soft Computing Techniques, Intelligent Control (IC) and Fuzzy Cognitive Maps (FCM) motivate all involved parties to work together in a friendly way in order to develop and use new models, theories and tools addressing Medical Problems and especially for DSS.

The purpose of this paper is not to present new research results. Instead it is a review paper in which the use of advanced engineering theories, specifically the Fuzzy Cognitive Maps (FCMs), can add new knowledge to Decision Support Systems (DSS) for medical problems [1]-[3], [6], [7]. The paper is to focus on the construction of the use of well known and previously published theories of FCM in modeling and analyzing medical problems.

II. MEDICAL DIAGNOSIS

A. Medical Diagnosis – Introduction

A medical diagnosis is an attempt at classification. Just as chemists attempt to classify naturally occurring elements into a periodic table and biologists attempt to classify plants and animals into species and genes so too do physicians attempt to classify disease into separate and distinct categories that allow medical decisions about treatment and prognosis to be made. Medical Diagnosis refers to the Decision Making Process of attempting to determine and/or identify a possible disease or disorder and the opinion reached through this process by physicians. The word "Diagnosis" has its origin from the Greek word «διάγιγνώσκειν», meaning to «discern-distinguish». This Greek word is formed from «διά», meaning «apart-through» and «γιγνώσκειν» meaning to «learn-know thoroughly»

Diagnosis may be performed by various health care professionals such as: a physician, healthcare scientists, nurse practitioners, physical therapists or physician assistants. Necessary Medical tests are performed depending on each case and are ordered by the person in charge of the process. Diagnosis and etiology are often used synonymously, especially since germ theory began to link causative agents with disease. Later, the development of antibiotics allowed physicians to treat the cause (pneumonia bacilli) and cure the disease. This effective linkage of diagnosis with etiology is widely accepted, even by physicians. New taxonomies of medical classification, however, do not require the etiology of disease in order to treat the patient. For instance, a common disorder such as pneumonia was nevertheless used as a diagnosis before the germ theory was accepted, and the disease was defined as a complex of many symptoms consisting of cough, sputum production, fever and chills. Later, as the actual cause was assigned to micro-organisms, the term diagnosis included the causality, e.g., pneumococcal pneumonia, suggesting not only a spectrum of symptoms but also a cause for the symptoms. Now the problem of Making Decisions, which lead to developing Clinical – Medical Decision Support Systems, becomes difficult but a challenging one.

Widespread disagreement exists between medical and psychiatric practitioners as to whether causalities for various diseases and disorders are known or not. If causalities are assumed to be known, then authentic cures can be obtained by correcting the causal abnormalities. If causalities are assumed to be unknown, then palliative treatments to reduce symptoms are the best treatments possible. This challenging characteristic brings FCM and its theories to medical diagnosis process.

B. Decision Support System for Medical Applications

Advanced Computer Systems have long been promoted for their potential to improve (not to replace) the quality of health care, including their use to support medical-clinical decisions [15]. The term Medical Decision Support Systems (MDSS) is used while many others are using the term Clinical DSS (CDSS) [15]. Here, however, we will use the generic term Medical DSS (MDSS) in order to cover the wider field of Health Care. MDSS is an interactive Computer Software System, which is designed to assist physicians-doctors and other professionals with Decision Making tasks as analyzing and determining health data of a patient.

MDSS integrate patient-specific information, perform complex evaluations, evaluate clinical treatments and even recommend certain therapeutic treatments and finally present the results to physicians-doctors in a timely fashion and uniform way. The MDSS field lately is rapidly and dangerously evolving due to fast and new technological advances been introduced to clinical practice. This has a result that new powerful computer systems and associated new sophisticated software tools are added everyday in Health care Systems. However as with any innovative health care intervension, these should be rigorously analyzed and properly evaluated before their wide spread introduction into medical-health practice produces catastrophic results. Nevertheless, the last 5-6 years MDSS have been promoted as one of the key features of available health records most likely to lead to a real transformation in the medical-clinical system. In my opinion if properly combined with other available and fast changing mathematical-scientific methods MDSS can indeed revolutionize completely the whole health care system.

The main purpose of any MDSS is to assist a physician-doctor-clinician at the point of care. This means that a “clinician” would interact with a MDSS to help determine a diagnosis, using and analyzing, available data of a patient. Previous theories of MDSS were to use them to literally make decisions for the “clinician”. The “clinician” would input the information and wait for the MDSS to output the “right” choice and the “clinician” would simply act on that output. This was the reason for the use of Clinical DSS (CDSS) which is still been used by many “clinicians”. Today the whole MDSS practice is formulated on a total new philosophy. A team composed of physicians, doctors, clinicians, nurses, scientists, engineers and medical technicians collaborate in a harmonious and constructive way to develop new and sophisticated MDSS. Today MDSS are “active health Knowledge systems which are designed to integrate a health knowledge base, scientific tools, patients’ data and an inference engine to generate case-specific advice”.

C. FCMs and Medical Problems

Given the previous two interesting analysis although in a rather simplistic way, the next question is how new and unexplored yet advanced interdisciplinary methods could be utilized for improving diagnostic methodologies and more efficient, effective and acceptable MDSS tools. Various methods of Fuzzy Systems, Neural Networks and AI have been used since the early 1970’s in addressing complex problems [4], [5]. However, the new and challenging methodology of FCMs and their techniques were not used until the early 2000 although they were introduced in the late1970’s [7]. For first time a 7- member Research team at the Laboratory for Automation and Robotics of the University of Patras in 1998 under my supervision tried to use FCMs and studied three specific medical problems under funding with grants from the Greek Government and the EC. The three medical problems were: a) Birth Delivering, b) Speech Therapy and c) Radiotherapy. The obtained results at that time were beyond physicians’ expectations and very encouraging to the team to continue in this particular path namely, using FCMs in addressing difficult medical problems and providing new methods, techniques and software tools to analyze them had become a reality. The first results from all three cases were presented in international conferences and/or published in International Journals, and/or invited chapters to books [6], [7], [12], [14].

III. FUZZY COGNITIVE MAPS

Fuzzy Cognitive Maps (FCMs) consist of concept nodes and weighted arcs, which are graphically illustrated as a signed weighted graph with feedback.

Figure 1 illustrates a simple FCM consisting of seven (7) concepts and twelve (12) weighed arcs. FCMs are directed graphs capable of modeling interrelationships or causalities existing among concepts. Concept variables and causal relations constitute the fundamental elements of an FCM. Causal variables always depict concept variables at the origin of arrows; effect variables, on the other hand, represent concepts-variables at the terminal points of arrows. Each concept is characterized by a number A_i that represents its value and it results from the transformation of the real value of the system’s variable, for which this concept stands, in the interval [0,1]. Causality between concepts allows degrees of causality and not the usual binary logic, so the weights of the interconnections can range in the interval [-1,1].

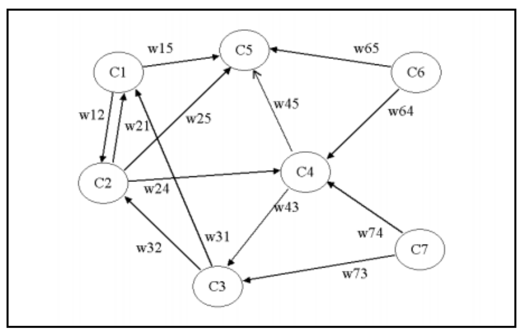

Figure 1. A simple Fuzzy Cognitive Map Drawing

Existing knowledge on the behavior of the system is stored in the structure of nodes and interconnections of the map. Relationships between concepts have three possible types; a) either express positive causality between two concepts ($W_{ij} > 0$) b) negative causality ($W_{ij} < 0$) and c) no relationship ($W_{ij} = 0$).

A formulation for calculating the values of concepts at each time step, of a FCM, has been proposed [8]:

$$A_i^{t} = f\left(\sum_{\substack{j=1\\ j\neq i}}^{n} A_j^{t-1} W_{ji} + A_i^{t-1}\right) \quad (1)$$

The function f is a threshold function to squash the result in the interval [0,1]. Fuzzy Cognitive Maps have discrete nature, at each time step, values of all concepts are recalculated and change according to equation 1.

There are well formulated mathematical theories on how to construct FCM, how to assign numerical weights and specific algorithms have been developed. All these can be found in [7].

IV. MEDICAL DECISION ANALYSIS AND FCM

Medical Decision Analysis (MDA) is based on a number of quantitative methods that aid in choosing amongst medical alternatives decisions. Traditional decision analysis is used to indicate decisions favouring good outcomes even though there is an uncertainty surrounding the decision itself. Furthermore, the value of each possible outcome of a decision, whether measured in costs and benefits or utility, usually varies.

Over the last years, several approaches have been investigated in the field of MDA, with the most popular one to be used that of Decision Trees (DT). Some methods combine DT with other machine learning techniques, such as Neural Networks [9], [10]. However, very little work has been reported in combining DT with FCMs. Some research work of this combination has seen the literature the last ten years [6]-[7]. In this approach the technique of combining a DT with a FCM model (DT-FCM) in MDA has been reviewed and uniformly presented for a number of medical applications.

This methodology can be used for three different circumstances, depending on the type of the initial input data: (1) when the initial data are quantitative, the DT generators are used and an inductive learning algorithm produce the fuzzy rules which then are used to update the FCM model construction; (2) when experts' knowledge is available, the FCM model is constructed and through the unsupervised NHL algorithm is trained to calculate the target output concept responsible for the decision line; and (3) when both quantitative and qualitative data are available, the initial data are divided and each data type is used to construct the DTs and the FCMs separately. Then the fuzzy rules induced from the inductive learning restructure the FCM model enhancing it. At the enhanced FCM model the training algorithm is applied to help DT-FCM model to reach a proper decision [7].

V. IMPLEMENTATION OF THE DT-FCM MODEL FOR BLADDER TUMOR GRADING

This new DT-FCM technique was used by our research team on a number of medical problems [6], [7]. Ninety-two cases of urinary bladder cancer were obtained from the archives of the department of pathology of University Hospital of Patras Greece. Histopathologists-experts had diagnosed 63 cases as low-grade and 29 as high-grade using conventional WHO grading system. Following grade diagnosis, each tissue section was evaluated retrospectively, using a list containing eight well documented in the bibliography histopathological criteria essential for tumor grading. The DT-FCM model for tumor grading had been developed and presented analytically in [6]. The DT-FCM grading tool was able to give distinct different values for the majority of high-grade and low-grade cases using a simple Bayesian classifier for the output data. Except the experts' knowledge for determining DT-FCM model, quantitative data for the eight main histopathological features [6] were also available and used. Then, a set of association rules was derived using the inductive learning procedure. The necessary If-Then rules were induced and introduced in the DT-FCM model enhancing its initial structure.

After the development of the DT-FCM model and the determination of specifications for the implementation of the NHL algorithm, the hybrid system was used to examine cases and assigned sensitivity and specificity for grading bladder tumors. Simulation studies were performed with real data and interesting results were obtained, which were satisfactory to the physicians [6], [7].

VI. A SECOND APPLICATION OF FCMs IN MDSS FOR RADIOTHERAPY

This second example was also used and presented on earlier publications [7], [14]. It is used here to illustrate the usefulness of the FCM in analyzing such a complex medical problem. Radiotherapy is the implementation of ionizing radiation to cure pathological illness by eliminating the infected cells. In the case of cancer cells, there are used photons or electrons and the major issue is the determination of radiation dosage distribution. For the determination of' the treatment, it is necessary to know how this tumor will he destroyed by irradiation and how surrounding healthy tissue is likely to be adversely affected by the applied radiation. Doctors have to take into consideration many different factors that some are complementary, other similar and other conflicting. On the other hand, each factor influences the selection of the dose and finally the result of the therapy with a different degree [11].

The clinical use of irradiation is a complex process that involves many professionals and a variety of interrelated functions and procedures. For determining the treatment of a patient, it is necessary to know how this tumour will be destroyed and how the surrounding healthy tissue is likely to be adversely affected by the applied radiation dose.

A good number of approaches and methodologies, algorithms, and mathematical tools have been proposed and used for optimizing radiation therapy treatment plans. Dose calculation algorithms, dose-volume feasibility search algorithms, and biological objective algorithms have been utilized and dose distributions have been calculated for the treatment planning systems, satisfying objective criteria and dose-volume constraints. Algorithms have been proposed for optimizing beam weights and beam directions. Dose-volumehistograms analyses of the resultant dose distributions appear to indicate some merit to these approaches. Furthermore, knowledge-based expert systems and neural networks have been proposed for the optimization of treatment variables and decision support during radiotherapy planning.

Scientists have put much effort into developing the above approaches to optimize treatment variables and dose distributions. This fact makes apparent the need for a fast, flexible, accurate, and adaptive tool, based on an abstract cognitive model, which will be used for the clinical practice simulation and decision-making. The number, kind, and nature of the parameters-factors that have to be taken into consideration in determining the radiation treatment bring up the fuzziness, the complexity and the uncertainty of the whole procedure. These characteristics point out the need for the use of soft computing modeling techniques such as Fuzzy Logic and especially FCMs in order to create a sophisticated approach for decision-making in Radiation Therapy. The aim of an FCM model is to make apparent the cause and effect relationship among the various fuzzy factors that determine the radiation dose, keeping it in a minimum level and at the same time having the best result in destroying tumours with minimum injuries to healthy tissues and organs at risk, and always in accordance with the uppermost goal of radiation therapy treatment. The first attempt to use FCM theories in Radiotherapy was made by a research team at the Laboratory for Automation and Robotics of the University of Patras during the late 1990s' [7]. Those first efforts, had succeeded to develop a clinical diagnostic decision model based on human knowledge and experience, consisting of a two-level hierarchical structure with an FCM structure in each level that creates an Advanced Decision Making Support System.

The two-level Hierarchical FCM-Radiotherapy Model

Hierarchical systems have been used extensively since the late 1960s' to model complex systems. The two-level hierarchical models have proven the most useful structure in developing DSS for modelling and controlling such systems. Such a two-level hierarchical structure was used for the Radiotherapy case. The proposed two-level structure is shown on Figure 2.

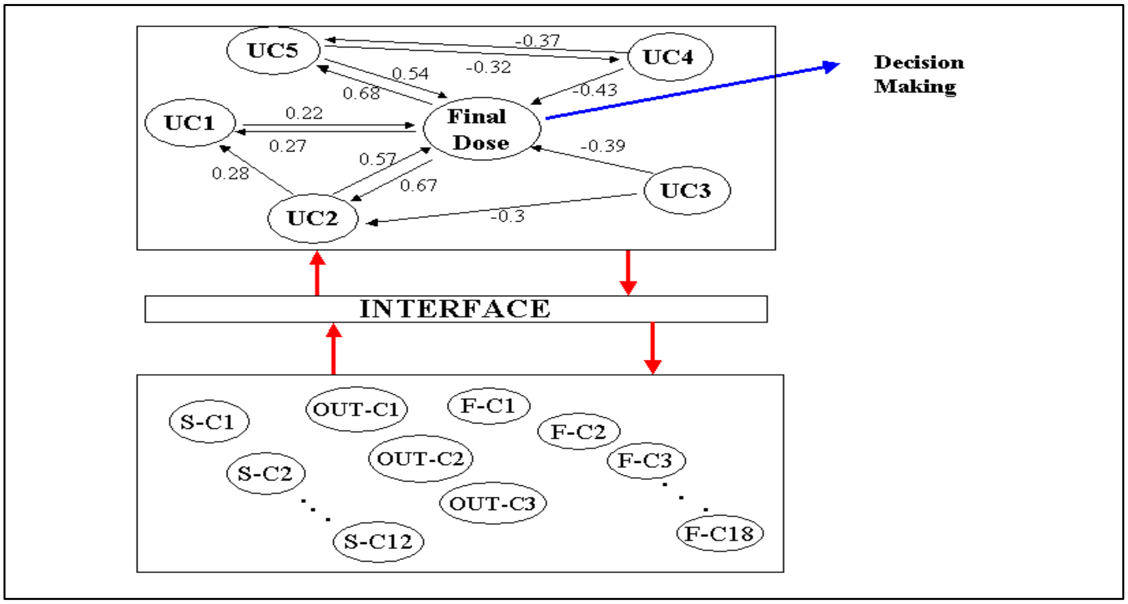

Figure 2. The proposed two-level hierarchical Radiotherapy FCM Model

The lower-level FCM models the treatment planning, taking into consideration all the factors and treatment variables and their influence and been defined as 33 concepts. These 33 concepts are divided into three categories: Factor-concepts (F-C), Selector-concepts (S-C), and Output-concepts (O-C). Factors and Selectors concepts represent treatment variables with given, measured or desired values, and the corresponding causal weights are calculated by experimental data. The values of the Selector concepts are influenced by the Factor-concepts with the corresponding causal weights and the values of the Output-concepts are influenced and determined by the Factor-concepts and the Selector-concepts with the corresponding causal weights. The final decision-making is based on the determination of the values of the Output-concepts that figure out the final decision. Values of concepts are described using five positive linguistic variables depending on the characteristics of each particular concept, such as very high, high, medium, weak, and zero. The degree of the influence is represented by a linguistic variable of the fuzzy set positive very high, positive high, positive medium, positive weak, zero, negative weak, negative medium, negative low, negative very low. When concepts represent events and/or discrete variables, there is a threshold (0.5) that determines if the event is activated. Experts develop the FCM model of the radiotherapy treatment procedure. The final Clinical Treatment Simulation Tool based on FCM (CTST-FCM) was consisted of 33 concepts and 195 interconnections with numerical weights. Indeed a very FCM complex model. The CTST-FCM model was used for a number of Clinical Case Studies with very good results [6]. Radiotherapy physicians and medical physicists choose and specify the initial values of concepts and weights of the proposed CTST-FCM model and they were involved in the process of validating the CTST-FCM model. A good number of simulation runs were performed with real clinical data. More details of this application can be found in [14].

VII. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This paper was an overview paper. Its purpose was more to recognize the need to better analyze and evaluate the important contributions that can be made by a different of engineering theories to the Decision Support Systems for Medical Problems and especially FCM theories in Medical Diagnosis. The basic theories of FCM were used successfully in modelling problems in a wide number of Medical applications. In the case of Decision Trees (DT) in Medical DSS, a new integrated DT-FCM system was used for simulation runs with real data for the bladder problem. The obtained results were comparable with other results obtained using today's most popular DT algorithms. Similarly for the case of Radiotherapy the usefulness of using FCM theories in studying such an interesting but at the same difficulty problems has been explained and briefly analyzed. The proposed two-level CTST-FCM model was developed in close collaboration with medical physicians. It is of interest to point out that, back in 2002, for the first time the Radiotherapy problem was modelled with an FCM structure, having 33-medical parameters in a simple and comprehensive way. Numerous simulation runs were performed obtaining very interesting and useful results to the medical profession. Some future direction of this research effect could include: a) further improvement of the Supervisor-FCM model for medical applications, b) investigation of the optimization methods of soft computing tools, c) running more simulations with new clinical data from more difficult cases, d) define sensitivity analysis with FCMs models for medical applications and perform studies.

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