RHEUMexpertWeb — Research Studies on a Medical Diagnosis System Dealing with Uncertainty

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Abstract

RHEUMexpertWeb is a web-based and knowledge-based medical diagnosis system for general practitioners in progress. It bases on the former systems RHEUMexpert-I, RHEUMexpert-II, and RheumaNet. The new and web-based version RHEUMexpertWeb consists of three subsystems for consultation, evaluation, and knowledge aquisition. The main part of the inference process is realized with the method of certainty factors that is well known from MYCIN.

1 Introduction

More than 100 different indisposition are indicated as rheumatic diseases including e.g. back pain, gout, fibromyalgia, tendinitis, and autoimmune diseases. Rheumatic diseases usually are devided into those that primarily involve joints known as Arthritis, and those involving other tissues, called Connective Tissue Diseases. Arthritis is further devided into Inflammatory and Non Inflamatory Arthritis. Rheumatic diseases can effect the heart, bones, joints, kidney, skin, and lung. They can have different and multiple causes and therefore diagnosing rheumatic diseases is not easy because symptoms and signs (e.g. swelling, stiffness, redness) are common to other diseases too, that are characterized by pain, swelling, and limited movement in joints and connective tissues in the body. To deal with these uncertainties in the medical diagnostic process RHEUMexpert-Web uses certainty factors that have been introduced in knowledge based medical systems in the 1970s, at first in MYCIN [11, 10]. Rheumatic dieseases require different kinds of treatments, but general practioners are not specialized in treating rheumatic diseases, but to evaluate the patient and to refer her/him to a rheumatologist (or not) a medical knowledge based system can give support.

2 RHEUMexpert Systems

RHEUMexpert-I and RHEUMexpert-II are medical expert systems for documentation and diagnosis of rheumatic diseases. They were developed since 1998 by the Austrian Society for Rheumatology in cooperation with physicians of the Vienna General Hospital (Wiener Allgemeines Krankenhaus, AKH), medical computer scientists at the Department of Medical Computer Sciences in the former medical faculty of the University of Vienna, since 2002 Core Unit for Medical Statistics and Informatics of the Medical University of Vienna, and the company Software Unlimited for support of general practitioners [8]. By means of the knowledge base of RHEUMexpert-I the web based system RheumaNet was implemented in 1999 [5].

In the year 2000 the knowledge base of RHEUMexpert-I was revised and on the basis of this newly created knowledge base the standalone-application RHEUMexpert-II was developed [13]. The revision comprises the overhaul of the symptoms (some new symp-

toms were added, while some symptoms were combined) and the diagnoses (the term "diagnosis" was extended to the terms "suspected diagnosis" and "excluded diagnosis") in order to achieve more accurate results. Furthermore the graphical user interface (GUI) has been reengineered (GUI-elements were added and rearranged respectively, a new graphic was included) to make the process of data capture more intuitive for the user. Finally an explanation component was implemented that shows the medical definitions of the diagnoses on the one hand and the symptoms (and their weight for the decisions made by RHEUMexpert-II) which led to the results on the other hand.

3 Knowledge-Base of RHEUMexpertWeb

The knowledge base of RHEUMexpertWeb comprises 617 findings called single data elements (SDE; empirical measurements), 76 symptoms (SYM; signs of diseases), 626 interpreted single data elements (ISDE; combinations of single data elements), 626 single data element to interpreted single data element rules, 76 interpreted single data element to symptom rules, 20 diagnoses (DIAG), 1520 certainty factors (CF) that represent the symptom to diagnosis proofs of evidence, 1 algorithm for accumulating the relevant CF per diagnosis (CF-ACC), 1 algorithm for calculating correction factors for each diagnosis (CF-COR), and 1 algorithm for distinguishing relevant results from nonrelevant ones (DIAG-FIL). An overview of the elements is given in table 1.

3.1 Single Data Element

The single data elements (SDE) include 3 elements of patient data (birthdate, examination date, and sex), 22 elements for anamnesis, 544 elements for joint status, 33 elements for the status of spine, 4 elements for laboratory findings, and 14 elements for X-ray findings. The SDE and their values respectively are the input of the system.

#	Label
617	SDE
626	ISDE
76	SYM
20	DIAG
1520	CF
626	rules: SDE to ISDE
76	rules: ISDE to SYM
1	algorithm: CF-ACC
1	algorithm: CF-COR
1	algorithm: DIAG-FIL

Table 1: Contents of the knowledge base of RHEUMexpertWeb.

3.2 Interpreted Single Data Element

The interpreted single data elements (ISDE) represent the data symbols (of the data symbol conversion) of the system and result from combination of the SDE by the rules: SDE to ISDE. The ISDE can only reach one of the two values true and false.

3.3 Symptom

The symptoms (SYM) include 20 elements of anamnesis, 15 elements of joint status, 14 elements of spine status, 13 elements for laboratory findings, and 14 elements for X-ray findings. They result from combination of the SDE by the rules: ISDE to SYM. A SYM can only reach one of the two values true and false.

3.4 Diagnosis

The diagnoses (DIAG) comprise 7 so called main diagnoses and 13 sub diagnoses and result from the combination of true SYM. DIAG can reach values from -1 to $+1$.

3.5 Certainty Factor

The certainty factors (CF) comprise 1520 symptom-diagnosis proofs of evidence (weighted assignments of symptoms to diagnoses). They represent the core of the knowledge base.

3.6 Rules: Single Data Element to Interpreted Single Data Element

These rules act for the data symbol conversion and map the input (SDE and their values respectively) to internal symbols (ISDE). While some SDE are mapped directly on a corresponding ISDE representing the symbol of the SDE (e.g. psiorias within the family yes or no), others represent ranges of the given value (e.g. erythrocyte sedimentation rate after 1 hour in mm), and a few ISDE are the result of (mainly simple) calculations (e.g. the length difference of the legs).

3.7 Rules: Interpreted Single Data Element to Symptom

Those rules represent the first inference step after the data symbol conversion and map ISDE to SYM by simple to quite complex combinations of the ISDE.

3.8 Algorithm: Certainty Factor Accumulation

The certainty factor-accumulation (CF-ACC) represents the algorithm for "parallel accumulation of certainty factors" that has been introduced with MYCIN [11, 10]. Each CF of a "true" SYM corresponding to a DIAG is accumulated and the final sum is assigned to the corresponding DIAG. Due to the algorithm used, the range of CF and DIAG $[-1, +1]$ remains to be the same.

3.9 Algorithm: Certainty Factor Correction

The certainty factor-correction (CF-COR) represents the algorithm introduced by Adlassnig [8] and was first described in detail in [9]. It (slightly) changes the calculated values for the CF of the DIAG by a kind of relative weight that is measured by the number of only positive CF per DIAG.

3.10 Algorithm: Diagnosis Filtering

Diagnosis-Filtering (DIAG-FIL) stands for a method of filtering all DIAG to reduce them to only the relevant ones so the user is not stunned because of seeing all possible DIAG of the system.

4 Inference Process

The inference process of RHEUMexpertWeb consists of five subprocesses. See table 2 for an overview.

4.1 Interpretation of Single Data Elements

The first subprocess is called "single data element→interpreted single data element conversion" (SDE→ISDE) that represents the process known as data symbol conversion.

4.2 Conversion from Single Data Elements to Symptoms

The second subprocess is called "interpreted single data elements→symptom conversion" (ISDE→SYM) that represents the process of combining simple (and lone or basic) observations to more complex signs of diseases or symptoms respectively.

4.3 Diagnosis Certainty Factor Calculation

The third subprocess is called "diagnosis-certainty factor calculation" (D-CF-Cal). This task of RHEUMexpertWeb is realized following MYCIN's rule-based approach [11, 10]. Buchanan and Shortliffe built the knowledge-based system MYCIN as a rule-based system associating to every rule a certainty factor to express the degree of belief (of a medical expert) for that rule. Thus, CF(a→b) is the certainty factor that conclusion (diagnosis) b is true if premise (symptom) a is true. We have CF(a→b) > 0 if premise a supports conclusion b and we have CF(a→b) > 0 if this not the case. CF(a→b) = 1 and CF(a→b) = -1 respectively means that be is definitely true and false respectively. If CF(a→b) = 0 than we do not know anything about the relationship between a and b. The system calculates the certainty factors for the diagnoses by means of proof of evidence about

the relationships between symptoms and diagnoses found in the knowledge base.

MYCIN was one of the first medical expert systems that was developed at Stanford University in the 1970s to diagnose and recommend treatment for certain blood infections. The certainty factors range in the interval [-1, +1]. They must not be mistaken for probabilities that range in the interval [0, +1] [4], but Heckerman noted in [6] that certainty factors were eventually given a probabilistic interpretation. However there still remain problems with certainty factors and their meaning in knowledge based systems that will be focused in further work. We consider to replace the method of certainty factors by the method of fuzzy sets in the next version of RHEUMexpertWeb.

4.4 Certainty Factor Correction

The fourth subprocess is called "diagnosis-certainty factor-correction" (D-CF-Cor) that increases the certainty factors of diagnoses which have only a few symptoms that allude to the diagnosis. An allusion is represented by a measure of believe.

4.5 Diagnosis Classification

The fifth subprocess is called "filtering" that brands each diagnose as suspected, excluded, or other (not relevant). On the basis of this classification the output can be reduced (filtered) to finally contain only relevant diagnoses.

The result of the third subprocess can be seen as the main output of RHEUMexpertWeb. The fourth subprocess and its underlying algorithm has been introduced by Adlassnig (described in [9]) to increase the parallel accumulated certainty factors (for details of the parallel accumulation of certainty factors see [12, 9]) for diagnoses that have only a few alluding symptoms while the certainty factors of other diagnoses are left unchanged (theoretical problems evolving with the use of this algorithm are described in [9]). This procedure shall improve the accuracy of the system but yet there exists no study that proves the worth of this course of action. Such comparison shall be carried through once all components of RHEUMexpertWeb are fully operational and working fine together. The fifth subprocess finally is ment to reduce the output of all diagnoses and their certainty factors to only the most important ones (suspected and excluded diagnoses). Therefore an algorithm again introduced by Adlassnig has been used that is described in detail in [9]. Though the reduction of the output doesn't seem to be necessary in the case of 20 diagnoses total covered by RHEUMexpertWeb it might prove its worthiness as the systems possibly gets more complex in the future.

ID	Subprocess	Result/Outcome
1	SDE→ISDE	interpreted single data elements
2	ISDE→SYM	all relevant symptoms
3	D-CF-Cal	diagnosis certainty factors of all diagnoses
4	D-CF-Cor	corrected diagnosis certainty factors
5	Filtering	Marks diagnosis certainty factors (suspected, excluded, and others)

Table 2: Inference process of RHEUMexpertWeb.

5 Gold Standard Cases

In conjunction with the RHEUMexpert systems there exist two sets of gold standard cases that can be used to verify the medical expert system.

5.1 Structure

Each gold standard case consists of two components: the observations or empirical measurements called single data elements (input) and the discharge diagnoses (output).

5.2 Source

The data for both sets originates from the "Rheuma-Sonderkrankenanstalt der Sozialversicherungsanstalt der gewerblichen

Wirtschaft" in Baden/Lower Austria/Austria (a 140-bed hospital for rheumatic diseases under the former medical head: Gernot Kolarz). Originally the cases have been collected for testing the accuracy of the decisions made by RHEUMexpert-I (104 cases) and the fuzzy version of the viennese medical expert system CADIAG (*C*omputer *A*ssisted *DIAG*noses) and CADIAG-2 (3488 cases). For description of the medical expert system CADIAG-2 see [1, 3].

5.3 Preparation of the set containing 104 cases

The 104 cases have been rendered by Kolarz for the software RHEUMexpert-I. Thus clinical records of the Rheuma-Sonderkrankenanstalt have been entered into RHEUMexpert-I (that includes a proprietary database) as long as the single data elements of the clinical records could be matched to single data elements of RHEUMexpert-I. After further development of RHEUMexpert-I to RHEUMexpert-II the same data was hacked into RHEUMexpert-II which computes far more single data elements than its predecessor due to a higher level of granularity of the observations.

5.4 Preparation of the set containing 3488 cases

The 3488 cases have been rendered by Kolarz for CADIAG-2. Thus clinical records of the Rheuma-Sonderkrankenanstalt have been entered into the former hospital information system in the General Hospital of Vienna WAMIS (the German acronym for *W*iener *A*llgemeines *M*edizinisches *I*nformations-*S*ystem, Vienna General Medical Information System) where it was used as input for the CADIAG-2 system implemented in WAMIS. At a later date a new development of the CADIAG-2 system was done during the development of the expert system shell MedFrame. For this implementation the data has been exported from WAMIS into MedFrame. Finally the data had to be exportet from MedFrame to RHEUMexpert-II to make the data available for RHEUMexpert-II. At least by exporting the data from MedFrame to RHEUMexpert-II the data had to be modified. That is because CADIAG-2 handles far more numbers of and far more differentiated single data elements (for input) and diagnoses (for output) than RHEUMexpert-II. In some cases simply different terms for the single data elements and diagnoses have been used that had to be matched together but there are also sophisticated matching algorithms. While RHEUMExpert-II as a small system covers 617 single data elements, 76 symptoms, and 20 diagnoses, CADIAG-2/RHEUMA[1] covers 2232 single data elements (originally referred as patient data), 906 symptoms, and 182 diagnoses ([2]; the countings of single data elements, symptoms, and diagnoses differ slightly in later works in the cause of research so the main work is cited). From these possible 182 rheumatic diseases, 100 are found in the studies of 104 and 3488 cases. The most commonly found disease in the studies are spondylosis (12%) and spondylathropathy (12%), followed by irritation of neck spinal nerve roots (9%), gonarthrosis (9%), just to name a few. The process of preprocessing and describing the data is discussed in [7].

5.5 Amount

The gold standard cases can be used to verify the accuracy of RHEUMexpert-II by using the single data elements as input and comparing the systems output with the discharge diagnoses. As this operation sounds very simple it shall be mentioned that it consists of the two processes test and interpretation. Testing is technically easy procedure whereas an interpretation of the results requires more soqhisticated methods.

6 RHEUMexpertWeb Components

Primarily for ease of use (presentation, testing usage, and publication) the web based system

[1] CADIAG-2 contains four "disease profiles": CADIAG-2/RHEUMA (rheumatic diseases), CADIAG-2/GALL (gall bladder and biliary tract diseases), CADIAG-2/PANCREAS (pancreatitic diseases) and CADIAG-2/COLON (colon diseases).

RHEUMexpertWeb was developed in the year 2004. It is a widely platform-independent application which basically provides most of the functionality of RHEUMexpert-II that is accessible with nearly any modern browser over the internet.

In addition two accessory components were implemented to make an evaluation of the knowledge base on the basis of gold standard patient data sets possible and to provide the chance to incorporate new medical cognitions (e.g. change of certainty factors) or even some structural modifications (e.g. new symptoms) into the underlying knowledge base. The three resulting subsystems are called consultation system (leading from input data given to suspected or excluded diagnoses), evaluation system (ascertainment of the knowledge base quality), and knowledge acquisition system (to modify the knowledge base).

The inference process and the knowledge base are initially identical with the ones of RHEUMexpert-II. But while the inference process is static, the knowledge base can be modified by the knowledge acquisition system mentioned before.

6.1 Implementation

RHEUMexpertWeb is a full web-based medical expert system. It consists of three independent partial systems: consultation, evaluation and knowledge acquisition system. The implementation of the systems is done using the programming language Java to achieve and guarantee a platform independent realization with graphical user interface. Each partial system consists of an applet that can be executed in every common browser and the according server application, the applets communicate via an XML-formatted interface. To store the knowledge base and the gold standard cases the relational data base management system MySQL is used.

6.2 Consultation

The consultation system is a web application for the general practitioner available on the internet. It has more or less the same features

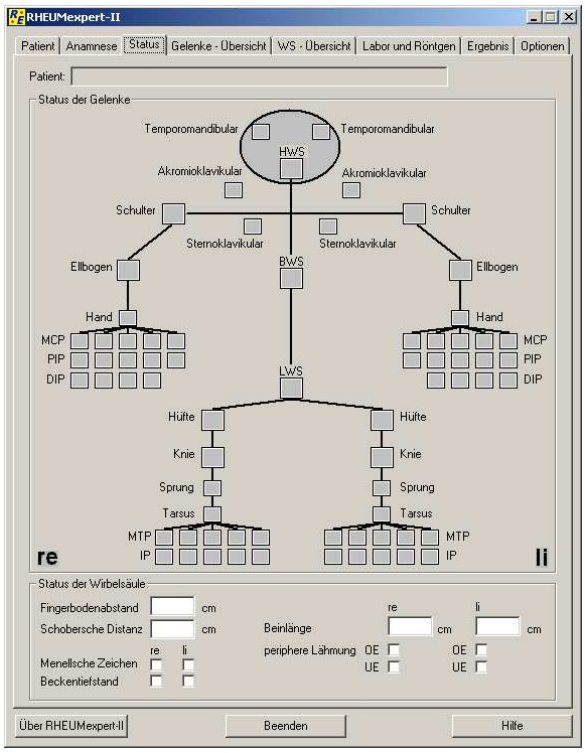

Figure 1: Example input formular 1.

of the already existing standalone-application RHEUMexpert-II. One goal of the development is to produce a clone of the "old" GUI as good as possible (examples are given in figure 1 and figure 2. The resulting system consists of six input formulars for patient data, anamnesis, labor data, X-ray findings and other clinical signs.

The result screen shows the most possible and impossible diagnosis hypothesis. An important feature is the explanation component that is integrated into the result screen and shows the medical definitions of the diagnoses on the one hand and the symptoms (and their weight for the decisions made by RHEUMexpertWeb) which led to the results on the other hand. There is the chance to find out which symptoms were responsible for the result; each symptom with its proof of evidence. The system can also display which given single data element caused the symptom.

6.3 Evaluation

The knowledge base can be tested and modified against the gold standard data sets by the

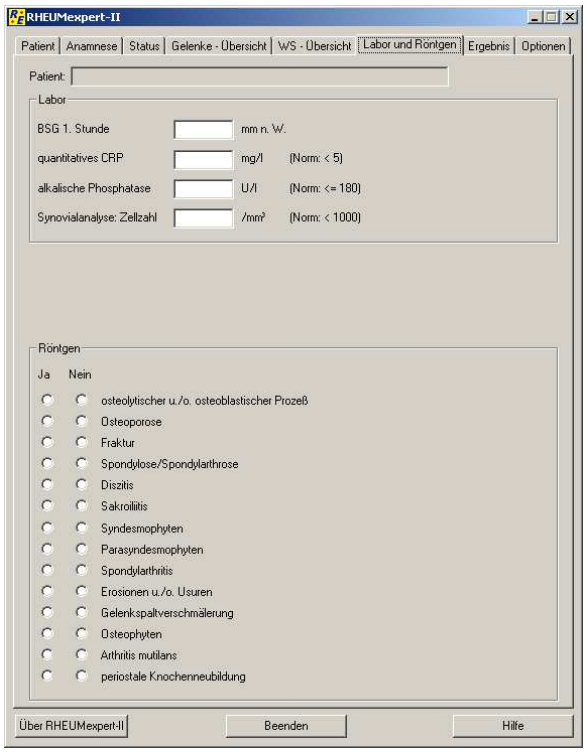

Figure 2: Example input formular 2.

evaluation system. These are composed of single data elements and the corresponding final diagnosis, extracted from patient's histories. These data elements have been prepared for RHEUMexpertWeb. Users can select one of actual two groups of gold standard cases in the database to evaluate the knowledge base using an adapted inference algorithm of RHEUMexpertWeb.

The Inference Algorithm calculates the values of sensitivity and specificity for each gold standard case in the group and average values for the whole group, respectively. The calculated results are sent back to users in XML format via network. Filtering functions lead to represent the result in a useful view that corresponds to an actual question, e.g. the results can be classified in main diagnoses or differentiated in main and subdiagnoses.

From those test results, a single test case can be selected for a detailed view. In this input formular, and also in the overview formular of the knowledge base the proofs of evidence for the relationships between symptoms and diagnoses can be altered and then a new test can be initiated and processed.

Modified knowledge bases can be saved temporarily to compare them to the original knowledge base and they can be printed to paper. The evaluation system is restricted to authorized knowledge engineers because massive use, as a result of huge amount of data, causes the reduction of hardware efficiency and therefore affects other program processes.

6.4 Knowledge Acquisition

With the knowledge acquisition system modifications and new medical cognitions respectively can be worked in the knowledge base. This concerns the acquisition of new symptoms, diagnoses and proofs of evidence about their coherences [9]. Special attention was turned on a clearly arranged graphical knowledge representation and intuitive user guidance.

The use of the knowledge acquisition system is restricted to authorized knowledge engineers in order that accomplishable modifications influence the knowledge base used by the inference of the consultation system and basic alterations of that ilk are reserved for medical experts. Moreover, these modifications should be tested seriously.

7 Conclusion

RHEUMexpertWeb will offer a full web-based knowledge based medical system to support general practitioners for the early diagnosis of rheumatic diseases. This system RHEUMexpertWeb will help to avoid unnecessary diagnostic tests and therefore to reduce costs.

RHEUMexpertWeb consists of three independent partial systems: consultation, evaluation and knowledge acquisition system. The consultation system creates suspected or excluded diagnoses based on inputs of patient data. The inference is realized by a modified certainty factor based process. The result is elucidated by the explanation component. The knowledge base can be tested against the "gold standard cases" by the evaluation system in order to calculate sensitivity and speci-

ficity. Finally there exists a knowledge acquisition system to modify and extend the knowledge base.

RHEUMexpertWeb is a research project in progress that is expected to be realized in 2007.

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