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A Framework for Clinical Decision Making and Medical Experience Storing

J. Colloc
Universite Jean Moulin (Lyon III), colloc@univ-lyon3.fr

L. Bouzidi
Universite Jean Moulin Lyon, bouzidi@univ-lyon3.fr

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J. COLLOC
Université Jean Moulin Lyon 3,
GRAPHOS Santé - UMR CNRS 5823
18, Rue Chevreul 69007 Lyon France
Colloc@univ-lyon3.fr

L. BOUZIDI
Université Jean Moulin Lyon 3,
Centre de recherche IAE,
15 quai Claude Bernard, BP 0638, 69239
Lyon cedex 02 France
Bouzidi@univ-lyon3.fr

***Abstract*-Different models of Decision Support Systems (DSS) are used in medicine to help physicians in disease diagnosis, prognosis evaluation and therapy prescription. The DSS models rely on mathematical or computer theories. Each of them offers advantages and drawbacks. We propose a DSS system architecture which tries to integrate the different kinds of decision models and to use them to deal with the successive clinical decision steps. Besides, the decision process includes patient data, experts' knowledge, statistical and epidemiological data, experience. The Case Based Reasoning (CBR) approach is used to store and retrieve the previous clinical cases. The object case components are clustered, indexed and stored in an object data base. To sum up, we propose a framework for clinical decision making and experience storing based on the main DSS models. Each step of the decision process is supervised by a finite state automaton which triggers the appropriate module and knowledge or data sources. At last, we illustrate our approach through an example : the epilepsy diagnosis and therapy.**

I. INTRODUCTION

Physicians have to take the most appropriate decisions within a minimum of time while they must deal with the huge complexity and the increasing specialisation of the medical domain. Some Decision Support Systems have been proposed to help the practitioner during the different steps of the clinical decision. Unfortunately, he needs to deal with different kinds of data and knowledge and no DSS model has the ability to manage all of them. Therefore, we propose a clinical decision support system which try to integrate the different existing models. A Case based reasoning approach is used to store the medical experience. A finite state automaton supervises and triggers the system modules according to knowledge an data needed at each step of the decision process. the section 2 presents the clinical context, provides a decision model classification. The third section presents the different part of a standard DSS, then it defines the different steps of a clinical decision models and represents the module interactions with the help of a finite state automaton. At last the third section depicts a CBR cycle.

In the section 4, we present a clinical decision support system framework and we applied it to epilepsy diagnosis and therapy.

II. THE CLINICAL DECISION CONTEXT

A decision problem can be defined as a choice between several options in order to achieve a goal as efficiently as possible. Most of the time, the physician ability is further beyond the computer capability and thus, trying to supply an help tool is worthless. The best example is diagnosis. However, The medical activity could be defined as a decision chain (more exactly a network) that involves the following steps: the diagnosis, the prognosis, the therapeutic and the treatment follow-up.

Some of these steps become more and more complex and an aid tool will be useful, especially during the prognosis and therapy stages.

"Artificial Intelligence" scientists were very interested in the cognitive nature of the physician diagnosis activity. So, many applications were built in this domain. We have to admit that most of them are unused, because they do not bring any actual enhancement. Paradoxically, many physicians are interested in information systems and some of them have developed small or sometimes more sophisticated **D**ecision **S**upport **S**ystems (**DSS**). However, these systems are very locally used inside a hospital or a research department by a small group of specialists who have to solve very accurate problems.

In France, the system end user and designer is very often the same person who prefers well suited home made solutions. In such department, the medical activity is so specialised that there is no outlet for this kind of DSS. Only one copy of the software is actually used. The complexity of the medical domain is another drawback to build efficient DSS. To sum up: in one hand, the physicians know very well the interesting domains where a decision tool is required, but as clever they are, their computer science level is seldom sufficient to design and develop such a system. In the other hand, computer scientists must cope with the difficulty to understand the doctors' needs and the complexity of the medical domain. Thus, they often provide expensive and inappropriate tools. The legal and ethical aspects of using a DSS to cure a patient should be also under consideration. The responsibility of taking inappropriate and harmful actions scares physicians away from using a DSS during their practice. Hence, clinical DSS must be very secure and the transactions should be journalised.

A. Medicine complexity

Medicine is a science based on the human organism observation.

The human being complexity forbids the exhaustive representation of organism mechanisms and moreover of disease appearance. Different aspects of the medical knowledge uncertainty are listed below : *The medical theories,* based on the studies of clinical signs and on experiments, can vary with medical schools. *The patient medical history :* the same disease can express itself in a single manner for each patient. Therefore, the semiology knowledge only describes typical clinical pictures. *The topography :* some diseases are multifocal, they show various clinical pictures according to the damaged organ or apparatus. For example : bones tuberculosis and pulmonary phthisis are two forms of the same disease, (sharing the same etiology). *The periodicity :* diseases are dynamic processes, clinical syndromes are only pathology snapshots, corresponding to evolution stages. Some diseases progress in a linear way (step by step). For example the multiple sclerosis displays successive evolution steps. Others progress in a cyclic manner such as the duodenal ulcer or the herpes infection. Therefore, time is a major factor when describing pathologies [13][18]. *The effect of an inappropriate therapy* or another underlying disease can interfere and give unusual clinical aspects. Futhermore, they can produce iatrogenic diseases, expression of toxic mechanisms which need supplementary arguments to connect causes and effects together. *The science progress :* medical knowledge is continually changing according to the new discoveries. The amount of knowledge is regularly increasing.

All these aspects must be kept in mind during the decision process. A physician and a DSS have to detect when the problem is beyond their capabilities.

B. Integrating quantitative and qualitative decision methods

1) A decision classification : Usually, the decision-support models in health care can be grouped into two main categories :

- The quantitative models are based on statistical methods which try to assess the disease occurrence probability for a given patient belonging to a population, when he or she shows some clinical signs or symptoms. To use such a quantitative model, the physician must know the results of previous epidemiological studies concerning the prevalence of the disease in this population and the specificity and sensibility of the corresponding relevant clinical signs. The main drawback of quantitative models is that such data are seldom available and they cannot be generalised from one population to another [8].

- The qualitative models are relying on expert knowledge and symbolic reasoning methods which handle Boolean logic rules. Making the use of qualitative methods needs to cope with the experts' knowledge acquisition bottleneck, the heuristic detection and the knowledge base implementation. This could be achieved through the use of a knowledge acquisition methods like KADS (Knowledge Acquisition and Design Structuring) [21], KOD (Knowledge Oriented Design) [20] or Q4 (Quis,Quid, Quando, Quomodo) [19]. Most of the time, clinical decision heuristics provided by several domain experts are formalised with the help of flowcharts or decision trees [12]. These flowcharts are very well suited to express the way of triggering rules that express physician expert decision heuristics.

The drawback is the binary aspect of these rules and the difficulty for experts to set thresholds and the uncertainty to achieve such a task. At last, the qualitative methods are well suited to take decision to cure a patient but they are not relevant to solve population health care problems. Such models show their limits when public health decisions should be taken, i.e. : to decide a vaccination campaign, or when collective aspects are under consideration like in emergency or crisis medicine. For example when a earthquake occurred, the physicians must sort the patients to cure first, according to the vital likelihood and the available resources. In this latter domain, quantitative methods are more efficient, but not sufficient as well.

TABLE I
A DECISION MODEL CLASSIFICATION

	Supervised learning	**Unsupervised learning**
Quantitative models	Neural networks fuzzy sets Bayesian models	Neural networks Genetic algorithms Case-Based reasoning
Qualitative models	Semantic models Object and frames Logic rules Decision trees	Case-Based reasoning

The models can also be grouped according to the learning method. Two types of learning are used : *supervised learning* in which, for each case of a training set, the correct solution is provided to system by one or several expert and *unsupervised learning*, where the system must automatically determine in a set of features which feature subset or cluster is relevant to characterize a given identified situation (i.e.: a disease) [2]. The table 1 displays a Caroll diagram which represents a classification of the main decision models.

2) The Case Based Reasoning Model (CBR) : The CBR approach can be described as a third intermediate model, because it makes use of concepts coming from both qualitative and quantitative methods. In one hand, the quantitative methods provides the CBR approach with tools to automatically select the relevant features and to achieve the previously solved case indexing. In the other hand, the qualitative methods offer means to represent the gained experience in solving previous problems. knowledge models have indeed the necessary semantic capabilities and thus are well suited to describe the case environment and circumstances. We briefly present a CBR model to store the clinical experience in the third section of this paper.

III. THE MEDICAL DECISION PROCESS FEATURES

A. Components and stages of a standard decision process

One of the main enhancement of information system is based on flexibility: the interface evolution, media and communication improvement. The article shows how computer science is able to support human decision in complex domains like medicine. A standard decision system architecture is composed of three main components : The first one represents the usual information system implementing static data and making use of mathematical and statistical quantitative models [11]. The second component is a knowledge base that contains the domain experts knowledge and know-how: qualitative models. The latter aspect needs to store and retrieve experience from previous solved or unsolved cases: CBR models. The third component merely concerns the decision aspects based on well-tried heuristic provided by experienced decision-makers: decision supervision.

Therefore, according to Simon [16] [17], the decision process is composed of four successive stages :

1. collecting static and dynamic data; 2. designing scenarios; 3. choosing the more relevant scenario; 4. evaluating the issues and if necessary provide a strategy update. These four stages were proposed in a previous decision system architecture [3] :

- The data collection is mainly supported by data bases and mathematical or statistical model bases.
- The dynamic information, provided by the decision-makers, is stored in knowledge bases.
- The decision bases are designed and implemented with the help of the two previous modules, so called subsystem 1 and subsystem 2 (figure 1).
- The chosen decision evaluation is based on the consecutive action impact analysis.

The DSS is composed of four subsystems :

- *The subsystem 1* is used to collect static data and is mainly based on databases, mathematical and statistical models and their corresponding management systems. Therefore, qualitative and quantitative data are extracted and then used by treatments according to the decision maker. Relevant information is provided to the decision maker in various formats: feature tables, scenarios, forecasting simulations, dashboards…All this information are called result Info. in the figure 1.
- *The subsystem 2* collects dynamic information based on experienced decision maker's knowledge and know-how. The domain knowledge is structured in chunks which are distributed according to a competence hierarchy or lattice. The subsystem execution is controlled by an inference engine (IE) but is supervised by the decision maker. The result is an expert knowledge base (Expert KB).

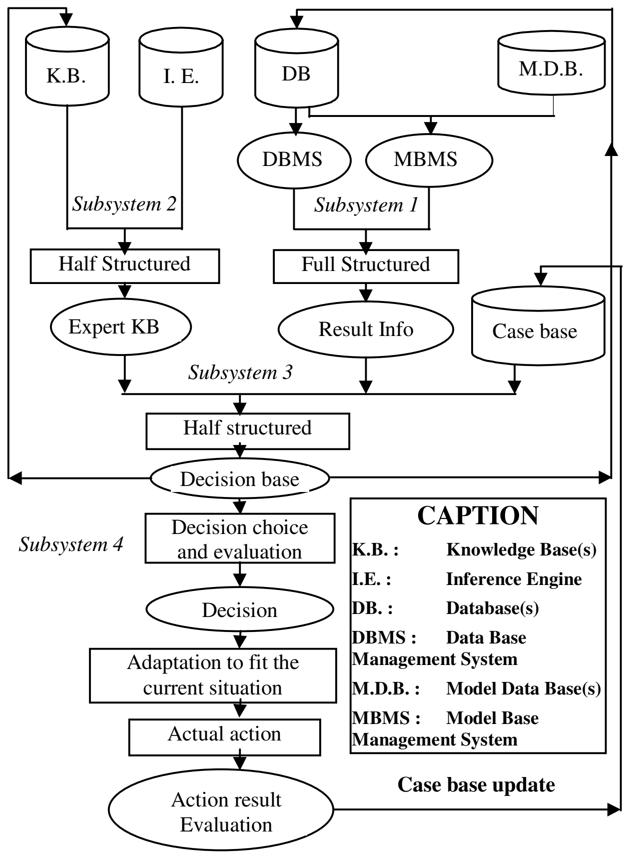


Fig. 1. The decision support system architecture

- *The subsystem 3* is concerned with designing and generating the decision base. It helps the decision maker to build a set of relevant decisions. This operation is based on the information provided by the two previous subsystems 1 and 2 and a case base. The case base memorises the context and the previous reasoning processes that was used to solve (or fail to solve) previous problems. The subsystem 3 issue is a decision matrix, so called decision base in the figure 1.
- *The subsystem 4* is used to choose the more appropriate decision between those that was selected during the previous stage and to evaluate the impact of the applied decision. During a first step, the decision maker is browsing and analysing the weight of each potential decision. Next, he has to list the relevant actions to achieve the selected decision (*strategic level*, *operational level* and *control level* actions). At last and later, the decision maker will be invited to evaluate the results and the impact of the taken decision in terms of facts, events, action consequences and to enrich the case base with the gained experience. This operation is depicted on figure 1 by the *case base update* labelled arrow. The subsystem 4 closes the decision cycle.

B. A clinical decision model

Beforehand, every medical decision needs to correctly diagnose the disease(s) and to evaluate the clinical state of the patient. The physician must predict the disease evolution, know the previous therapies and their results in order to choose an appropriate treatment to improve the patient health. We define four general clinical stages that are respectively called : diagnosis, prognosis, therapy and the therapeutic follow-up.

They interact together and then contribute to provide a relevant decision which is, most of the time, a treatment strategy to apply. The diagnosis, the therapy and the prognosis need four different types of informations :

- The patient-related information : current complaints, recent clinical course, past medical history and genetic and social background.
- The related clinical experiences with similar cases (the essence of the case based reasoning approach).
- The related formal medical knowledge : segments of textbooks pertinent to diagnosis, therapy, prognosis, and clinical course.
- The theories, concepts and experimental hypotheses concerning all related areas.

But, to this classification, we must add the knowledge related to the physician decision process.

We provide a definition and a representation for diagnosis, prognosis, therapy and therapeutic follow up.

1) Diagnosis : The diagnosis is based on medical and surgical semiology, that is to say on the study of clinical signs and events which guides the physician to identify the disease. The semiology is a science which studies the sign nature, and how their combinations, their evolutions define clinical pictures. The medical semiology is a method which teaches the different necessary steps to elaborate a correct diagnosis to medicine students. The experienced physicians memorized these decision schemes, made them unconscious and, thus, difficult to formalize. There are different kinds of diagnosis steps involved in the decision process :

- During the **positive diagnosis step (D+),** the physician considers current complaints, the medical history, the genetic and social background, and through the examination of the patient, searches for the clinical signs which we classify in three different types : pathognomonic signs (characterizing a disease), evocative sign (making sense to think about some diseases), accessory signs (completing the clinical picture). During the positive diagnosis, the physician is making hypotheses relevant to the patient clinical state.
- During the **differential diagnosis step (D≠),** the physician is searching for the existence or the lack of specific signs in order to eliminate those which are not relevant from the previously elaborated hypotheses.
- The **etiological diagnosis (Det)** is the right issue of the diagnosis process. It explains the disease appearance, manifestations and evolution causes. Sometimes, the physician is not able to find the disease etiology (**D?**), because the clinical picture is very unusual and he must act very quickly to avoid the patient death. So, he must cure the main syndroms to get time to do further investigations. To sum up, the clinical diagnosis includes the positive and differential diagnosis steps, the goal is to discover the etiological diagnosis.

Most of the time, it makes use of static superficial knowledge (heuristic), while the etiological diagnosis is based on « deep knowledge » able to explain the causes of the disease appearance and the subsequent events that are going to take place during its evolution. The latter information will be useful to the prognosis, as well.

2) The prognosis : This clinical stage is often ignored in medical DSS and is nevertheless essential because it allows to fix the therapeutic goal. The prognosis is an act in the course of which, the physician tries to predict the patient clinical state evolution and the probable outcome (healing, stabilization, death). This prediction is always very difficult to do, because, one must take into account not only the disease classical clinical pictures, but also the patient individual parameters such as : the genetic and social background, the psychological factors, the physical characteristics, the past medical history, and of course, the probability for the chosen therapy to succeed.

The necessary knowledge and facts which help to elaborate the prognosis derives from several sources :

- the etiological diagnosis, the patient general clinical state, the stage of the disease;
- the qualitative knowledge concerning well known clinical scenarios that represents likely evolutions.
- The quantitative knowledge provided by epidemiological studies that allow to get the disease evolution statistical data.
- Perhaps, the more relevant knowledge comes from the obervation of some similar cases, which let the physician think that the evolution will be similar.

The latter knowledge can't be handled through an experts system (ES) but rather with the help of a CBR approach. The most probable clinical stages sequence constitutes the prognosis selected as relevant to the patient under consideration.

3) The therapy : The physician must know what treatments will enhance the patient clinical state. To cope with this problem, the practitioner must have different kinds of knowledge concerning the available therapies : indications for administering the drugs, pharmacology data, contraindications, drug interactions, drug toxic and adverse effects. The physician have prescription experiences which allow him to predict the effect of a therapy strategy in similar cases.

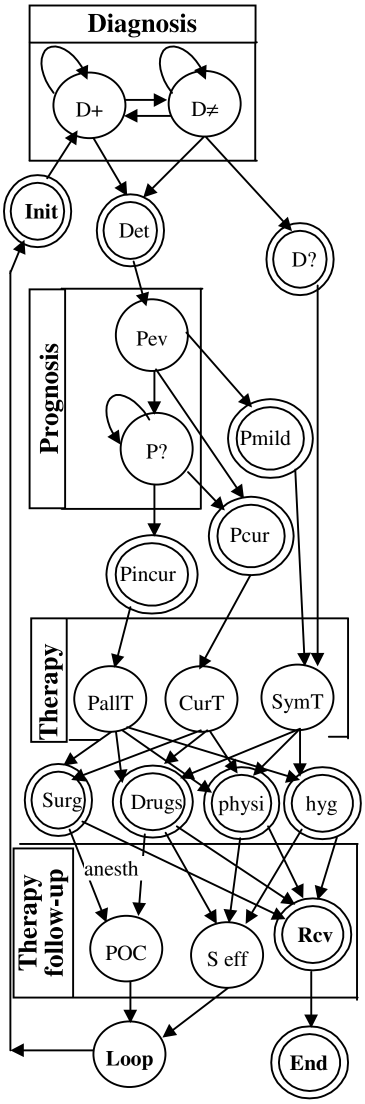
A therapy is prescribed to achieve a goal. Therefore, we provide a therapy classification :

- **The curative treatment (CurT)** goal is to totally cure the patient or consolidate his clinical state (to stop the disease evolution). For example : an antibiotic prescription to cure a tonsilitis. The physician must be provided with the etiological diagnosis to be able to choose an appropriate curative treatment.

- **The preventive treatment (PrvT)** is prescribed to prevent a serious disease to happen. For example vaccination or antibiotic prescription before a septic surgical operation.

- **Symptomatic treatments (SymT)** are used to cure disagreeable effects , that is to say functional manifestations of a disease, without knowing the etiological diagnosis. For example : to cure an headache.

- **Palliative treatments (PallT)** are prescribed when the prognosis is hopeless and when we only try to cure the disease manifestations, (for example : pain relieve), to procure more comfort to the patient.



Caption	
D+	Positive diagnosis
D≠	Differential diagnosis
Det	Etiological diagnosis
D?	Uncertain diagnosis
Pev	Prognosis evaluation
Pmild	mild illness
P?	reserved prognosis
Pcur	curable disease
Pincur	incurable dis
PallT	palliative therapy
CurT	curative treatment
SymT	Symptomatic treatment
Surg	Surgery
Drugs	Drug prescription
Physi	Physiotherapy prescription
hyg	hygiene advise
POC	Postoperative complications
S Eff	Side effects
Rcv	Recovery
○	Intermediate state
◎	Final state
→	State transition

Fig. 2. The clinical decision system cycle

4) The therapy follow-up : When the therapy is decided and applied, the physician must watch over the patient clinical state and observe the disease evolution towards the recovery. He must detect the possible occurrence of drug side effects, postoperative complications or the appearance of a iatrogenic disease.

The patient follow-up is a diagnosis task which is oriented by the knowledge that concerns the current prescribed treatment, the identified drug side-effects and the surgery technique drawbacks.

5) Conceptual clinical module interactions : The whole decision model is depicted in figure 2. The first physician's goal is to find the etiological diagnosis, alternatively using positive and differential decision method. Then, the physician begins to define the treatment goal, according to the etiological diagnosis and the prognosis.

Therefore he needs knowledge concerning the available therapies (indications, contraindications, toxic and adverse effects, drug addiction...) which he uses to build up a therapy strategy composed of drug administration according to an appropriate periodicity, surgery, physiotherapy prescription, hygiene advices.

The physician makes use of analogic reasoning and epidemiological knowledge to compare similar clinical courses when different treatments are prescribed.

During the follow-up stage, the physician is searching for side-effects and is controling the patient clinical state evolution towards the recovery.

C. Medical experience storing and retrieving

The Case-Based Reasoning (CBR) is a powerful concept which provides an analogic reasoning mode in problem solving [1]. This capability allows to express the medical experience knowledge and thus to use it to enhance the diagnosis, prognosis, therapeutic and patient follow-up by comparing new cases with previously stored indexed clinical cases, to retrieve those similar and to apply the corresponding decision and actions to the new patient, expecting that what was good one time, will be good several times [22] [23]. The CBR approach includes the appropriate steps to deal with analogic reasoning.

Two main functions are provided : case storing through the " *new case indexation module* " and the *"case retrieval"* handled by the so called module. These two complementary features implement the CBR cycle.

The case base contains patient cases composed of diagnosis, prognosis and therapeutic facts. The figure 3 describes the main steps of the CBR cycle.

During the case retrieval stage, the CBR module computes structural similarities between the composite objects representing previously stored cases and the new clinical case under consideration.

A decomposition process of the case composite object provides sub-objects representing the following feature : the problem definition and goal (**PG**), the environment representation (**E**), the reasoning protocol (**RP**), the applied decision(**D**), the necessary actions (**A**), the actual result (**Rs**). During the case indexation stage, the new object case is instantiated and provided with diagnosis, prognosis and therapeutic components. The user must supply information that concerns the case features and circumstances {PG, E, RP, D, A, Rs}. Then the new case is indexed and stored in the case base. The process is depicted on the right side of the figure 3. The case indexation relies on a distance computation. different distance model can be used to sort the cases: fuzzy logic[15], the theory of evidence[4]…). However, this topic is not the purpose of this paper.

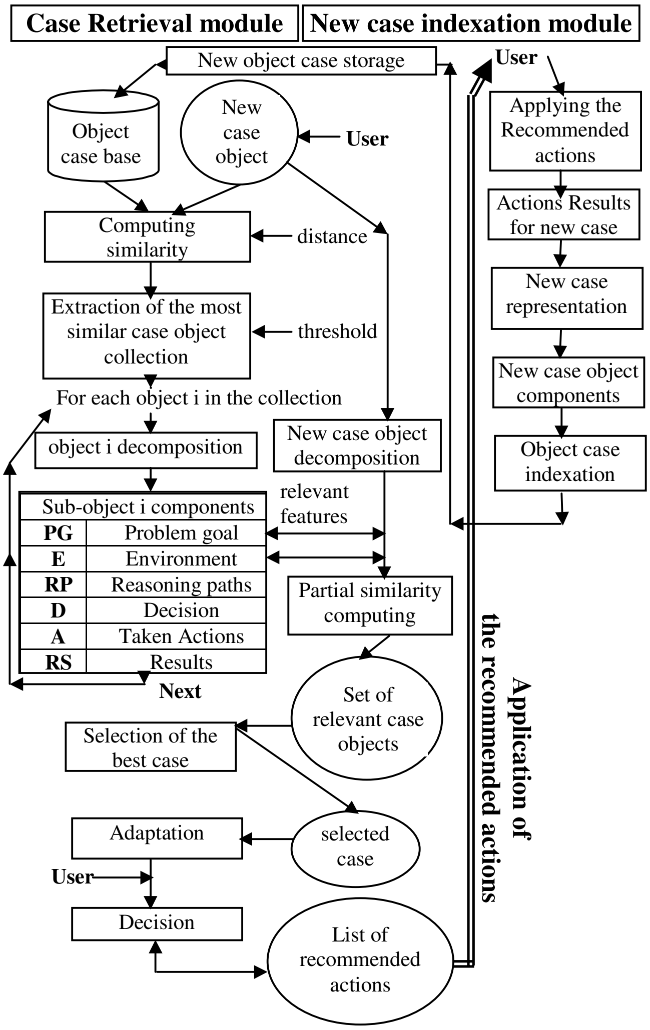


Fig. 3 : The CBR cycle

IV. A DECISION SUPPORT SYSTEM FRAMEWORK

A. The clinical decision process supervision

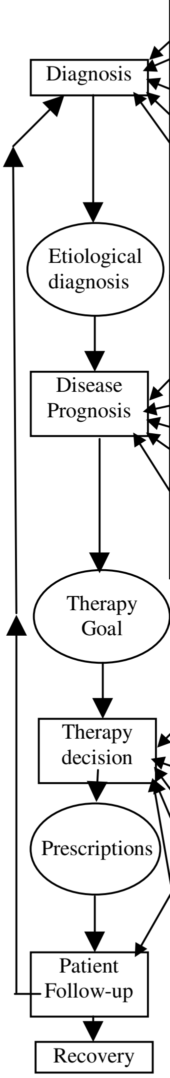
The purpose of our system is to integrate quantitative with qualitative decision methods. Most of the existing systems are based on only one of these two kinds of methods. In order to achieve this goal, some authors have proposed a flexible architecture which uses a Multi-Agent system (MAS) [5], [24],[19] which is based on a communication language like KQML [25] and a negotiation protocol like the contract net protocol [26] [27]. A MAS is an interesting solution to build such a decision support system but it is much more difficult to implement and to control. Our system use a finite state automaton (FSA) which represents the states and transitions depicted on the figure 2 and triggers the appropriate procedure. This approach is similar to a supervised system [7]. The FSA describes the module interactions but it do not represent the data and knowledge flows. Each state corresponds to a procedure which triggers the appropriate decision module. Some state are intermediate states and others represent a decision step final state. The implementation of such a FSA can be achieved with syntax analyser like Yacc.

B. Integrating the data and the knowledge sources in a decision cycle

For each clinical decision step, data and knowledge sources are necessary. Some of the data are provided through the interface by the user, others are stored in databases or knowledge bases. These information sources are displayed on the figure 1 in the subsystems 1, 2 and 3.

The next figure 4 depicts the required knowledge chunks to achieve the decision, the corresponding decision subsystem and the data or knowledge sources.

The small arrows represents the relationship between the knowledge chunk and the decision step. The big arrows show the decision step succession and their results



Decision knowledge chunk	DSS	Data & Knowledge Sources
Patient clinical states, antecedents, history	S1	Patient record
Semiology Knowledege	S2	Medical academic knowledge
Epidemiology Data	S1	Epidemiological studies
Previous diagnosis experience	CBR	Previous disease cases
Diagnosis Decision	FSA	Supervisor : Finite

Decision knowledge chunk	DSS	Data & Knowledge Sources
Patient clinical current state evaluation	S1	Patient record
disease evolution expert knowledege	S2	Disease knowledge base
disease statistical data	S1	Epidemiological studies
Previous same disease case experience	CBR	Previous disease cases
Prognosis evaluation method	FSA	Supervisor : Finite State Automaton

Decision knowledge chunk	DSS	Data & Knowledge Sources
Patient antecedents, current prescriptions, contraindications, laboratory results	S1	Patient record
Drug indications, contraindications interactions, toxic and adverse effects	S2	Pharmacology, pharmacokinetic data & knowledge
Drug testing statistical data	S1	Drug testing studies
Drug prescription experience	CBR	Previous prescription cases
Therapy decision method	FSA	Supervisor : Finite State Automaton

Fig. 4 : The clinical DSS architecture and sources

The different data and knowledge sources are represented with different models. They must share a common interface. One solution is to use a multiagent system with an ontology that allows the DSS to share the same terminology. The agent is used to encapsulate the

DSS module and to manage the communication and the negotiation between the agents in the system. Such an approach is presented in [19] and [5]. Another solution is to use an object oriented approach to encapsulate the DSS modules and thus to inherit a general interface which allows them to communicate between each other.

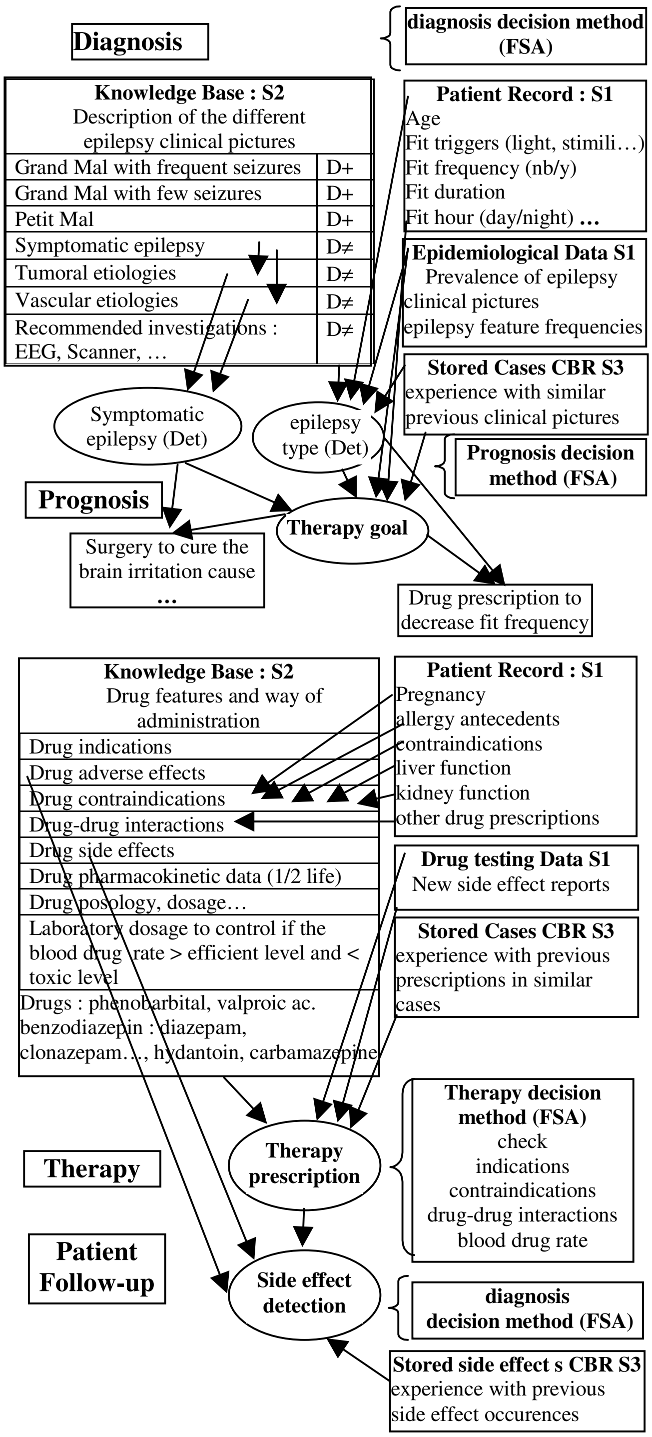


Fig.5 : Epilepsy diagnosis and therapy

The transaction and the clinical case recording is achieved by the CBR module. It must index and store the already solved clinical cases coming with the knowledge chunks that was used to provide a solution. The environment : the facts, the events and especially the results must also be stored. The main CBR drawback is that at the beginning of the system use, the case base is void or contains very few cases. This gives no chance to find a case closed to the one under consideration.

C. Illustration : the epilepsy diagnosis and therapy

We briefly present an example of our approach application, the epilepsy diagnosis and therapy (figure5).

The diagnosis process makes use of the patient record (which is, for short, not exhaustive). It describes the patient epileptic fits. A knowledge base is used to detect the matching clinical pictures during the positive diagnosis step. During the differential diagnosis, it tries to discard the non relevant hypotheses. The use of epidemiological data can help to know the probability for the patient to be ill. The CBR module is especially interesting if the clinical picture is unusual and if previous similar cases have already been stored. The result is the etiological diagnosis. If the epilepsy is symptomatic, the actual cause have to be search for and then cured. The type of epilepsy allows to determine the prognosis and then the therapy goal. The drug knowledge base and the patient record allow to choose the treatment, to avoid the contraindicate drugs, to detect the drug-drug interaction with a previous treatment.. Using testing data and precedent prescription cases is also useful to set a therapy prescription. During the follow-up, some examination and laboratory tests are provided in order to detect drug side effects. An EEG is also helpful to evaluate the patient disease evolution.

V. CONCLUSION

We showed that different kinds of DSS models, data and knowledge are complementary, they all will be useful to take an appropriate decision in a complex domain like medicine. We have presented a framework to cope with the different decision paradigm integration. The system supervision is managed by a finite state automaton which triggers queries to the appropriate database and knowledge base. The main advantage of this approach is the system modularity. Therefore, the system can be built up incrementally. This advantage increase the system flexibility and feasibility. If some modules are quite easy to implement and test, others are rather difficult to elaborate.

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