CHAPTER 4

Expert Systems Technology and the Medical Domain

4.1. Introduction

Expert systems (ES) technology is one of the application areas of Artificial Intelligence (AI) which is a sub field of computer science concerned with the study and creation of computer systems that exhibit some form of intelligence. A number of computer systems have been built over the past few decades that can perform tasks which are comparable to many human mental activities. These systems can diagnose diseases, plan the synthesis of organic chemical compounds, solve differential equations in symbolic form, drive automobiles, understand limited amounts of human speech and natural language text, analyse electronic circuits or write small computer programs - we say that such systems possess some degree of artificial intelligence. AI systems are developed, undergo experimentation, and are improved (table 4.3).

One major area of AI that can claim a large measure of responsibility for the current AI awareness in the world is the expert systems technology which is computer software that embodies human expertise. The scarcity of human expertise exists in almost all fields, specially in medical domain. But, however an expert advice is always necessary. One solution to the dilemma is the expert systems technology, an intelligent assistance to human experts as well as others who otherwise might not have access to expertise.

An expert system is a computer program that encodes the knowledge and reasoning of human expert(s) in a given area and applies this knowledge and reasoning to derive problem-solving interfaces for the user of the system. To solve a given particular problem, the ES examines facts about the problem supplied by the user. The facts are interpreted in terms of the system's search of its knowledge base and processed through its built-in reasoning procedures to find a solution.

In order to have successful development of an ES in a domain, different potential issues have to be fixed up. This chapter is meant for fixing up two potential issues, namely (i) why it is an expert system domain, and (ii) what requirements the domain lays on an expert system. These two issues should unfold some important aspects relating to design and implementation of an expert system.

The next section, undertakes some issues such as categories and application areas, desirable features, life cycles, typical architecture, and types of expert systems. In section 4.3, an attempt has been made to explain why the paediatric domain may be considered suitable for an expert system domain. In section 4.4, we have tried to find out what requirements the domain lays on an expert system. At the end, a discussion has been provided.

4.2. Expert systems technology

4.2.1. Categories and application areas of expert systems

Expert systems may be applied to any situation that normally requires human expertise. One can divide typical expert system applications into thirteen functional categories [1, 2] shown in table 4.1. In table 4.2, we indicate application areas for which some expert system has been developed [2, 3]. Some examples of expert systems developed for different application areas are shown in table 4.4.

Table 4.1. Generic categories of expert system applications.

Category	Problem addressed and application types
Control	Governing overall system behavior for - air traffic control and battle management.
Debugging	Prescribing remedies for malfunctions for computer software.
Design	Configuring objects under constraints for circuit layout and CAD.
Diagnosis	Inferring system malfunctions from observable for medical and electronic fields.
Instruction	Diagnosing, debugging and repairing student behaviour
Interpretation	Inferring situation descriptions from sensor data for speech and image analysis and surveillance.
Planning	Designing actions - automatic programming and military planning.
Prediction	Inferring likely consequences of given situations for weather forecasting and crop estimation.
Prescription	Recommending solutions to system malfunctions.
Monitoring	Comparing observations to expected outcomes - for power plant and fiscal management.
Repair	Executing plans to administer prescribed remedies for automobiles/computers.
Selection	Identifying the best choice from a list of possibilities.
Simulation	Modeling the interaction between system components.

Table 4.2. Application areas of expert systems.

Aerospace	Law
Agriculture	Manufacturing
Business	Mathematics
Chemistry	Medicine
Communications	Meteorology
Computer System	Military Science
Education	Mining
Electronics	Physics
Engineering	Process Control
Environment	Power Systems
Geology	Science
Image processing	Space Technology
Information Management	Transportation

The predominant role of expert systems has been the diagnosis. One reason for the result is that this is the role most experts play. Fields such as medicine, engineering, agriculture, and manufacturing have many individuals who help diagnose problems. Another reason for the large percentage of diagnostic systems is their relative ease of development. Most diagnostic problems have a finite list of possible solutions and a limited amount of information needed to reach a solution. These bounds provide an environment that is conducive to effective system design.

Table 4.3. Areas of research in AI adapted from [34].

Area	Research focus	References
Problem solving and planning	Deals with systematic refinement of goal hierarchy, plan revision mechanisms and a focused search of important goals.	Hewitt, 1971
Expert systems	Deals with knowledge processing and complex decision-making problems.	Feigenbaum,1977; Newell and Simon, 1976; Shortliffe,1976
Knowledge based systems	Generation expert systems characterized by two approaches: combining multiple models and reasoning techniques and using knowledge-level approaches for designing systems.	David et al., 1993
Natural language Processing	Areas such as automatic text generation, text processing, machine translation, speech synthesis and analysis, grammar and style analysis of text etc.	Hayes-Roth and Lesser,1977
Robotics	Deals with the controlling of mechanical equipment to manipulate or grasp objects and using information from sensors to guide actions etc.	Engelberger, 1980
Computer vision	Deals with intelligent visualization, scene analysis, image understanding and processing and motion derivation.	Minsky, 1975
Learning	Deals with research and development in different forms of machine learning.	Smith et al., 1977
Genetic algorithms	These are adaptive algorithms that have inherent learning capability. They are used in search, machine learning and optimization.	Holland, 1975; Goldberg, 1989
Neural networks	Deals with simulation of learning in the human brain by combining pattern recognition tasks, deductive reasoning and numerical computations.	Selfridge, 1959
Case-based reasoning	A problem-solving strategy based on the similar past problem-solving experience to help the designer to exploit the useful details for application to a particular similar case.	Hammond, 1986; Kolodner, 1987; Riesbeck and Schank, 1989
Rough set theory	New mathematical tool to deal with vagueness and uncertainty.	Pawlak et al., 1995
Intelligent agent	Computational systems that inhabit some complex, dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals or tasks for which they are designed.	Maes, 1995

Table 4.4. Examples of expert systems in application areas.

Application areas	Examples of Expert Systems
Aerospace [4]	REX
Agriculture [5-12]	COTFLEX, COMAX, SMARTSOY
Business [13]	SUTA
Chemistry [14]	DENDRAL, CONGEW, MOLGEN
Communication [15]	COMPASS
Computer System [16]	DART, ISA, MIXER, XCON
Education [17]	MIKE
Electronics [18]	SYN, ACE, SADD, FOREST
Engineering [19]	SACON, DELTA, REACTOR
Geology [20]	PROSPECTOR, ADVISOR
Image processing [21]	3DPO
Information Management [22]	GCA, CODES, FOLIO
Law [23]	LRS, AUDITOR, SARA
Manufacturing [24]	ISIS, IMACS
Mathematics [25]	MACSYMA, MATHLAB68
Medicine [43, 44]	Section 4.2.2.
Meteorology [26]	WILLARD
Military science [27]	MES, ACES, ASTA, DART
Mining [28]	Dust Pro
Physics [29]	MECHO, GAMMA
Process control [30]	FALCON, PDA
Power systems [31]	ENERGY MANAGEMENT
Space technology [32]	ECESIS, FAITH, LES
Transportation [33]	CARGEX

4.2.2. Expert systems in Medicine

Medical expert systems lead to less undiagnosed cases, lower iatrogenic disorders and more effective treatment i.e. improved and cost-effective healthcare. They can also be used for effective education and training and be beneficial for physician, patients, care-givers, health-workers and associated stakeholders.

A detailed review on ES in medical management can be seen in Peart et al. [35]; Lambert and Wood [36]; Jones [37]; Barret et al. [38]; Carrascal and Pau [39]; Edward-Jones [40]; Mohan and Arumugam [41] and Kumar and Mohanti [42].

Many ES and DSS found their application only in the later part of the last decade. The development of ES and DSS applications and their continuous improvement has resulted in their expansion and application in the different domains of medicine.

In table 4.5., we show some typical globally available medical expert systems/ decision support systems.

Table 4.5. Some globally available Medical Expert Systems/Decision Support Systems.

Name	Type	Purpose
ACORN (Admit to the Ccu OR Not)	ES	Advising on management of chest pain patients in the emergency room.
ADE (Adverse Drug Event) Monitor	ES	Assisting the staff pharmacists to monitoring patient clinical data for potential adverse drug events.
Apache III (Acute Physiology and Chronic Health Evaluation)	ES	For prediction of an individual's risk of dying in the hospital.
Becton Dickinson Laboratory Systems	ES	Provides possible medical interpretations of a patient's haematologic test results & determines the minimum Inhibitory Concentration values for a variety of drugs
CaDet	DSS	For Early Cancer Detection
CADIAG-II (Computer-Assisted DIAGnosis)	ES	Consultation system to support the differential diagnostic process in internal medicine.
Cancer, Me??	ES	For automated delivery of personal advice on how to reduce risk of cancer.
CCIS, Cervical Cancer Information System	DSS	Monitors the impact and effectiveness of a cervical cancer screening program.
Clinical Event Monitor	DSS	Generates alerts, interpretations, screening messages, etc. for health care providers.
Colorado Medicaid utilization review system	ES	Performs quality review of drug prescribing for Medicaid patients.
Computerized Medical Diagnosis,CMD	DSS	For diagnosis of Gastrointestinal Disorders.
DermaDex	DSS	Assisting in the diagnosis of skin disorders.
DiagnosisPro	DSS	Support to provides differential diagnosis in the field of general internal medicine, family practice, pediatrics, geriatrics and gynecology.
DoseChecker	ES	Assisting the pharmacists with monitoring drug orders for a set of drugs impairment.
Dr. Gait III - Intelligent Support of Gait Analysis	DSS	Providing the means to view and electronically annotate all the information commonly presented for gait analysis of medical history, physical examinations, time/distance data, joint ankle graphs, moments, powers, force plates, EMGs & video and stick figures.
Epileptologist`s Assistant	ES	Produce preliminary progress notes for physicians in epilepsy follow up clinic.
FACTS (Finding Appropriate Clinical TrialS)	DSS	Helps breast cancer patients find clinical trails for which they may qualify.
GermAlert/Germwatcher	ES	Assists the Infection Control activities including surveillance of microbiology cultures data.
5GL-Doctor	DSS	Assists professionals of general medicine.
GIDEON	ES	For diagnosis and reference in the field tropical and infectious diseases, epidemiology, microbiology and antimicrobial chemotherapy.

HDP, The Heart Disease Program	ES	Assist physicians with the diagnosis of heart disease, particularly those conditions leading to hemodynamic dysfunction and heart failure.
HELP System	DSS	Supports not only the routine application of an HIS including ADT, order entry/charge capture, pharmacy, radiology, nursing documentation, ICU monitoring,
Hepaxpert I, II and III/WWW	ES	For interpretive analysis of Hepatitis A and B serology findings.
Hypertension	DSS	Supports Clinicians for use clinical practice guidelines of Hypertension by hiding the complexities.
ICONS	ES	Advice antibiotic therapy for patients in an intensive care unit with additional complications.
ILIAD v. 4.5	ES	Used for diagnostic consultant covers more than 1200 diseases includes internal medicine, pediatrics, dermatology, psychiatry, obstetrics and gynecology, peripheral vascular diseases and sleep disorders and provides treatment protocols.
IMM/Serve	DSS	Helps in management of childhood immunization.
Interpretation of acid-base disorders	ES	For interpretation of acid-base disorders is in routine use
Jeremiah	DSS	Provides dentists with orthodontic treatment plans for cases suitable for treatment.
Larsen: Computer-Assisted Scoring of Rheumatoid Arthritis	DSS	Allows fast, accurate, and reliable documentation of erosive and degenerative changes on radiographs of hands, wrists, and feet in rheumatoid arthritis.
Liporap	ES	Developed for the Automatic Phenotyping of dyslipoproteinemia.
MammoNet	DSS	Mammography Decision Support
MDDB	ES	For diagnosis of dysmorphic syndromes
MetaNet	DSS	Assist in the diagnosis of inborn errors of metabolism in children.
MINERVA	ES	For analysis of pathological images or manifestations.
Managed second surgical opinion (MSO) system	ES	Provides an automated second surgical opinion for areas where surgery is often over prescribed
MONI		
NeoGanesh	ES	For management of mechanical ventilation in Intensive Care Units (ICUs).
Orthoplanner	ES	Provides dentists with orthodontic treatment plans for cases where fixed orthodontic appliance techniques must be employed
PEIRS (Pathology Expert Interpretative Reporting System)	ES	For interpretative comments to chemical pathology reports.
PEPID (Portable Emergency Physician Information Database)	DSS	Management essentials for virtually all medical and drug problems encountered in the emergency or urgent care settings.

PERFEX (Perfusion Expert)	ES	For interpretation of 3D tomograms of myocardial perfusion distribution
Phoenix & ISIS	DSS	been designed to act as a Radiology Consultant. PHOENIX is now superceded by ISIS (Intelligent Selection of Imaging Studies).
POEMS (Post Operative Expert Medical System)	DSS	Supports relatively inexperienced medical staff assigned for post-operative care.
PRODIGY - Project Prescribing Rationally with Decision - Support in General - practice StudY	DSS	A recommending tool for diagnosis and prescribes cost-effective evidence-based clinical advice/ therapy.
Puff	ES	For diagnoses the results of pulmonary function tests.
QMR (Quick Medical Reference)	DSS	Supports the process of clinical diagnosis of internal medicine disorders & allows physicians to review disease manifestations, do patient simulations, and access reference citations.
RaPiD (Computer Aided Partial Denture design)	ES	For designing Removable Partial Dentures (RPD).
Reportable Diseases		
RheumExpert	ES	A tool for a computer-based documentation of patient data covering the most important findings and symptoms for rheumatic diseases.
SETH	ES	For management of acute drug poisoning, gives specific advice concerning the treatment and monitoring of drug poisoning.
TDW,Thallium diagnostic workstation	ES	To diagnose thallium myocardial scintigraphy from a training set of examples.
Thorask	ES	Assists health professionals, hospitals and managed care providers in optimizing the triage, diagnosis, and management of non-traumatic chest pain.
T-IDDM Project (Telemetric Management of Insulin Dependent Diabetes Mellitus)	DSS	concerns the design, implementation and testing of an intelligent telemedicine service to assist Insulin Dependent Diabetes Mellitus (IDDM) patients.
ToxoNet	ES	Support the clinician in analyzing the test results of routinely made toxoplasmosis tests with the objective of assuring quality by setting standards for therapy.
TraumAID	ES	Assist physicians with the diagnosis and treatment of penetrating trauma (gunshots and stab wounds) to the chest and the abdomen.
TxDENT	DSS	To improve the process of screening, selecting and tracking dental patients.
Vented	DSS	Used for monitoring and supporting patients with different kinds of imminent and obvious ventilatory insufficiencies.
VIE-PNN (Vienna Expert System for Parenteral Nutrition of Neonates)	ES	For calculating the composition of parenteral nutrition solutions (PNS) for neonates at intensive care units.

4.2.3. Typical features of an expert system

The following features [45] are typical to an expert system:

- An ES should solve difficult problems in a domain as good as or better than human experts. This is a fundamental criterion.

- Such systems should process vast quantities of domain-specific knowledge to the minute details. These are pieces of knowledge a human expert acquires after long years of professional experience in a field. These private pieces of knowledge being termed as 'heuristics' need to be incorporated into the system along with the conventional knowledge acquired from various sources.

- An ES permits the use of heuristics search process. An ES provides facilities for incorporating these heuristic search procedures.

- The system explains why they ask a question and justifies its conclusions. Explanation facilities enhance the credibility of the system in the mind of human.

- An ES accepts advice, modifies, updates and expands. These characteristics form the basis for learning.

- The system deals with uncertain and irrelevant data. Like human experts, ES also have to deal with a lot of uncertain and irrelevant data.

- The system communicates with the users in their own natural language. This is a characteristic that everybody is looking for. However, a few primitive natural language front end systems have developed which one can hook up with the ES.

- An ES possesses the capacity to cater to the individual's desire. By this we mean that an ES can be used in different modes of operation.

- The system provides extensive facilities for symbolic processing rather than numeric processing. Symbolic processing is the core of any AI program and hence an ES should provide facilities for doing so.

- A final characteristic is from the point of economists and financial people. ES need heavy investment and there should be considerable Return-on-Investment (ROI).

4.2.4. Life cycle of an expert system

There are five major stages in the development of an ES. Each stage has its own unique features and a correlation with other stages shown in fig. 4.1.

Stage 1: Identification of the problem. In this stage, the expert and the knowledge engineer interact to identify the problem. The major points discussed before for the characteristics of the problem are studied. The scope and the extent are analysed. The resources and finance are identified and estimated. The return-on-investment analysis is also done.

Stage 2: Mode of development. Once the problem is identified, the immediate step would be to decide about the vehicle for development. The knowledge engineer can develop the system from scratch using a AI language like PROLOG or LISP or any conventional language or adopt a shell for development. In this stage, various shells and tools are identified and analysed for their suitability. Those tools whose features fit the characteristics of the problem domain are analysed in details.

Stage 3: Development of prototype. One important factor to be decided here is the level of knowledge. Starting with coarse granularity, the system development proceeds towards high granularity. In this stage, the task of knowledge acquisition begins. The knowledge engineer and the domain expert interact frequently and the domain-specific knowledge is extracted. Once the knowledge is acquired, the knowledge engineer decides on the method of knowledge representation. When the knowledge representation scheme and the knowledge is available, a prototype is constructed. This prototype undergoes the process of testing for various problems and revision of the prototype takes place.

Stage 4: Planning for a full-scale system. The success of the prototype provides the needed impetus for the full-scale system. In prototype construction, the area in the problem that can be implemented with relative ease is first chosen. In the full-scale implementation, interactions with additional experts takes place. Extensive planning is done.

Stage 5: Implementation, maintenance and evaluation. This is the final life cycle stage of an ES. The full scale system developed is implemented at the site. The basic resource requirements at the site are fulfilled and parallel conversion and testing techniques are adopted. The final system undergoes rigorous testing and later it is handed over to the user.

Maintenance of the system implies tuning of the knowledge base because knowledge, the environment and types of problems that arrive are never static.

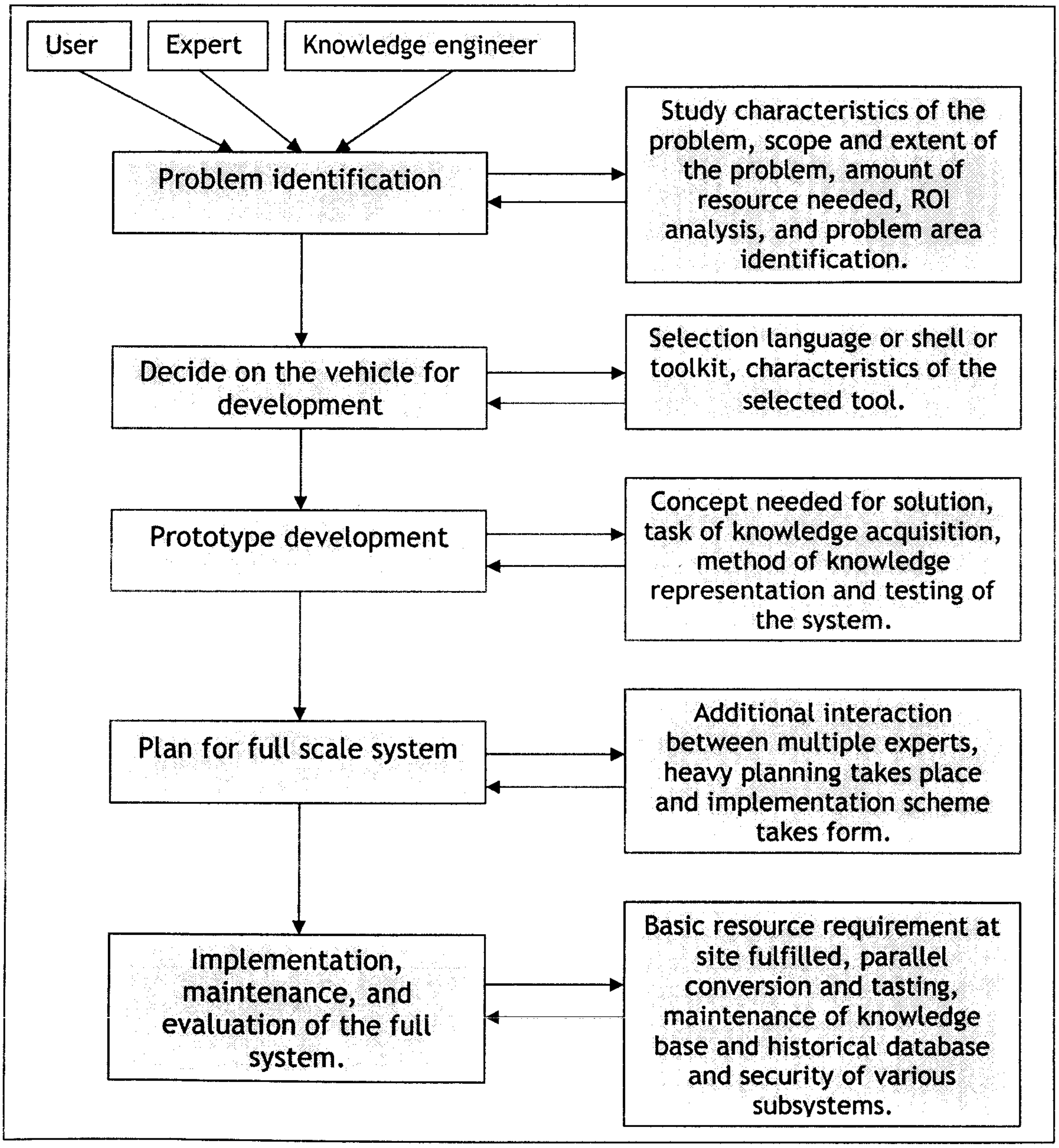

Fig. 4.1. Expert system life cycle.

Evaluation is a difficult task for any AI program. Solutions for AI problems are only satisfactory. Since the yardstick for evaluation is not available, evaluation becomes difficult. However, what one can do utmost is to supply a set of problems to the system and a human expert and compare the results.

4.2.5. Components of an expert system

Every expert system should have a knowledge base, an inference engine and a user interface. AI environments for expert system development are shown in block diagrams (figure 4.2 and figure 4.3) which are more or less self explanatory. The component of the expert system that contains collection of the domain knowledge for the system is called its knowledge base. The knowledge base of an expert system contains both declarative (facts about objects, events and situations) and procedural (information about courses of action) knowledge depending on the form of knowledge representation chosen that two types of knowledge may be separate or integrated. There are several knowledge representation schemes such as Logic, Semantic Networks, Frames, Rules etc. which will be discussed in chapter 5.

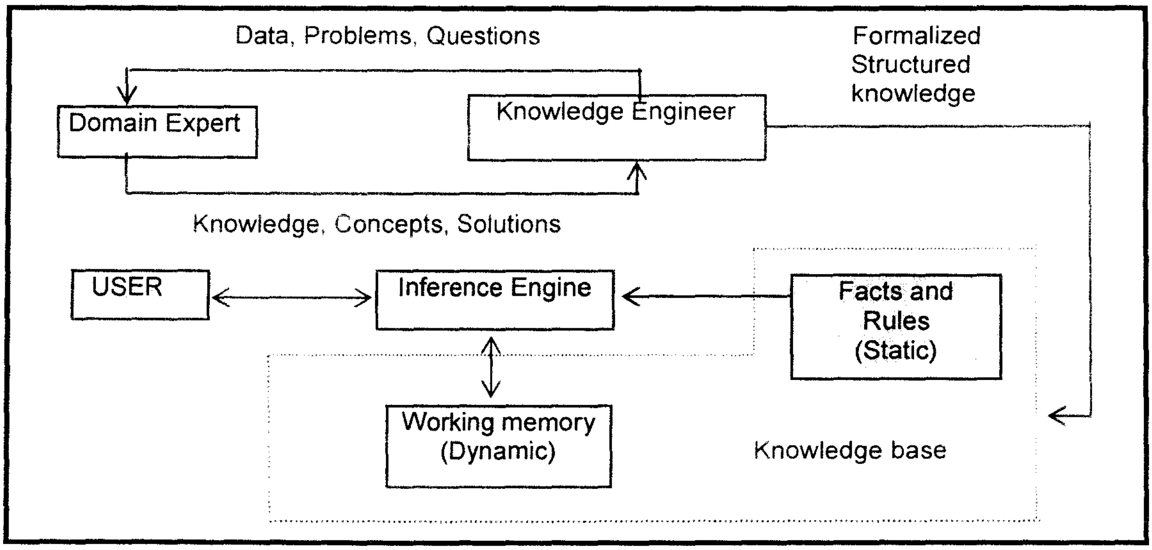

Fig. 4.2. An architecture of a typical expert system.

Simply having a knowledge base itself does not make an expert system intelligent. The component that is responsible for making an ES intelligent is known variously as the control structure, the rule interpreter, or the inference engine. The inference engine defines which heuristic search techniques are used to determine how the rules in the knowledge base are to be applied to the problem. The knowledge in an expert system is not intertwined with the control structure. As a result of which an inference engine that works well in one expert system may work just as well with a different knowledge base. For example, the inference engine of one of the most famous medical expert system MYCIN is available separately as EMYCIN (essential MYCIN). EMYCIN can be used with a different knowledge base to create a new knowledge system eliminating need to develop a new inference engine.

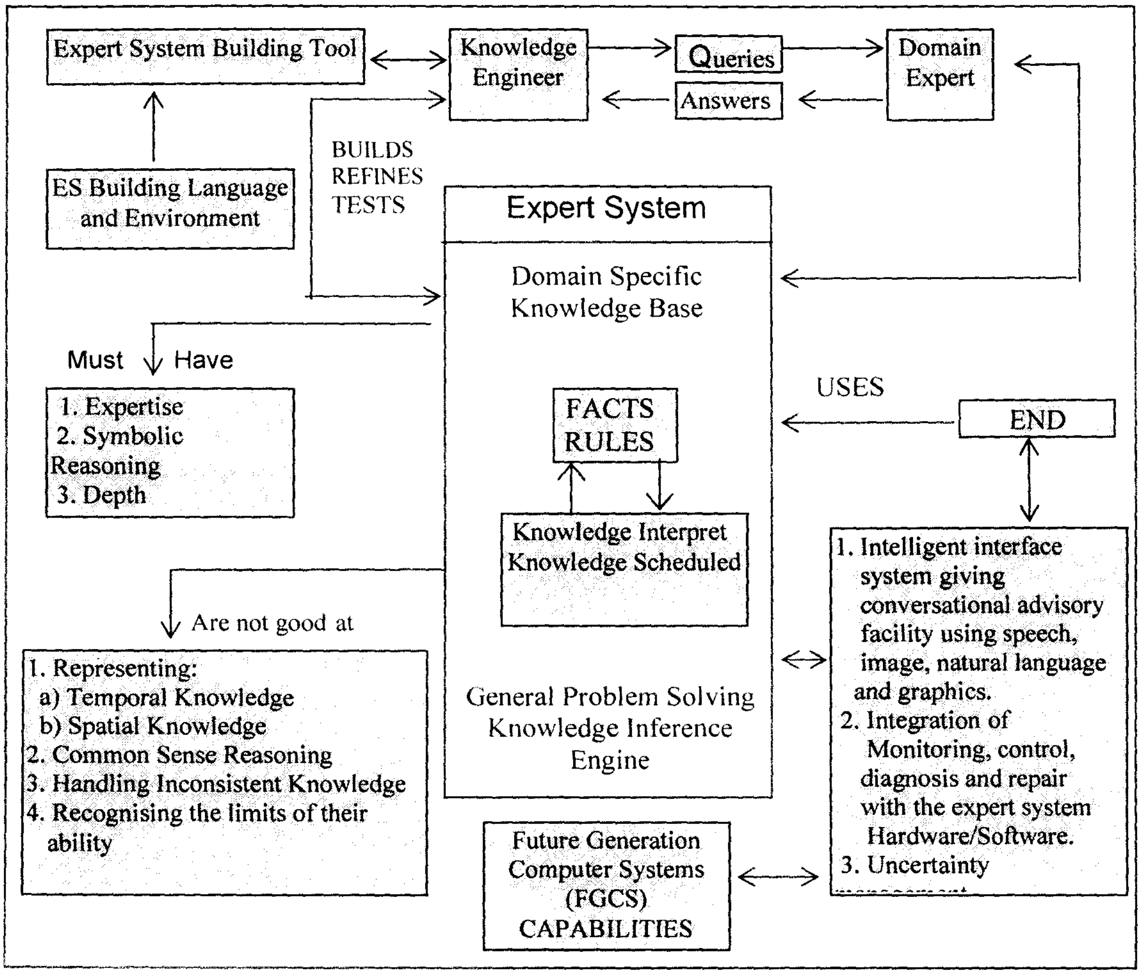

Fig. 4.3. A block diagram indicating ES-development environment [46].

Next important component is the user interface. This enables user to communicate with an expert system. The communication performed by a user interface is bi-directional. At the simplest level the user must be able to describe his problem to the expert system and the system must be able to respond with its recommendations. The user may also ask the system to explain its reasoning. The system may also ask the user for additional information about the problem. In figure 4.3 different features that are desirable for the end-user interface is described.

4.2.6. Classifications of expert systems

4.2.6.1. Based on knowledge representation

- **Rule-based**

This is one of the mostly used reasoning in developing an expert system. A type of knowledge representation in which the knowledge about a domain is expressed in rules that define relationships between facts. Rules provide a formal way of representing recommendations, directives or strategies.

- **Case-based**

In case-based reasoning [47] is a set of relevant examples rather than general rules from the knowledge base. These cases are applied to new problems by an analogical reasoning process. The idea is that if a suitable measure of similarity exists, the new case can be related to one or more similar past cases in an appropriately indexed database. This approach was first tried by Kolodner in psychiatry [48] and a number of other domains. Proponents of case-based reasoning argue that this is closer to human reasoning. Case-based approaches have played an important role in expert programs in law and medicine. A comparison of rule-based reasoning vs. case-based reasoning has been shown in table 4.6.

- **Frame-based**

Reasoning with frames is much more complicated than reasoning with rules. The slot provides a mechanism for a kind of reasoning called expectation-driven processing. Empty slots (i.e. unconfirmed expectations) can be filled, subject to certain conditioning, with data that confirm the expectations. Thus, frame-based reasoning looks for confirmation of expectations and often just involves filling in slot values.

Table 4.6. Comparison of Case-based and Rule-based reasoning [49].

Criterion	Rule-based reasoning	Case-based reasoning
Knowledge unit	Rule	Case
Granularity	Fine	Coarse
Knowledge acquisition units	Rules, hierarchies	Cases, hierarchies
Explanation mechanism	Back track of rule firings	Precedent cases
Characteristic output	Answer, plus confidence measure	Answer, plus precedent cases
Knowledge transfer across problems	High, if backtracking Low, if deterministic	Low
Speed as a function of knowledge base size	Exponential, if backtracking; Linear, if deterministic	Logarithmic, if index tree balanced
Domain requirements	Domain vocabulary Good set of inference rules Either few rules or solution is probably still good Domain mostly obeys rules	Domain vocabulary Database of example cases Stability - a modified good Rules apply sequentially Many exception to rules
Advantages	Flexible use of knowledge Potentially optimal answers	Rapid response Rapid knowledge acquisition Explanation by examples
Disadvantages	Computationally expensive Long development time Black-box answers	Sub-optimal solutions Redundant knowledge base

The reasoning process that takes place with frames is essentially the seeking of confirmation of various expectations. This amounts to filling in the slots and verifying that they match the current situation. With frames, it is easy to make inferences about new objects, events, or situations because the frames provide a base of knowledge drawn from previous experience.

Frame-based systems are most applicable to biological classification systems, and similar types of systems, in which a static hierarchical classification is a part of the knowledge.

- **Model-based reasoning**

Model-based reasoning is based on knowledge of the structure and behavior of the devices the system is designed to understand. Model-based systems are especially useful in diagnosing equipment problems. The systems include a model of the device to be diagnosed that is then used to identify the cause(s) of the equipment's failure. Because they draw conclusions directly from knowledge of a device's structure and behavior, model-based expert systems are said to reason from 'first principles'.

4.2.6.2. Based on some technological artifacts

Two major problems in building expert systems: (i) constructing and debugging knowledge base, and (ii) management of uncertainties might be relevant here. In the recent years, different ideas, concepts, methodologies have been introduced in circumventing the above and allied problems in building knowledge-based expert systems and/or in improving the performance in decision making systems. The resulting basic modules of various expert systems [50] are shown in fig. 4.4.

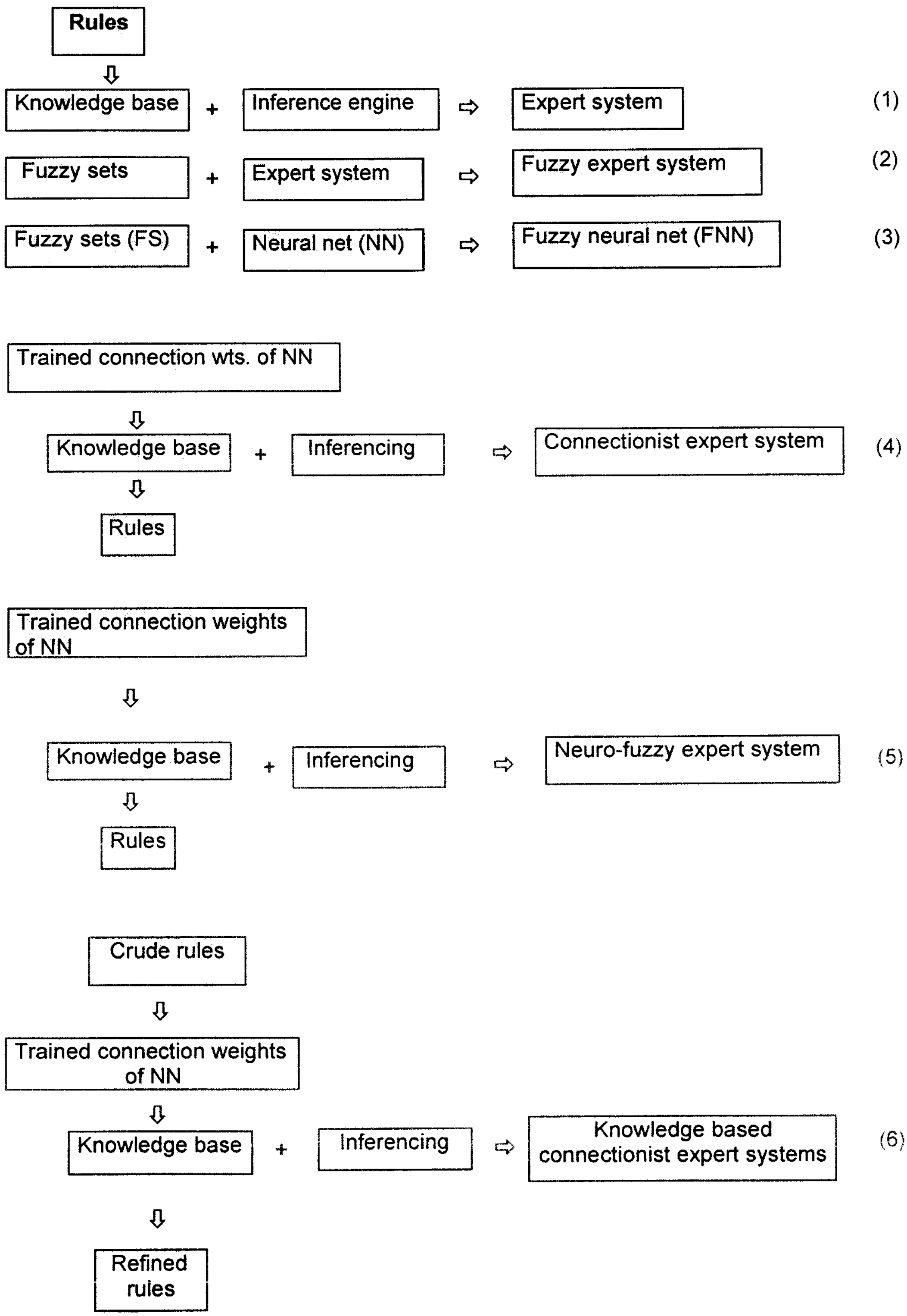

Fig. 4.4. Block diagram of the basic modules of various expert systems.

Artificial neural networks [51-54] can be formally defined as massively parallel interconnections of processing elements that interact with objects of the real world in a manner similar to biological systems. All information is stored distributed among the various connection weights. The networks can be trained by examples and sometimes they generalize well for unknown test cases.

Fuzzy logic is based on the theory of fuzzy sets. It aims at modeling the imprecise (or inexact) modes of reasoning and thought processes with linguistic variables that play an essential role in making rational decisions in an environment of uncertainty and imprecision.

The fuzzy set theoretic models [55, 56] try to mimic human reasoning and the capability of handling uncertainty, whereas the neural network models attempt to emulate the architecture and information representation schemes of the human brain. Integration of the merits of fuzzy set theory and neural network theory therefore promises to provide more intelligent systems to handle real life recognition/decision making problems. For the past few years, there have been several attempts [57-60] by researchers over the world in making a fusion of the merits of these theories under the heading 'neuro-fuzzy computing' for improved decision making systems.

The knowledge base of an expert system is a repository of human knowledge and some of these may be imprecise in nature. This may result in a collection of rules and facts which for the most part are neither totally certain nor totally consistent. The expert system is also likely to be required to infer from premises that are imprecise, incomplete or not totally reliable. The uncertainty of information in the knowledge base of the question-answering system thus induces some uncertainty in the validity of its conclusions [61]. Hence a basic problem in the design of expert systems is the analysis of the transmitted uncertainty from the premises to the conclusion and the association of a certainty factor [62]. Fuzzy expert systems [62, 63], incorporating the concept of fuzzy sets at various stages, help to a reasonable extent in the management of uncertainty in such situations.

Neural networks are also used in designing expert systems. Such models are called connectionist expert systems [64], and they use the set of connection weights of a trained neural net for encoding the knowledge base for the problem under consideration.

The block diagram of the basic modules of an expert system, fuzzy expert system, fuzzy neural net, connectionist expert system, neuro-fuzzy expert system and knowledge-based connectionist expert system have been provided in figure 4.4. A fuzzy neural net constitutes the knowledge base of a neuro-fuzzy expert system. The rules are collected by knowledge engineers for designing the knowledge base of a traditional expert system or fuzzy expert system. The connectionist models use the trained link weights of the neural net/fuzzy neural net to automatically generate the rules. This automates and also speeds up the knowledge acquisition process. The use of fuzzy neural nets helps in the handling of uncertainty at various levels (e.g. input, output, learning and neuronal) and generates fuzzy rules capable of more realistically representing real-life situations. The knowledge-based connectionist expert systems, on the other hand, initially encode crude domain knowledge among the connection weights of the neural net, thereby speeding up the training phase and generating better performance. Refined rules are later extracted from the less redundant trained network.

A comparative analysis of the basic features of these models with those of the traditional and connectionist (non-fuzzy) versions is provided in table 4.7.

Table 4.7. Comparative study of various expert systems.

	Expert system	Connectionist expert system	Neuro-fuzzy expert system	Knowledge-based connectionist / Neuro-fuzzy expert system
Knowledge base	Knowledge acquisition and representation in the form of rules, frames, semantic nets or belief networks	Connection weights of trained neural net that were initialised with small random values.	Connection weights of trained fuzzy neural net that were initialised with small random values.	Connection weight of trained nonfuzzy / fuzzy neural net that were initialised with crude domain knowledge in rule form with binary link weights a prior class information and distribution of pattern points.
Knowledge refinement	Addition of new knowledge (say, as new rules)	Empirical addition of hidden nodes/links	Empirical addition of hidden nodes/links	Network optimization using growing and pruning of nodes/links, based on training data and additional knowledge.
Inferencing	Matching facts with the existing knowledge base	Presentation of crisp input, forward pass and generation of crisp output	Presentation of fuzzy input, forward pass and generation of fuzzy output	Presentation of input, forward pass and generation of output
Rule generation		Crisp rules obtained during backward pass using changes in levels of input and output units, magnitude of connection weights	Fuzzy rules obtained during backward pass using node activation and link weights	Rules obtained during backward pass; negative rules also possible

4.3. Why it is an expert system domain?

There are two distinct parts under this aspect: (i) why does the domain demand ES-technology? and (ii) why does the ES-technology suit the domain? Let us consider the first issue, the foundation of which may be traced in Chapter 1 and chapter 2. Proper and prompt management of child ailment are very much required. As an ideal case, at least one pediatrician should be placed at each primary/community health centre. But human experts are really a scarce commodity. To mitigate such needed expertise, an automated knowledge-based consultation system would be helpful. Let us now examine how the ES-technology suits the problem domain. The key attributes of a domain, to be a good candidate for expert system domain, are neither all absolute nor limited to the following [65-67]:

- The Knowledge associated with the domain must be bounded;
- Non-algorithmic approach is more useful than conventional algorithmic approach;
- Human experts or literature should be available or some prior case studies should be conducted to gather knowledge where human experts knowledge is neither adequate nor any literature is available;
- There should be some advantage to using computers with a significant payoff;
- The complete logic is not known in advance;
- Primarily it requires symbolic reasoning;
- There may be use of heuristics by the expert(s). Problems require multi-criteria decision making (MCDM) [68] or use of incomplete or uncertain information;
- The domain is fairly stable or at least slowly changing;
- No alternative solution to the problem is being pursued or is expected to be pursued. The present solution under investigation for the domain problem will be used for quite some time.

The knowledge associated with the domain is large and varied. Reaching a conclusion with such unbounded knowledge may not be possible. Therefore, experts somehow confine their knowledge while handling any problem. We confine ourselves within such expertise knowledge during the knowledge acquisition process. So, it is better to use here a non-algorithmic approach. Multiple experts of the domain are available here. We have no doubt to state that a significant pay off from the completed system will be achieved. This pay off may be in terms of tangible benefits or may be in terms of social values. Knowledge of this problem domain is vast and varied and hence complete and sound knowledge may not be available in advance. This requires the use of expert systems technology where one may expect the ease of updating and maintainability of knowledge base. Primarily, the domain requires to deal with some symptoms (medical vocabulary or symbol) like 'Grimace' or 'Flaccid' or 'Abnormal character gasping'. So, symbolic reasoning is the primary component here [69]. It is such a domain where the use of heuristics by the experts gained in a number of years of practice will be useful. Multiple criteria decision making and incomplete or uncertain information processing are also the characteristics of the domain. From the economic point of view, no better solution seems feasible. It may not be possible to appoint even one human expert (pediatrician) in all health-care centres. The needs of the domain may be fulfilled, at least partially, by the present system under investigation. It is expected that the full system once achieved will partially be used as long-term basis, an important pay off.

4.4. What requirements the domain lays on an expert system? [69]

With the above justifications of using expert systems technology for the domain, let us now investigate the requirements the domain lays on an expert system.

- **Portability**

To have its increased usage an expert system is expected to be portable. This essentially means that the system can be run on different types of target machines which can be procured at low cost and can be transported easily to different remote locations. Moreover, the recurring expenditure should be low in terms of power consumption, maintenance etc. During the system development, one has to select a software development tool to satisfy the said purpose. For example, one may suitably select PROLOG/LISP or an ES-shell or a tool-kit based on PC running under MS-DOS/Windows. Summarily, a low cost and easily manageable by the end users PC-based system is being proposed here. This portability feature should certainly encourage the usage issue discussed in chapter 1. It should be easier then for health-care providers who already have hardware with them to procure this system. This may require a small upgradation rather than procuring specialised LISP-based machines or AI workstations.

- **Modifiability**

The domain knowledge in knowledge base may have to be enhanced owing to different reasons. Three specific reasons may here be noted. First, when complete and sound knowledge may not be available in advance, a fact for the present domain, existing system should easily and quickly incorporate the required changes, specially bearing in mind the state-of-the-art knowledge of the domain. Secondly, the complete and sound knowledge may not be possible to acquire in the initial stage of the knowledge acquisition process. At the later stage of the development, further enhancement would be required. Third, for its survival, a system should be of open type. This essentially means that the system should cope with the advanced development, obviously small, suggesting the modifiability feature to incorporate in the system. A closed system should eventually die. In a system, the modifiability has to be taken care of at two levels: i) at the design level, and ii) at the implementation level.

- **Dealing with inexact information**

In real world, we have the experience that sometimes either we have no knowledge about an object or we have some incomplete, fuzzy or uncertain knowledge about the object. But, one has to reason in this situation and has to reach a decision. For a medical domain this is more critical. An expert system should be capable of handling these inexact situations.

- **Transparency**

For firm identification and diagnosis as well as for further course of action(s), an expert may not be satisfied with the decision only offered by an expert system. He/she may demand the total reasoning path traversed by the system, for their mental satisfaction. Generally, 'HOW' and 'WHAT IF' types of transparency are expected. So, an explanation tracing procedure should be there, as a module, with the system. This particular feature should assist them to view the chain of reasoning leading to a conclusion. This chain of reasoning should certainly support for further analysis and control planning. This chain of reasoning should also be useful to non-monotonic reasoning issue.

- **Learning facility with a dynamic knowledge base**

It may be useful to remember the results or facts of at least one previous consultation session for better comparison, especially for the healthcare field. It is true that the deficiency in growth and development should be estimated in comparison with a set standard i.e. milestones what are stored in static part of knowledge base. But, however, it should also be useful to estimate the increment/decrement of growth parameters in comparison with the previous consultation session. This should give us an idea about the parameters which need more attention. This is essentially a learning facility with the system. This facility may be achieved with a dynamic knowledge base. We call this dynamic portion of knowledge base as short-term knowledge base (STKB). This STKB may also help to achieve 'improved backtracking' compared to 'blind or chronological backtracking'. This STKB, we observe, may also play an active role on non-monotonic reasoning.

- **Structured and modular data structure**

Let us now identify some key requirements of the domain in connection with its knowledge representation where structuredness and modularity are demanded for:

Managing a large and varied knowledge base

The domain knowledge size is significantly large and varied. In this situation, the knowledge can become unmanageable. To make it manageable, it will be worthwhile to use structured and modular data structure for knowledge representation.

Avoiding redundancy and thereby removing inconsistency

Any component of knowledge is expected not to be duplicated in a knowledge base either in the design phase or in the implementation phase. This redundant information requires more space and also leads to inconsistency problem during upgradation of knowledge. Using a structured and modular data structure one can avoid this redundancy problem.

High level of abstraction

An abstraction is a way of representing a group of related things by a single thing which expresses their similarities and suppresses their differences. For the present domain, the level of abstraction is expected to be high for the ease of proper identification and diagnosis from a large and varied knowledge base. A high level of abstraction may be achieved using an equally highly structured and modular data structure for knowledge representation.

In chapter 5, a detail discussion has been provided on the knowledge representations schemes along with their relative merits and demerits.

4.5. Discussions

After a brief introduction to expert systems technology, categories and application areas of expert systems with some examples have been provided. Components of a typical expert system, typical features of an expert system, major stages of expert system development have been provided in brief. Then we have discussed the types of expert systems with a note on the recent trends of the technology.

Case-based and/or model-based reasoning are preferred by some researchers in some domains (e.g. medical, agricultural etc.). For the generation of more intelligent decision making systems some researchers propose fuzzy systems, some propose neuro-fuzzy models, some propose knowledge-based networks model and some propose connectionist model. They have their relative merits and demerits. A comparative study of the various methodologies has been provided in tabular form.

In our present study we have explored the development of a rule based object-oriented knowledge based system for the peadiatric healthcare domain and as well as case-based reasoning for the development of our models for case-based learning and case-based classifier approach.

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