ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF INFORMATION SCIENCE

DEVELOPING A KNOWLEDGE BASED SYSTEM FOR COFFEE DISEASE DIAGNOSIS AND TREATMENT

By

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Information Science

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ACRONYMS AND ABBREVATIONS

ADS	Automated decision support
AI	Artificial intelligence
CABI	CAB International
CBB	Coffee berry borer
CBD	Coffee berry disease,
CLR	Coffee leaf rust
CWD	Coffee wilt disease
ES	Expert system
ETB	Ethiopian birr
g	gram
GDP	Gross domestic production
ha	hectare
IAR	Institute of agricultural research
JARC	Jimma agricultural research center
KBS	Knowledge base system
KBSCDDT	Knowledge base system for coffee diseases diagnosis and treatment
KE	Knowledge engineer
Kg	kilo gram
KR	Knowledge representation
l/ L	liter

masl	Meter above sea level
ml	Milliliter
PROLOG	PROgramming in LOGic
USD	United states dollar
WM	Working memory

ABSTRACT

Arabica coffee (Coffea arabica L.) is the most important cash crop that has been contributing a great share to the Ethiopian economy. Although, it plays a significant role in the economy of the country, the crop suffers from many production constraints like diseases and pests. Detecting those diseases and pests at early stages enable us to overcome and treat them appropriately. This process requires an expert to identify the disease and pests, describe the methods of treatment and protection, but the expert is not always available to be referred. Expert systems help a great deal in identifying those diseases and pests and describing methods of treatment to be carried out. By taking into account such advantages of expert systems, this paper presents a knowledge based system (KBS) in the area of agriculture and describes the design and the development of the rule based system, using prolog programming language. It focuses on the development of KBS for coffee disease and pest control where it is intended for the diagnosis of common diseases and pests occurring in the coffee plant. An expert system is a computer program normally composed of a knowledge base, inference engine and user interface and the proposed system basically composed of these components. The system integrates a structured knowledge base that contains knowledge about symptoms and medication of diseases and pests in the coffee plant appearing during their life span. Agricultural officers and planters who involve directly with coffee plantation may use this system as an assistant for helping them in managing the crop activities especially in diseases and pest control. For development purposes, knowledge engineering methodology was selected as a guide. Perhaps, this system may become the most popular alternative for performing and work as an assistant to produce a better quality of coffee product. The system was evaluated using visual interactive method; it was shown that the system agreed with human expert opinions in 83.6 percent of the decision.

CHAPTR ONE

INTRODUCTION

1.1. Background of the Study

Ethiopia is gifted with enormous biodiversity and diverse agro ecologies. In particular, the country is home, primary origin and diversity of many plants. Among all, Arabica coffee (Coffea arabica L.,) is the greatest gift of the country in which it has economical, social and environmental importance. Ethiopia is the center of origin and diversity of Arabica coffee, which is a stimulant beverage crop, and belongs to the family Rubiaceae and the genus *Coffea* (Getu, 2011). There are different types of coffee in the world. Among these, the major economic species are coffee Arabica and coffee Robusta. Arabica accounts 80% of the world coffee trade, and Robusta most of the remaining 20%. Coffee Liberica and Excelsa together supply less than 1% (Habtamu, 2008).

As a commodity, coffee represents 1% of the total value of global imports and exports. A number of African countries are heavily dependent on coffee as a source of foreign exchange earnings and government income through taxation. Coffee also provides employment through cultivation, processing, marketing, transportation, and exportation of the crop. It constitutes a cash crop of fundamental importance to the livelihoods of millions of resource poor farmers across the continent, many relying on coffee as their only source of income (Rutherford, 2006).

Ethiopian economy is highly dependent on agriculture. Among the agricultural production, coffee sub-sector plays a major role in the economy of the country. It is the biggest source of foreign currency earning and has a major contribution to Gross Domestic Product (GDP)(Habtamu, 2008). Coffee is not only one of the highly preferred international beverages, but also one of the most important trade commodities in the world next to petroleum and nowadays its use as input in some food processing industries is increasing, for instance, it is used as a flavoring to various pastries, ice-creams, chocolate, canddies etc. (Arega, 2006 and Habtamu, 2008).

Coffee production systems in Ethiopia are grouped into four broad categories namely, forest coffee, semi-forest coffee, garden coffee and coffee plantations. The most important cultivation areas are southwestern and southern Ethiopia. Ethiopia is the only country in the world where coffee grows wild as an understorey shrub or small tree in the Afromontane rainforests. It is believed that forests harbor a large genetic pool of arabica coffee that represents a potential source to develop the crop for the benefit of present and future human generations in the world (Tesfu, 2012).

Many abiotic and biotic factors are the major constraints of coffee production in the country, the most important of which are diseases caused by many etioletic agents, mainly the fungi and pests especially insect pests. The crop is prone to a number of diseases and insect pests that attack fruits, leaves, stems and roots, and reduce the yield and marketability. Major coffee diseases in Ethiopia are coffee berry disease (CBD), coffee wilt disease (CWD) and coffee leaf rust (CLR) (Hindorf and Omondi, 2011), and the insect pests are Antestia bug, Coffee blotch miner, Coffee berry borer (Fuad, 2010). The most important diseases both in severity and wide distribution are coffee berry disease (CBD) and coffee wilt disease (CWD). Coffee berry disease (CBD) is a disease caused by fungal pathogen, an anthracnose of green and ripe coffee berries. It is one of the three species of *Colletotrichum* that have been isolated from coffee berries, leaves and branches: and it is the top major disease of coffee in Ethiopia, which attack mainly the green berries of coffee. It was first observed in Ethiopia in 1971. Since then it spreads and found in all coffee producing areas in which it has been favored by favorable environmental conditions (Eshetu, 1997; Hindorf and Omondi, 2011). To manage these constraints basically chemical control, planting resistant cultivars, cultural control and biological Control are mostly practiced.

Agriculture requires information and application of knowledge from different interacting fields of science and engineering to make a suitable decision making that in turn depends on interplay of these data and knowledge. This needs agricultural specializations and technical awareness in farmer or a human expert to help the farmers in decision making (Abu-Naser *et al.,* 2008).

In agriculture, applications of expert system are mainly found in the area of diseases diagnosis and pest controls (Sarma *et al*., 2010). Knowledge-based systems are a branch of artificial intelligence which is a computer program that attempts to replicate the reasoning processes of a human expert. It can make decisions and recommendations and perform tasks based on user input. The expert`s knowledge is available when the human expert might not be and so that the knowledge can be available at all times and in many places, as necessary. Experiences showed that knowledge base system can be used as a tool to disseminate the available best ways to combat plant diseases. The suitability of this technology has been recognized and realized in the field of agriculture and a few successful expert systems have been developed (Abu-Naser *et al.*, 2008).

1.2. Statement of the Problem

Coffee is vital to the economy of East and Central Africa, providing a major source of foreign exchange earnings and, as a cash crop, supporting the livelihoods of millions involved in cultivation, processing, marketing, and export (Rutherford, 2006). Coffee is one of the most important commercial commodity and foreign currency earnings in more than 80 developing countries. The worldwide exports of Coffee currently go beyond 12 billion dollar, and the sector employs millions of people around the world (Getachew, 2010).

Ethiopia has served in the past and continues to serve as the source of several economically important cultivated crops around the world. Among these crops, the most important gift of Ethiopia is coffee known as *Coffea arabica* L., which had and still has a tremendous economic, social and spiritual impact on many people of different geographical locations, cultural backgrounds and psychological behaviors. Ethiopia is believed to be the country of origin of arabica coffee. Current contributions of coffee is more than 60% of the country's foreign exchange earnings, 6% of the GDP, 12% of the agricultural sector output, and 20% of the government revenues. Coffee also directly supports the livelihoods of more than 25 percent of the population, and is at the centre of social and family life About 55% of the production is exported and the rest is consumed locally (Arega, 2006; Tadesse and Feyera, 2008 and Getachew, 2010). Environmentally, the situation in Ethiopia is also unique, as coffee is still produced mainly in its natural habitat (María, 2008). However it is not free from disease and pest constraints and other factors that reduce its quality and productivity. In Ethiopia, coffee farmers are continuously threatened by a range of pest and disease problems. Such as coffee berry disease, coffee leaf rust and coffee wilt disease (tracheomycosis) can be very serious indeed and can have a major impact not only on individual farmers but on the economy of the country or regions heavily dependent on coffee for foreign exchange earnings. These reduce its production and productivity significantly (Hindorf and Omondi, 2011 and Tesfu, 2012). For instance the overall national average loss due to coffee berry disease is estimated to range 25-30%, which amounts to well over 600 million Ethiopian Birr (ETB) per annum and in high rainfall and high altitude areas, losses may reach up to 100% on individual (Arega, 2006).

Given the perennial nature of coffee, some pests and diseases are able to survive and multiply throughout the cropping season and are always present on the coffee crop, although their populations and hence their effect on the crop may vary through the year. Others may only visit and attack coffee during periods when conditions are favorable. Either way, the damage they cause and their impact on crop yield and quality can be considerable. Coffee berry borer, green scales, leaf rust and brown eye spot, however, will have more of a debilitating effect on plant growth, by causing defoliation and can seriously affect berry quality. Hence it is vital that farmers should aware about the threats presented by pests and diseases and appropriate steps that may be taken to manage them and prevent their occurrence (Fuad, 2010). Coffee disease can causes very heavy crop losses in arabica coffee if not conrolled. There may be a great danger for the coffee based industries and the people depending on them if the production of coffee fails due to unforeseen biological calamities such as outbreaks of diseases or pests (Arega, 2006).

Traditionally, samples of the diseased or infested crop are sent to extension services, and the diseases can be controlled by the use of resistant coffee varieties, spraying fungicides or by cultural practices, but the mailing and delivery processes are time consuming and lead to delays in implementing control recommendations and there is irrational use of fungicides among the farmers due to lack of adequate training and experience as well as limited number of coffee pathology section staffs. The information about the plant disease is only available from human expert, user need refer to the expert, but the number of expert is small (Eshetu, 1993).

Agricultural production has evolved into a complex business requiring the accumulation and integration of knowledge and information from many diverse sources. In order to remain competitive modern farmers often rely on agricultural specialists and advisors to have information for decision making (Prasad and Vinaya, 2006 and Sarma *et al.*, 2009).

Usually, human experts are needed to provide the diagnostic knowledge; however, in some areas, pest management experts are not readily available to carry out disease diagnosis or insect identification, even if available consultation may be very expensive. In order to alleviate this problem, knowledge base systems were identified as a powerful tool with extensive potential in agriculture. An expert system (ES) is a computer program that reasons with the knowledge of a specialist subject with a view to solving problems or giving advice. As the diagnosis may also be performed by an expert system, computer aided diagnoses could play an important role in speeding up disease and pest diagnosis and control. Such a system may completely fulfill a function that normally requires human expertise, or it may play the role of an assistant to a human decision maker (Mahamana *et al.*, 2003).

The less expert in agriculture can be replaced with expert system. User can refer to the expert system to get the information about the crop especially in diagnosing the disease and pests (Abu-Naser *et al.*, 2008). In addition, it is possible to store much of the information that an expert needs to make decisions and can make them on hand for others; therefore the notion of knowledge based agriculture has an adequate prospective to improve the agricultural production. The following are some of the expert systems developed in agricultural area and are well successful.

Riley *et al.* (2002) have developed an expert system for Plant disease diagnosis based on visual observations of symptoms expressed by the infected plant. EI-Dessoki *et al.* (1993) developed an integrated expert system for crop management of cucumber. Rajkishore *et al.* (2005) developed an expert system for the diagnosis of pests, diseases and disorders in Indian mango. Lopez-Morales *et al.* (2008) developed an integral intelligent system for the diagnosis and control of tomatoes diseases and pests in hydroponics greenhouses. Gonzalez-Andujaret (2008) developed an expert system for pests, diseases and weeds identification in olive crops. Abu-Naser and Fayyad (2008), developed an expert system for plant disease diagnosis. And in our country Bethlehem (2010) developed knowledge base system for pepper diseases diagnosis.

This indicates that in many countries today, farming has become technologically advanced and expert systems are widely used in the field of agriculture. In this way farmers can get experts opinion on their specific problems like selection of most suitable crop variety, diagnosis or identification of crop/livestock disorder, suggestion, and tactical decisions throughout production cycle from the expert system. Although many applications have been developed for crop production; disease and pest management abroad, in Ethiopia there are very few works done to design knowledge base system for agricultural sector. In this paper, a Knowledge Based System for Coffee Diseases Diagnosis and Treatment (KBSCDDT) is presented. The aim of this study was to elicit the knowledge of agricultural experts about coffee diseases and pests and come up with a knowledge base system prototype that enables coffee disease and pest identification and provide detail description, best recommended ways of treatments and how to prevent them.

Basically, in this study an attempt was made to answer the following research questions

- What are the common diseases and pests that attack coffee plant in Ethiopia?
- What looks like the availability of experts to combat these coffee constraints?
- What are the appropriate management techniques taken by experts to manage them?
- How to design KBS for coffee disease and pests diagnosis and treatment?
- How to acquire, model, represent, and implement KBS prototype for coffee constraints?
- How to evaluate the performance of KBS prototype developed for KBSCDDT?

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this research is to develop a prototype knowledge based system for coffee diseases and pests diagnosis and treatment in order to provide better information for non experts (farmers), directly or indirectly, about major pests and diseases that threaten coffee production in Ethiopia, especially at places where there are less number of experts to assist them and, as a consequence, to empower them to take actions on the constraints occurred as required.

1.3.2. Specific objectives

The specific objectives of the study are the following:

- To review literature in order to have an understanding on concepts, principles and technologies of knowledge base systems.

- To acquire the necessary tacit and explicit knowledge about major coffee diseases and pests from primary and secondary sources using interview, detailed discussion with domain experts and document analysis.
- To analyze and model the domain knowledge used in the real life
- To develop a knowledge base that consist information about common disease and pests that attack coffee plant and to provide suggestion to control them.
- To develop prototype knowledge based system that demonstrates the capacity of knowledge based system for diagnosing and treating coffee diseases and pests.
- To test and evaluate the performance and user acceptance of the developed prototype.
- To forward recommendation and suggestion for future work in the application of knowledge base system in agricultural sector.

1.4. Methodology of the Study

In order to achieve the objectives of this research the following methods and techniques are employed.

1.4.1. Data collection method

In this study to acquire the desirable knowledge both secondary and primary (documented and undocumented) source of knowledge are used. Primary knowledge is gathered from agricultural specialists (such as plant pathologist and entomologist), in Jimma Agricultural Research Center (JARC) by using interviewing and critiquing knowledge elicitation methods. In the same way secondary source of knowledge are collected by using document analysis.

Both unstructured and structured interview were used to collect tacit knowledge from domain experts. In addition critiquing (analyzing) elicitation methods are used to purify the collected knowledge. The acquired knowledge is refined with the consultation of the expert. Moreover, secondary sources of knowledge are gathered from the internet, coffee diseases and pests guide lines, research papers and articles by using document analysis technique.

1.4.2. Sampling techniques and sample size

Purposive sampling technique is used to select domain experts for knowledge acquisition. The selection criteria of domain experts for the study are based on the profession or expertise, educational qualification level, year of experience and their immediate position in the coffee diseases diagnosis. Purposive sampling is one of the most common sampling techniques in qualitative research in which participants are decided to preselected criteria relevant to a particular research question (Mack *et al*., 2005).

At the beginning, to get some interview about coffee disease and pests unstructured interviews were conducted with four experts who include plant pathology and entomology. Among these two experts were selected purposely for detail discussions using structured interview to discover relevant tacit knowledge and for further consultations throughout the study these experts were selected based on their professional and specialization.

1.4.3. Knowledge representation methods

After the knowledge is acquired it is represented using rule based knowledge representation method. For this research the knowledge representation method, rule based is chosen because it clearly demonstrates the domain knowledge. In a rule based system much of the knowledge is represented as a rule that is as conditional sentences relating statements of facts with one another. Most plant disease is predefined sets of rules. There are already defined sets of symptoms that enable to identify the infection. As a result rule based representation method is more appropriate to represent and demonstrate the real domain knowledge in diagnosing coffee infections. Additionally, rule based systems are the most commonly used knowledge representation language in agriculture.

1.4.4. Implementation tools

Prolog programming language is used to develop the prototype knowledge based system. Prolog (programming in logic) is one of the most widely used programming language, especially in the artificial intelligence research, natural language processing, system development and so on. It is very useful especially on those mentioned areas to specify the situation (rule and facts) and the goal (query). The reason of the selection of this programming language is the features and abilities of the language that incorporate it. Prolog is a declarative language (we specify what problem we want to solve rather than how to solve it) and has the capacity to describe the real world. In addition

- ✓ It is easy to learn the design tools
- ✓ It has rule based programming and built in pattern matching features

- ✓ It has comprehensive help system on each feature and
- ✓ It is readable code that will also make updating of the system a relatively manageable task.

SWI prolog is the most inclusive and widely used prolog development environment. It has flexible and fast interface. In addition it is portable to many platforms including almost all UNIX/LINIX platform and window vista. Additionally it is non commercial version of prolog. So it can be easily accessed. Therefore the prototype knowledge based system is developed in SWI-Prolog (Multi-threaded, Version 5.4.5)

1.4.5. Testing and evaluation

The developed prototype rule based system is tested and evaluated to ensure the performance of the system in meeting towards established objectives. The evaluation process is more concerned with system user acceptance validations of the prototype. User acceptance efforts are concerned with issues impacting how well the system addresses the need of the user. To assess human factors visual interaction together with questionnaires methods are used. Domain expert evaluators interact with the system by using appropriate cases. Then they evaluated the system by using closed ended questionnaires.

1.5. Scope and Limitation of the Study

The scope of this study was developing prototype knowledge base system and evaluating its application for coffee diseases and pests identification for the selected constraints found in Ethiopia. There are about 47 coffee pest species and many coffee diseases in Ethiopia. But the study makes reference to six pests and four diseases constraints, selected for inclusion on the basis of those identified and prioritized by participants (experts) at Jimma Agricultural Research center (JARC). Almost all of the major constraints identified at the research center are covered. These are supported by the symptoms they induce on coffee and physical appearance (shape, color) and feeding habitat of the pests. Detailed descriptions of the relevant fungal and insect organisms, treatments and preventions are also provided. Most of the constraints of coffee are rarely incidence in the country which led to incomplete information to deal with them, consequently the researcher unable to accommodate more pest species and disease in this study. This work mainly dealt with the most important selected disease and pests in the country. The selection depends on the most important diseases and pests and this has been done with the experts. Once a prototype system is developed and tested for its application it will be simple task to include all coffee disease and pests if their complete information is available.

The task involved in conducting this work includes literature review, problem identification, knowledge acquisition, modeling, representation and implementation or encoding. The prototype is consists of knowledge base, inference engine, user interface, explanation facility and rule based reasoning mechanism. Even though the prototype includes all these components this system has limitation in automatic updation of the knowledge base by the user when the new diseases and pests are introduced, that is due to time limitation the learning component of the knowledge base is not developed in this study.

1.6. Significance and Beneficiaries of the Research

The substantial significance of the study is to better inform farmers, directly or indirectly, about major pests and diseases that threaten coffee production in Ethiopia around there is less number of experts to help them and, as a consequence, to better empower them to take action as required. The system has been produced in a user friendly format and principally to meet the needs of service providers, including agricultural extension. However, it may also be suitable for direct consultation by some farmers.

Where possible, an integrated approach to pest and disease management, involving use of a combination of cultural, biological and chemical measures should be considered and followed. The study tried to explore such management practices and provide best recommended approaches or combination of them. Such an approach has advantages in terms of, for example: avoiding or minimizing use of chemical pesticides that are often costly and also damaging to other organisms, man and the environment; promoting crop growth and vigor, thereby helping plants to tolerate pest damage and fight off infections; and helping to maintain biodiversity and utilize natural organisms against those organisms responsible for pest and disease outbreaks. For each pest and disease included in the study, the various management measures known are addressed in order to facilitate development of an integrated approach. Where appropriate, control measures recommended by the experts are incorporated.

In general the research was carried out to:

- Benefit farmers by making easy and timely access to diseases identification and diagnosis knowledge. Access to the right information will help the farmers to effectively combat yeild loss due to diseases will be reduced and this in turn increases their income. Non expert can help farmers to identify and dignosis coffee disease and pests.
- Increase yield production throughout the country and increase Ethiopia's share in the global coffee market.
- To help non expert in diseases and pests identification and diagnosis work. Non expert can improve their knowledge and be effective in coffee diseases and pests indentification and diagnosis work as expert knowledge is readily available.
- Knowledge base system proffesionals can use the system as a base to conduct further research in the agricultural area. Agriculture is the base on which Ethiopia's economy is built. Loss of yield means a lot to a country. But as a matter of fact significant yield loss occurs due to crop diseases and lack of knowledge by farmers on effective ways to combat the diseases. Hence information science researchers can use this system as a reference to build similar works on other crops.
- The researcher benefited from this research by gaining hands on experience in knowledge base system development. Beside the researcher gained experience in research planning and design.

1.7. Organization of the Thesis

The remaining part of the thesis is organized as follows:

Literature Review (Chapter Two) – In this chapter, conceptualizing the basic ideas of knowledge based system is essential to understand sufficiently the notion of knowledge based systems. So this chapter attempts to give some overview, of knowledge based systems, state the merits of knowledge based systems, explore the applicability of knowledge based systems, assess the architecture of knowledge based systems and discusses the knowledge based system development phases and as well as the basics of coffee and its diseases and pests in Ethiopia.

Methodology of the study (Chapter Three) - In this chapter, the methodology used to carry out the research is discussed. The knowledge engineering methodologies, how knowledge for the research is acquired, modeled and verified is provided in detail. The development life cycle used in the research are explained.

Knowledge Base System Development (Chapter four)- In this chapter, the knowledge acquisition procedures followed are explained. The represented and implemented knowledge in the computer system is shown. Decision tree was employed to show the generic representation of the system and detailed knowledge representation was presented using IF_THEN representation technique; and chapter five of the study summarizes the basic concepts discussed in the entire body of the research and it forwards some future directions on top of this study.

CHAPTER TWO

LITERATURE REVIEW

2.1. An Overview of Knowledge Based Systems

2.1.1. Introduction

Conceptualizing the basic ideas of knowledge based system is essential to understand sufficiently the notion of KBS. So this chapter attempts to give some over view of knowledge based systems, its merits, applicability, architecture and development phases are included. In addition in this chapter history of coffee, its economic importance, its constraints (most important disease and pests) are discussed.

2.1.2. Definition of knowledge base system

Knowledge based systems are a branch of artificial intelligence, which is a computer program that attempts to replicate the reasoning processes of a human expert and it can make decisions and recommendations and perform tasks based on user input. Artificial Intelligence is all about how to make the system think, or act like human. The expert`s knowledge is available when the human expert might not be and so that the knowledge can be available at all times and in many places, as necessary. Expert systems derive their input for decision making from prompts at the user interface, or from data files stored on the computer **(**Mahamana *et al.*, 2003; Prasad and Vinaya, 2006 and Abu-Naser *et al.,* 2008).

The primary intent of expert system technology is to realize the integration of human expertise into computer processes. This integration not only helps to preserve the human expertise but also allows humans to be freed from performing the more routine activities that might be associated with interactions with a computer-based system. There exist a number of different definitions for a knowledge based system, but in this study the definition discussed by (Brown and Pomykalski, 1995) reviewed and presented as follow because it seems more detail and create the overall understanding of KBS definition.

An expert/knowledge based system is a computer program that is designed to mimic the decision making ability of the decision makers/experts in a particular narrow domain of expertise. In order to fully understand and appreciate the meaning and nature of this definition, four major component pieces are highlighted in detail as follow.

Knowledge based system is a computer program: A computer program is a piece of software, written by a "programmer" as a solution to some particular problem or client need. Because knowledge based systems are software products they inherit all of the problems associated with any piece of computer software.

Knowledge based system is designed to mimic the decision making ability: The specific task of a knowledge based system is to be an alternative source of decision making ability for organizations to use; instead of relying on the expertise of just one or a handful of people qualified to make a particular decision. KBS attempts to capture the reasoning of a particular person for a specific problem. Usually this system is designed and developed to capture the scarce, but critical decision making that occurs in many organizations. It is often feared to be replacements for decision makers, however, in many organizations; these systems are used to free up the decision maker to address more complex and important issues facing the organization.

Knowledge based system uses decision makers (experts): Webster's dictionary (Merriam-Webster Collegiate Dictionary, 10th Edition, 1943) defines an expert as "One with the special skill or mastery of a particular subject." The focal point in the development of KBS is to acquire and represent the knowledge and experience of a person(s) who have been identified as possessing the special skill or mastery.

Knowledge based system is created to solve problems in a particular narrow domain of expertise: Some of the most successful development efforts of KBS have been in domains that are well scoped and have clear boundaries.

2.1.3. History of knowledge based systems

Next the history of KBS will be briefly discussed. In this discussion, its historical place within the Artificial Intelligence area and highlight some of the early, significant of expert system development are included.

In the late 1960's to early 1970's, expert systems began to emerge as a branch of Artificial Intelligence. The intellectual roots of expert systems can be found in the ambitions of Artificial Intelligence to develop “thinking computers”. Domain specific knowledge was used as a basis for the development of the first intelligent systems in various domains.

In order to discuss the history of this system a brief history of the Artificial Intelligence field is necessary. Knowledge-based systems were the first major successful application technology to evolve from Artificial Intelligence research. The foundations of the field of Artificial Intelligence can be traced from many different disciplines including philosophy, mathematics, psychology, computer engineering, and linguistics (Russell and Norvig, 1995).

The first cited work in the area of Artificial Intelligence dates back to McCulloch and Pitts (McCulloch and Pitts, 1943) in 1943. They proposed a model of artificial neurons that mimic the structure of the human brain; this area later became the connectionist paradigm. In the summer of 1956, McCarthy organized a two month workshop at Dartmouth and 10 leading U.S. researchers interested in automata theory, neural networks, and the study of intelligence were invited. Two researchers from Carnegie Tech (now known as Carnegie Mellon University), Newell and Simon were the focus of the workshop due to their reasoning program known as the Logic Theorist (LT). Simon claimed “we have invented a computer program capable of thinking none numerically, and thereby solved the venerable mind body problem.” An interesting note is that a paper on the use of LT to prove the theorems was rejected by The Journal of Symbolic Logic. The Dartmouth workshop accomplished two major outcomes. First, it served as a forum to introduce the leading researchers to each other; for the next twenty years, the field of AI would be dominated by these ten individuals, their students, and colleagues at MIT, CMU, Stanford, and IBM. The second major accomplishment of the workshop and a more lasting one was an agreement to adopt McCarthy’s new name for the field: Artificial Intelligence (Russell and Norvig, 1995).

The work of Newell and Simon is the first documented work using the symbolic programming paradigm of AI. Their work on LT led them to develop another program known as general Problem Solver (GPS). The success of GPS was not as widely heralded however because of the limited class of problems that it could solve. GPS was designed from the start to imitate human problem solving protocols regardless of the information contained in the domain.

Researchers then took the opposite approach in the development of the DENDRAL program (Lindsay *et al.*, 1980). They applied the knowledge of analytical chemists to infer the molecular structure from the information provided by a mass spectrometer. DENDRAL holds a significant place in the history of expert/knowledge based systems because it was the first system to use the expertise of human problem solvers and translate that knowledge into a large numbers of special purpose rules, known as a rule based system (Pomykalski *et al.*, 1999).

2.1.4. Early significant of expert system

The work on DENDRAL leads to many others successful applications of this new technology known as expert systems. Feigenbaum and others at Stanford began the Heuristic Programming Project (HPP) to investigate other problem domains that could benefit from this new technology. The next major effort was in the area of medical diagnosis. Buchanan and Shortlife developed MYCIN to diagnose blood infections (Shortliffe, 1976; Buchanan and Shortliffe, 1985). Using about 450 rules, MYCIN was able to perform as well as some experts, and considerably better than some junior doctors were. MYCIN is one of the most widely known of all expert system applications developed. However, MYCIN is significant to the history of expert/knowledge-based systems for two particular reasons. First, unlike DENDRAL, which used a model of a particular molecule as the basis for its reasoning, MYCIN was constructed from interviews with various doctors in the particular domain. Therefore, MYCIN contains a number of heuristic rules that are used by physicians in the identification of certain infections. The second major contribution of MYCIN was the later development of EMYCIN (Empty MYCIN). EMYCIN was the first expert/knowledge-based system shell. It took approximately 20 years to develop the MYCIN program. The researchers realized that if expert systems were to become a viable problem solving technique this development time must be cut. In an effort to do reduce the time to develop an expert system the researchers developed EMYCIN by taking all of the rules out of the system and leaving just an empty "shell" in which other developers in other domains could then just "plug-in" their new knowledge base (Pomykalski *et al.,* 1999).

There were other significant expert system applications that were also developed in the early days of expert systems. These systems include PUFF, which used EMYCIN in the domain of pulmonary disorders, DELTA/CATS, which was developed at General Electric Company to assist railroad personnel in the maintenance of GE's diesel electric locomotives (Ignizio, 1991). Also at this time, researchers at CMU developed the first truly successful commercial application of expert systems. The system, developed for Digital Equipment Corporation (DEC), was used for computer configuration and known as XCON (R1). XCON, originally titled R1, was developed by John McDermott at CMU for aiding in the configuration of VAX and PDP-11 computer systems at DEC. There exist an enormous number of configurations for VAX and PDP-11 computer system DEC attempts to configure each system to meet specific customer needs. XCON was originally developed as a 500-rule prototype that examined the specific needs of the customer and decided the exact configuration of components necessary to meet the customer requirements. In particular, XCON's function was to select and arrange the components of a computer systems including: the CPU, the memory, the terminals, the tape and disk drives, and any other peripherals attached to the system. XCON works with a large database of computer components and its rules determine what makes a complete order (Pomykalski *et al.,* 1999).

2.1.5. Components of a knowledge base system

The three major components of Expert system are: Knowledge base (KB), inference engine (IE), and user interface (UI). For better interaction with users an ES should preferably contain an explanation subsystem component or justifier. The knowledge engineer converts experts' knowledge into a form that can be manipulated by computer software. This knowledge is then stored in a knowledge base. The user provides information about a specific problem via a user interface. The inference engine uses the knowledge provided to come to some conclusions and/or give advice about the specific problem (Warren, 1999).

2.1.5.1. The knowledge base

The knowledge base is the core component of any expert system. It contains knowledge acquired from the domain expert (Khan *et al.,* 2008). In rule based expert systems the knowledge base is modeled to include two components: rule base of heuristic rules that are used to solve specific problems in a particular domain, and facts. A rule is a conditional statement that links given conditions to actions or outcomes. A knowledge base can combine the knowledge of multiple human experts (Abraham, 2005). It represents the repository of knowledge for specific and narrow domain for the knowledge based system. So, the most important part of knowledge based system is the knowledge base and the power of any knowledge based system and Expert System inherently in the adequate and integration of knowledge representation forms used for the particular domain. In this sense, the most important phase, in building knowledge based system, is the building of the knowledge base; this process is part of knowledge engineering which is an important field at present century (Owaied and Moh'd Qasem, 2010).

2.1.5.2. The inference engine

The inference engine is the component that provides a methodology for reasoning and formulating conclusions. The inference engine provides directions about how to use the system's knowledge to solve problems (Ayman Al Ahmar, 2010). The purpose of the inference engine is to seek information and relationships from the knowledge base and to provide answers, predictions, and suggestions in the way a human expert would. The inference engine must find the right facts, interpretations, and rules and assembles them correctly. There are two broad kinds of inference engines used in rule-based systems: forward chaining and backward chaining systems. A rule-based system consists of if-then rules, a bunch of facts, and an interpreter controlling the application of the rules, given the facts. These if-then rule statements are used to formulate the conditional statements that comprise the complete knowledge base. A single if-then rule assumes the form 'if x is A then y is B' and the if-part of the rule 'x is A 'is called the antecedent or premise, while the then-part of the rule 'y is B' is called the consequent or conclusion.

Forward chaining starts with the facts and works forward to the conclusions. In a forward chaining system, the initial facts are processed first, and keep using the rules to draw new conclusions given those facts.

Backward chaining is the process of starting with conclusions and working backward to the supporting facts. In a backward chaining system, the hypothesis (or solution/goal) we are trying to reach is processed first, and keep looking for rules that would allow concluding that hypothesis. As the processing progresses, new sub-goals are also set for validation. Forward chaining systems are primarily data driven, while backward chaining systems are goal-driven (Abraham, 2005).

To arrive at conclusions about a problem, the inference engine must search for a solution in an efficient and effective manner. Forward chaining allows the knowledge engineer to use rules to develop information from a limited set of initial data. Backward chaining starts with a goal and works backward to check data and constraints to determine if the goal is feasible. In backward chaining, the inference engine identifies one or more hypotheses and begins searching for rules that contain the hypothesis as a consequent (i.e., concluding that the hypothesis is correct). For any such rule found, the inference engine tests the truth of the predicates (the if-clauses) of the rule. If the predicates are true, then the hypothesis is confirmed, and the inference engine moves on to the next hypothesis. If the truth of a predicate is unknown, the hypothesis that the unknown predicate is true is added to the inference engine's list of hypotheses to check. This initiates a search for rules with the new hypotheses as a consequent. This process forms a chain, linking rule predicates backward to consequents. This strategy is often used in selection or classification applications in which one item is to be selected from a fixed set of items (Abraham, 2005).

Both strategies will ultimately lead to a conclusion, but the efficiency of the search is dependent on the nature of the problem faced. A problem with few premises and many conclusions would generally be better off with a forward chaining strategy whereas a problem with many premises and few conclusions would normally do better with a backward chaining strategy. There are instances in which it would be wise to employ a combination of the two strategies (Ignizio, 1991). To determine when and where this is necessary, it is useful to structure the knowledge engineering process by diagramming system interdependencies, flow, and function (Plant and Stone, 1991 and Warren, 1999).

2.1.5.3. The explanation facility

Explanation subsystem helps in justification of ES conclusions by tracing conclusions to their sources and showing how was a certain conclusion reached. One of the key characteristics of an expert system is the explanation facility. With this capability, an expert system can explain how it arrives at its conclusions. The user can ask questions dealing with the what, how, and why aspects of a problem. The expert system will then provide the user with a trace of the consultation process, pointing out the key reasoning paths followed during the consultation. Sometimes an expert system is required to solve other problems, possibly not directly related to the specific problem at hand, but whose solution will have an impact on the total problem solving process. The explanation facility helps the expert system to clarify and justify why such a digression might be needed. (Ayman Al Ahmar, 2010). The explanation facility allows a user to understand how the expert system arrived at certain results (Abraham, 2005).

2.1.5.4. The user interface

The User Interface is one of the major components of an expert system which allows bi-directional communication between system and user is considered to be a critical part of the success of an expert system. The user interface consists of all screens of interaction between the user and the ES (Ayman Al Ahmar, 2010). The purpose of the user interface is to ease use of the expert system for developers, users, and administrators (Abraham, 2005).

The input/output interface defines the way in which the expert system interacts with the user and other systems. Interfaces are usually graphical with screen displays, windowing, and mouse control. They receive input from the user and display output to the user. Some systems use natural language front ends that accept English-like responses but most use a graphical user interface (GUI) with a mouse device to allow the user to choose from selections in dialog boxes and menu bars (Warren, 1999). All these components come together and form knowledge base system architecture. The following figure, taken from Angeli (2010), displays the architecture commonly associated with knowledge based system.

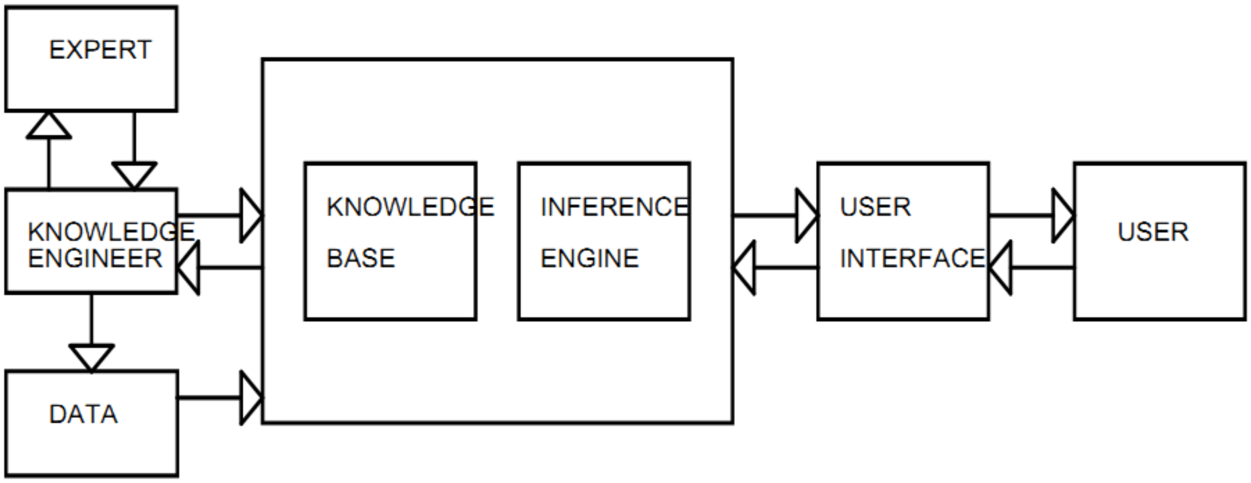


Figure 2.1 Basic Architecture of a rule-based expert system (Angeli, 2010).

2.1.6. Knowledge base system development procedures

Steps in the expert systems development process include determining the actual requirements, knowledge acquisition, constructing expert system components, implementing results, and maintenance. In order to develop an expert system the knowledge has to be extracted from domain expert. This knowledge is then converted into a computer program. Knowledge Engineer performs the task of extracting the knowledge from the domain expert. Rule based expert systems are the most commonly known type of knowledge based systems. The knowledge of the expert(s) is stored in his/her mind in a very abstract way. Also every expert may not be familiar with knowledge-based systems terminology and the way to develop an intelligent system. The Knowledge Engineer (KE) is responsible person to acquire, transfer and represent the experts' knowledge in form of computer system. People, Experts, Teachers, Students and Testers are the main users' groups of knowledge based systems (Sajja and Akerkar, 2010).

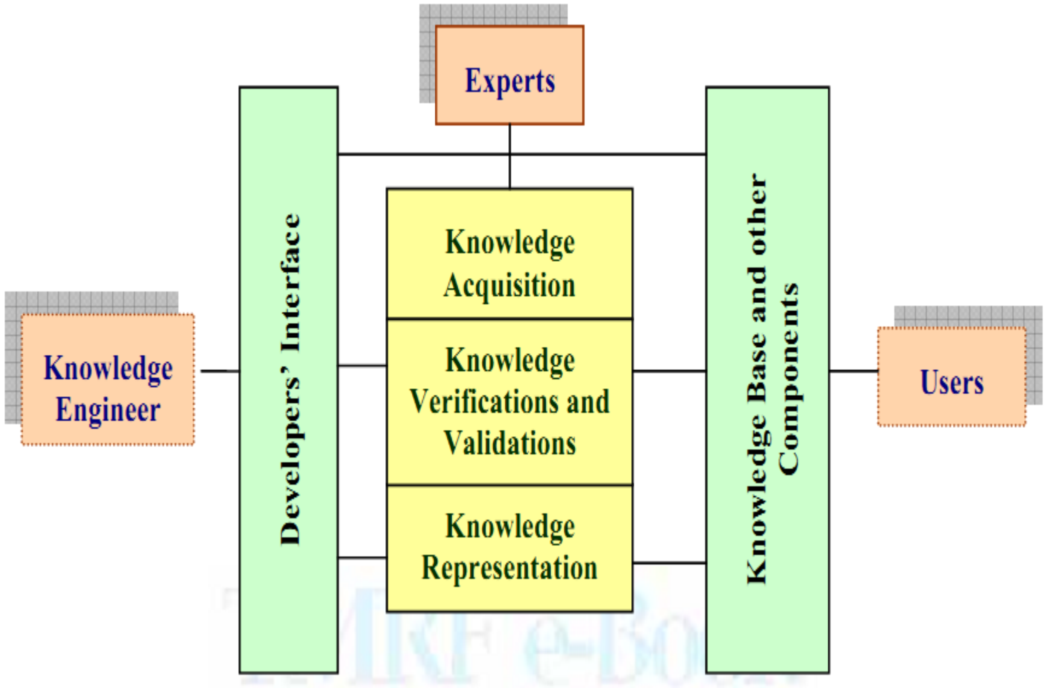


Figure 2.2 Development of a Knowledge Based System (Sajja and Akerkar, 2010)

2.1.6.1. Knowledge acquisition

The first task in the development of knowledge base is knowledge acquisition. Knowledge acquisition is considered as one of the most important phases in the expert system development life cycle. Knowledge acquisition is to obtain facts and rules from the domain expert so that the system can draw expert level conclusions. The process of knowledge acquisition is difficult especially in case if the knowledge engineer is unfamiliar with the domain. Knowledge acquisition is crucial for the success of an expert system and regarded as a bottleneck in the development of an expert system. The main reason for this bottleneck is communication difficulties between the knowledge engineer and the domain expert.

There exist several methods to extract human knowledge; some commonly used approaches of knowledge acquisition include interviews, questionnaires, record reviews and observation to acquire factual and explicit knowledge (Sajja and Akerkar, 2010). Knowledge acquisition is comprised of two tasks: knowledge elicitation and knowledge representation. In knowledge elicitation, domain knowledge is obtained through various means including interviews with experts and book and journal references. In knowledge representation, the elicited knowledge is converted to a form for efficient computer manipulation (Nikolopoulos, 1997).

Knowledge in its primary form can be obtained from four sources: literature, human specialists, existing models, and examples (Sell, 1985). Methods of collecting, organizing, and formalizing knowledge are many and vary widely depending on the source. When knowledge is extracted from human specialists, the acquisition process is often called knowledge elicitation. The job of knowledge elicitation from human experts can be very difficult due to the inexplicit nature of human knowledge (Schmoldt and Rauscher, 1996). There is no universal agreement on which knowledge elicitation technique to use when. It is most common to start with interviews and then use other methods when considered useful. The knowledge engineer must be versatile and willing to weigh the various methods in order to please the experts and elicit the most information (Hart, 1992).

Acquisition methods or techniques are often incorporated into knowledge acquisition strategies. These strategies usually fall into one of two categories: manual or automated. Automated methods are driven by computer programs and may include machine learning or automated interviews. Manual methods may include fast prototyping, evolutionary acquisition, ad hoc methods, and expert driven strategies. Selection of a strategy by the knowledge engineer will probably depend on human and financial resources, time availability, project complexity, and familiarity with available methods (Warren, 1999).

2.1.6.1.1. Knowledge acquisition tools

Many techniques have been developed to help elicit knowledge from an expert. These are referred to as knowledge elicitation or knowledge acquisition (KA) techniques. The knowledge acquisition phase requires a significant degree of interaction between the knowledge engineer and the specialist. During this phase, the knowledge engineer uses techniques and tools to elicit tacit knowledge from discipline specialists. A diversity of knowledge acquisition tools is presented in the Knowledge Acquisition Matrix (Emberey *et al*., 2007). The following list gives a brief introduction to the types of techniques used for acquiring, analyzing and modeling knowledge:

Interview is the most commonly used form of knowledge acquisition. It involves a direct dialog between the expert and the knowledge engineer. Information is collected with the aid of conventional instruments (e.g., tape recorders, questionnaires) and is subsequently transcribed, analyzed, and coded. The success of an interview session is dependent on the questions asked (it is difficult to know which questions should be asked, particularly if the interviewer is not familiar with the domain) and the ability of the expert to articulate their knowledge. The expert may not remember exactly how they perform a task, especially if it is one that they perform automatically". Some interview methods are used to build a particular type of model of the task. The model is built by the knowledge engineer based on information obtained during the interview and then reviewed with the domain expert. In some cases, the models can be built interactively with the expert, especially if there are software tools available for model creation. Interviews can be unstructured, semi-structured, or structured (Hudlicka, 1997).

A structured interview is a systematic, goal oriented process. It forces organized communication between the knowledge engineer and the expert. The structure reduces the interpretation problems inherent in unstructured interviews and allows the knowledge engineer to prevent the distortion caused by the subjectivity of the domain expert. Because every interview is different in very specific ways, it is difficult to provide comprehensive guidelines for the entire interview process. Therefore, interpersonal communication and analytic skills are important. However, several guidelines, check-lists, and instruments are available that are fairly generic in nature (McGraw and Harbison-Briggs, 1989).

Unstructured Interviews: Many knowledge acquisition interview sessions are conducted informally, usually as a starting point. Starting informally saves time; it helps to move quickly to the basic structure of the domain. Usually, it is followed by a formal technique. Unstructured interviewing seldom provides complete or well-organized descriptions of cognitive processes. There are several reasons for this: The domains are generally complex; the experts usually find it very difficult to express some of the most important elements of their knowledge; domain experts may interpret the lack of structure as implying that they need not prepare for the interview; data acquired from an unstructured interview are often unrelated, exist at varying levels of complexity, and are difficult for the knowledge engineer to review, interpret, and integrate; and few knowledge engineers have the training and experience to efficiently conduct an unstructured interview (Geiwitz, *et al.*, 1990).

Interviews are sometimes replaced by tracking methods. Alternatively, they can be used to supplement tracking or other knowledge acquisition methods. It is recommended that before interviewing the main experts, the knowledge engineer should interview a less knowledgeable or minor expert, using the interviewing approaches just described. This may help the knowledge engineer learn about the problem, its significance, the experts, and the users. The interviewer will also be able to better understand the basic terminology and (if he or she is a novice in the area) identify archived sources about the problem first. The knowledge engineer should next read about the problem. Then the main experts can be interviewed much more effectively.

Observations: Sometimes it is possible to observe an expert at work. In many ways, this is the most obvious and straightforward approach to knowledge acquisition. However, the difficulties involved should not be underestimated. For example, most experts advise several people and may work in several domains simultaneously. In this case, the knowledge engineer's observations will cover all the other activities as well. Therefore, large quantities of knowledge are being collected, of which only a little is useful. In particular, if recordings or videotapes are made, the cost of transcribing large amounts of knowledge should be carefully considered. Observations, which can be viewed as a special case of protocols, are of two types: motor movements and eye movements (Cordingley, 1989).

Protocols: Protocol analysis involves asking the expert to perform a task while "thinking aloud." The intent is to capture both the actions performed and the mental process used to determine these actions. As with all the direct methods, the success of the protocol analysis depends on the ability of the expert to describe why they are making their decision. In some cases, the expert may not remember why they do things a certain way. In many cases, the verbalized thoughts will only be a subset of the actual knowledge used to perform the task. For this method, the knowledge engineer interrupts the expert at critical points in the task to ask questions about why they performed a particular action.

For design, protocol analysis would involve asking the expert to perform the design task. This may or not be possible depending on what is being designed or the length of time normally required performing a design task. Interruption analysis would be useful in determining why subtasks are performed in a particular order (Ericsson and Simon, 1984). If time and resources were available, it would be interesting to perform protocol analysis of the same task using multiple experts noting any differences in ordering. This could obtain both alternative orderings and, after questioning the expert, the rationale for their decisions (Owen *et al.*, 2006).

Prototyping: In Prototyping, the expert is asked to evaluate a prototype of the proposed system being developed. This is usually done iteratively as the system is refined (Diaper, 1989).

Teach back: In Teach back, the knowledge engineer attempts to teach the information back to the expert, who then provides corrections and fills in gaps (Geiwitz, *et al.,* 1990)

Document Analysis: Document analysis involves gathering information from existing documentation. May or may not involve interaction with a human expert to confirm or add to this information (Cordingley, 1989).

2.1.6.2. Conceptual knowledge modeling

During the knowledge modeling phase, the specialist's knowledge (elicited by various techniques) is represented in a knowledge model. A knowledge model is a structured representation of knowledge using symbols to represent pieces of knowledge and the relationships between them. Knowledge models include symbolic character-based languages such as logic, diagrammatic representations such as networks and ladders, tabular representation such as matrices and structured text such as hypertext. The generation and modification cycle of a knowledge model is an essential part of the knowledge modeling phase. The model helps to ensure that all stakeholders in a project understand the language and terminology being used and quickly conveys information for validation and modification where necessary. The knowledge models are also of great value during cross-validation with other specialists (Emberey *et al.*, 2007). Models are used to capture the essential features of real systems by breaking them down into more manageable parts that are easy to understand and to manipulate. Models are very much associated with the domain they represent (Savolainen *et al.*, 1995). That domain will define their practicing communities, modeling languages and the associated tools used. "A model is a simplification of reality" (Booch *et al.,* 1999). Real systems are large entities consisting of interrelated components working together in a complex manner. Models help people to appreciate and understand such complexity by enabling them to look at each particular area of the system in turn. Models are used in systems development activities to draw the blueprints of the system and to facilitate communication between different people in the team at different levels of abstraction. People have different views of the system and models can help them understand these views in a unified manner.

The modeling process constructs conceptual models of knowledge intensive activities (Schreiber *et al.*, 1999). During the knowledge acquisition stage, most of the knowledge is unstructured and often in tacit form. The knowledge engineer will try to understand both the tacit and the explicit part of the knowledge and then use simple visual diagrams to stimulate discussion amongst users and knowledge experts. This discussion process generates ideas and insights as to how the knowledge is used, how decisions are made, and the factors that motivate and so on. The knowledge engineer then has to construct the conceptual model from what has been discussed during the knowledge acquisition stage. This communicates the knowledge to the information specialist who will transform the model into workable computer programs or codes. This approach is similar to that of software engineering where models are used to represent user requirements. The main difference here is that in knowledge engineering it is the modeling of knowledge and its related flows whereas software engineering models the information and process flow. The importance of knowledge modeling in knowledge management has been discussed by (Wielinga *et al.*, 1997). They argue that models are important for understanding the working mechanisms within a knowledge based system, such as: the tasks, methods, how knowledge is inferred, the domain knowledge and its schemas. Conceptual modeling is central to knowledge engineering (Schreiber *et al.*, 1999). Modeling contributes to the understanding of the source of knowledge, the inputs and outputs, the flow of knowledge and the identification of other variables such as the impact that management action has on the organizational knowledge (Davenport and Prusak, 2000).

As the paradigm has shifted from the transfer approach to the modeling approach, knowledge modeling has become an important aspect in the process of building knowledge base systems. With the modeling approach, systems development can be faster and more efficient through the reuse of existing models for different areas of the same domain. Therefore, understanding and selecting the modeling technique that is appropriate for different domains of knowledge will ensure the success of the knowledge base system being designed.

2.1.6.3. Knowledge representation

The acquired knowledge should be immediately documented in a knowledge representation scheme. In knowledge representation, the elicited knowledge is converted to a form for efficient computer manipulation. At this initial stage, the selected knowledge representation strategy might not be permanent. However documented knowledge will lead the knowledge engineer/ developer to better understanding of the system and provides guidelines to proceed further. Production Rules, frames, and semantic network are the typical examples of knowledge representation scheme. Some of them are described as follow:

a. **Production Rules-** Production rules are the most popular form of knowledge representation for ES and automated decision support (ADS) systems. Knowledge is represented in the form of condition/action pairs: IF this condition (or premise or antecedent) occurs, THEN some action (or result or conclusion or consequence) will (or should) occur. Each production rule in a knowledge base implements an autonomous chunk of expertise that can be developed and modified independently of other rules. When combined and fed to the inference engine, the set of rules behaves synergistically, yielding better results than the sum of the results of the individual rules (Sasikumar *et al.*, 2007).

   If-then rules are one of the most common forms of knowledge representation used in expert systems. Systems employing such rules as the major representation paradigm are called rule based systems. One of the first popular computational uses of rule based systems was the work by Newell and Simon on the General Problem Solver (Newell and Simon, 1972). A typical rule based system consists of three components (the working memory the rule base, and the inference engine), as presented in figure 2.3 below.

   The rule base and the working memory are the data structures which the system uses and the inference engine is the basic program which is used. The advantage of this framework is that there is a clear separation between the data (the knowledge about the domain) and the control (how the knowledge is to be used).

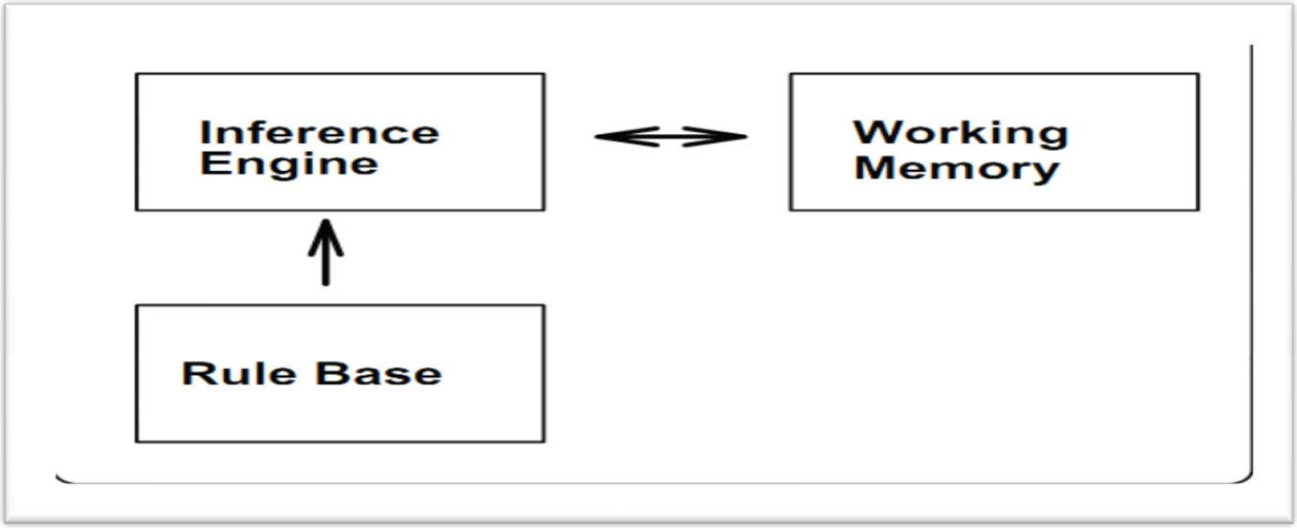


Figure 2.3 Components of a typical rule based system

The working memory (WM) represents the set of facts known about the domain. The elements reflect the current state of the world. In an expert system, the WM typically contains information about the particular instance of the problem being addressed. For example, in a medical expert system, the WM could contain the details of a particular patient being diagnosed. The working memory is the storage medium in a rule based system and helps the system focus its problem solving. It is also the means by which rules communicate with one another.

The actual data represented in the working memory depends on the type of application. The initial working memory, for instance, can contain a priori information known to the system. The inference engine uses this information in conjunction with the rules in the rule base to derive additional information about the problem being solved. The rule base (also called the knowledge base) is the set of rules which represents the knowledge about the domain. The conditions cond1, cond2, cond3, etc. (also known as antecedents) are evaluated based on what is currently known about the problem being solved (i.e., the contents of the working memory). Some systems would allow disjunctions in the antecedents. For example, rules like the following would be allowed.

If cond1

and cond2

or cond3

...

then action1, action2, ...

Such rules are interpreted to mean that if the antecedents of the rule together evaluate to true (i.e., if the Boolean combination of the conditions is true), the actions in the consequents (i.e., action1, action2, etc.) can be executed. Each antecedent of a rule typically checks if the particular problem instance satisfies some condition (Sasikumar *et al.,* 2007).

The consequents of a rule typically alter the WM, to incorporate the information obtained by application of the rule. This could mean adding more elements to the WM, modifying an existing WM element or even deleting WM elements. They could also include actions such as reading input from a user, printing messages. Sometimes the knowledge which is expressed in the form of rules is not known with certainty. In such cases, typically, a degree of certainty is attached to the rules.

The inference engine tries to derive new information about a given problem using the rules in the rule base and the situation speciation knowledge in the WM. Suppose the working memory contains the elements:

bird(crow)

bird(eagle)

aircraft(helicopter)

The action corresponding to a rule could be to add an element to the working memory, delete an element from the working memory or change an existing working memory element. It could also include some actions which do not affect the working memory, for instance printing out the value of a working memory element. Since ring a rule may modify the working memory, in the next cycle, some instantiations present earlier may no longer be applicable; instead, some new rules may be applicable. The most common strategies are: Forward Chaining and Backward Chaining. Systems can use either one of these strategies or a combination of both. Some systems allow users to specify which strategy they need for their application (Sasikumar *et al.,* 2007).

Advantages of Rule Based Systems

According to Alty (1987), some of the advantages of rule based systems are:

Homogeneity: Because of the uniform syntax, the meaning and interpretation of each rule can be easily analyzed.

Simplicity: Since the syntax is simple, it is easy to understand the meaning of rules. Domain experts can often understand the rules without an explicit translation. Rules therefore can be self-documenting to a good extent.

Independence: While adding new knowledge one need not be worried about where in the rule base the rule is added, or what the interactions with other rules are. In theory, each rule is an independent piece of knowledge about the domain.

Modularity: The independence of rules leads to modularity in the rule base. You can create a prototype system fairly quickly by creating a few rules. This can be improved by modifying the rules based on performance and adding new rules.

Knowledge is separated from use and control: The separation of the rule base from the inference engine separates the knowledge from how it is used to solve the problem. This means that the same inference engine can be used with different rule bases and a rule base can be used with different inference engines.

b. **Case based-** Case based reasoning is a process that uses similar problems to solve the current problem. It consists of two steps find those cases in memory that solved problems similar to the current problem, and adapt previous solutions to fit the current problem. The critical step is to find and retrieve a relevant case from the case library. Cases are stored using indexes. The stored case contains a solution, which is then adapted by modifying the parameters of the old problem to suit the new situation resulting in a proposed solution. The solution is tested and if found successful, added to the case library. Knowledge acquisition is easier in case-based reasoning because of the granularity of the knowledge. Knowledge is presented in precedent or resultant cases. Beyond the knowledge representation language (rules, semantic nets, frames, cases), the knowledge engineer needs further aids such as tools to edit the knowledge base; inference tracers to assist in error detection; and analytical tools to find, update and consistently check the represented knowledge or attributes (Klein & Methlie, 1995).

c. **Semantic networks-**Semantic networks focus on the relationships between different concepts. They are graphical depictions of knowledge composed of nodes and links that show hierarchical relationships between objects (Russell and Norvig, 2002). It is made up of a number of circles, or nodes, that represent objects and descriptive information about the objects.

An object can be any physical item, such as a book, a car, a desk, or even a person. Nodes can also be concepts, events, or actions. A concept might be the relationship between supply and demand in economics, an event such as a picnic or an election, or an action such as building a house or writing a book. Attributes of an object can also be used as nodes. These might represent size, color, class, age, origin, or other characteristics. In this way, detailed information about objects can be presented. Nodes are interconnected by links, or arcs, that show the relationships between the various objects and descriptive factors. Some of the most common arcs are of the IS-A or HAS-A type. IS-A is used to show a class relationship (i.e., that an object belongs to a larger class or category of objects). HAS-A links are used to identify characteristics or attributes of object nodes. Other arcs are used for definitional purposes.

d. **Frames-**If we need to focus on the properties of certain objects, then using frames and objects is a good choice. A frame is a data structure that includes all the knowledge about a particular object. This knowledge is organized in a special hierarchical structure that permits a diagnosis of knowledge independence. Frames are basically an application of object-oriented programming for artificial intelligence and ES. They Frames, as in frames of reference, provide a concise structural representation of knowledge in a natural manner. In contrast to other representation methods, with frames, the values that describe one object are grouped together into a single unit called a frame. Thus, a frame encompasses complex objects, entire situations, or a managerial problem as a single entity. The knowledge in a frame is partitioned into slots. A slot can describe declarative knowledge (e.g., the color of a car) or procedural knowledge (e.g., "activate a certain rule if a value exceeds a given level") (Fensel *et al.*, 1998 and Jackson, 1999).

e. **Decision tables-**Knowledge of relations can be represented in decision tables. In a decision table, knowledge is organized in a spreadsheet format, using columns and rows. The table is divided into two parts. First, a list of attributes is developed, and for each attribute, all possible values are listed. Then a list of conclusions is developed. Finally, the different configurations of attributes are matched against the conclusion. Knowledge for the table is collected in knowledge acquisition sessions. Once the table is constructed, the knowledge in the table can be used as input to other knowledge representation methods (Vadera, 2005).

f. **Decision trees-**Decision trees are related to decision tables and are popular in many places. They are composed of nodes representing goals and links representing decisions. The major advantage of decision trees is that they can simplify the knowledge acquisition process. Knowledge diagramming is often more natural to experts than formal representation methods Vadera, 2005). Decision trees can easily be converted to rules. The conversion can be performed automatically by a computer program. In fact, machine learning methods are capable of extracting decision trees automatically from textual sources and converting them to rule bases. It is responsibility of the knowledge engineer to select appropriate knowledge presentation scheme that is natural, efficient, transparent, and developer friendly and the degree of familiarity of the knowledge engineer with a technique. One may think for hybrid knowledge representation strategies (Sajja and Akerkar, 2010).

2.1.6.4. Implementation

Most expert systems are developed using specialized software tools called shells. These shells come equipped with an inference mechanism (backward chaining, forward chaining, or both), and require knowledge to be entered according to a specified format. One of the most popular shells widely used throughout the government, industry, and academia is the C LIPS. C LIPS is an expert system tool that provides a complete environment for the construction of rule and/or object based expert systems (Abraham, 2005).

2.1.6.5. System evaluation

Evaluation of expert systems is important part of the development cycle of an expert system. The evaluation of an expert system must address the justification for the employment of an expert system and the verification and validation of the knowledge base. In fact, these take a bulk of the development time for most typical domains. The first prototype of an expert system does not take much of the overall development time. However the first prototype often has problems like: the knowledge it has is incomplete or some of the knowledge is incorrect. If the system's knowledge is incomplete it may not be able to derive some Information it is expected to. It may also lead to incorrect conclusions. If the Knowledge is incorrect, the system could exhibit strange behavior {working for some cases and getting other cases totally wrong. Systematic verification and validation is then required in order to correct these problems. After you have corrected these problems in a rule base you may have to verify and validate the rule base again to see if there are any other problems. Therefore verification and validation are not just done once but have to be done more or less continuously after the first prototype of an expert system is developed (O'Keefe, *et al.*, 1987).

Verification refers to building the right system (that is, substantiating that a system performs with an acceptable level of accuracy), it is the process that should be implemented during system design and development to answer the question ‘Did we build the system correctly?’ verification checks whether the system has been developed according to its specification and confirms consistency, completeness and correctness of the system. Verification of an expert system deals with determining whether the system was developed correctly, that is, whether the system's knowledge satisfactorily represents the domain knowledge (Marcot, 1987).

Verifying an expert system is essentially verifying the knowledge which has been represented in the knowledge base of the expert system. We can normally assume that one is implementing an expert system on a well tested expert system shell. In that case the problem is normally because of the domain knowledge and not because of problems with the expert system shell. The type of problems which are common to rule based systems are: redundant, conflicting, subsumed and circular rules, unnecessary antecedents, unreferenced attribute values, illegal attribute values, unreachable conclusions and dead-end If conditions (Sasikumar *et al.*, 1988).

Validation is performed later to answer the question ‘Did we build the right system?’ Validation checks that the system performs the tasks for which it has been designed in the real working environment. Validation of expert systems deals with trying to determine whether the system does what it was intended to, and at an adequate level of accuracy. This is obviously related to refinement. While validating an expert system, if you find that it does not meet expectations, it has to be refined (Nikolopoulos, 1997).

There are several ways in which expert systems can be validated. Depending on the characteristics of the domain and the constraints the developer has, one or more of these methods may be chosen. In certain domains it is fairly straightforward to decide whether the conclusions which the expert system comes up with are correct or not. These domains include domains such as equipment fault diagnosis where you have defective equipment and can diagnose the fault using other methods. Other domains, where there are case histories giving previous cases with experts' conclusions on these cases, can also be validated using this information. In both these types of domains, the expert system can be validated by the expert system developer. An expert system can be validated by giving the same set of cases to the expert system and to a domain expert. The results of the expert system can then be compared with the domain expert to see if they agree or not. In cases where there is a disagreement, the domain expert could be asked to look at the reasoning which the expert system uses and point out any problems (Balci, and Smith, 1987 and Warren, 1999).

In domains where the domain experts normally agree, an expert system can be validated by allowing a number of experts to run the system through different cases and deciding whether the system comes to the same diagnosis as theirs', for the same input. The experts can also be asked to check the reasoning of the system and see if it is correct or not. The experts who are involved in validation should ideally not include any of the domain experts involved in the development of the expert system, to avoid any bias which may creep into the validation. In domains where the domain experts do not typically agree, the expert system can be validated against the domain expert who was involved in the development of the system. The domain expert can be asked to look at the rules which have been created and see if they correct respond to the knowledge he/she applies in that domain. The domain expert can also be asked to run test cases on the system to see whether it gives the desired results (Warren, 1999).

Field testing is a common method used for validating expert systems. By field testing it mean that the expert system should be put in real operating environment and its performance observed over a period of time. Based on these observations, one can find out whether the system is performing up to its expectations or not. In some domains, field testing may not be directly possible. In those cases, the system may be tested with real data in a lab. Finally one should remember that validation can never be perfect. Even if combinations of the techniques described above are used, there is still a chance that some problems may remain and turn up later. Validation however helps to reduce the number of such problems. The system test examines the complete system in its working environment. Validation is especially important for KBS (Verdaguer *et al.*, 1992).

Evaluation of human factor is the next phase of system evaluation. It answers the question: 'Will the system be accepted and used?' Even if a system has been verified and validated, it may be so awkwardly designed that it cannot be used in real life, because using the system is either too cumbersome or consumes too much time. To determine usefulness and usability, one must select appropriate quality indicators. Usefulness of a system is often measured by examining user satisfaction. User satisfaction has System dependent aspects, such as content satisfaction, interface satisfaction and organization satisfaction, but also system independent personal aspects such as individual dislike for computers (Ohmann *et al.*, 1997a).

Observation of the system and its users in their working environment and asking the users is the appropriate methodology for assessment of usefulness and usability. We can distinguish observation studies, log studies, reaction studies and interviews or questionnaires. In an observation study, an external observer will record critique, comments and recommendations of the user. In a log study one might want to check how often a certain part of the program has been used. In a reaction study, comments regarding the program are recorded directly, e.g. in an additional input window attached to the program. In a questionnaire study, the user is asked specific questions that serve as an indicator for usability. Questions may be either specific for the examined system or generic to assess the attitude of the users. To assess the latter, one can use evaluated questionnaire tools. A clear distinction between validation and human factor assessment is sometimes difficult. Both are tested in a realistic environment. However, validation focuses on the system, and human assessment focuses on the user (Ohmann *et al.*, 1997b).

The participant reaction is a measure of "customer satisfaction" indicating the level of effectiveness and usefulness of a system at the time the participants are experiencing it. It can be very useful for determining the quality of the developed system. The evaluation of participants' reaction could be very useful for the overall evaluation of the system for various reasons: It helps to know immediately what worked well and what should be improved (or changed all together), it provides information for improving the current system and designing future versions and it shows to the participants and stakeholders that are interested in improving their satisfaction with the course and that value their input (Dixon, 1990 and Le Rouzic & Cusic, 1998).

2.1.7. Knowledge base system development tools

A Knowledge Base System tool is a set of software instructions and utilities taken to be a software package designed to assist the development of knowledge-based systems. Personal computers, typical programming languages like java and framework like .NET can also be used in KBS development. These programming languages are general purpose and also being used to develop other application than AI applications. KBS shell with the readymade utilities of self learning; explanation and inference etc. like Java Expert System Shell (JESS), GURU, Vidwan are more specific and can also be useful to develop KBS. Tailor made KBS can be developed using programming languages like LISP and Prolog. McCarthy (1960) published a remarkable paper showing a handful of simple operators and a notation for functions, one can build a whole programming language. He called this language Lisp, for "List Processing," because one of his key ideas was to use a simple data structure called a list for both code and data. There are various versions of Lisp available namely KLISP and C Language Integrated Production System (CLIPS).

Prolog is a logic programming general purpose fifth generation (AI) language. It has a purely logical subset, called "pure Prolog", as well as a number of extra logical features. Prolog has its roots in formal logic, and unlike many other programming languages, Prolog is declarative. The program logic is expressed in terms of relations, and execution is triggered by running queries over these relations. The language was first conceived by a group around Alain Colmerauer in Marseille, France, in the early 1970s. According to Kowalski (1988), the first Prolog system was developed in 1972 by Alain Colmerauer and Phillipe Roussel. Packages software like MATLAB, Java Neural Network Simulator (Java NNS) etc. and markup open sources based tools like Artificial Intelligence Markup Language (AIML) and Project D (developed in AIML and open source) can also be used to develop KBS. Systems which work with multiple agents and intelligent agents may use Knowledge Query Manipulation Language (KQML) for agents' communication. Common KADS and Protégé also help in assisting KBS development process in user friendly way (Abraham, 2002).

According to Robertson & Kingston (1997), there are approximately 200 KBS tools. Alty (1989), groups the products into three main categories based primarily on functionality which also happen to differ markedly in the platforms on which they are available. These groups are (i) Shells, (ii) Languages, and (iii) Toolkits. Inference ART and KEE were among the first commercially successful toolkits to develop KBS. Besides support towards knowledge acquisition and representational features, there are other features like price, flexibility, ease of use, user friendliness and vendor availability and support, and documentation support from the tool need to be considered before final selection (Akerkar and Sajja, 2009).

2.1.8. Application area of knowledge based systems

Expert systems have applications in many domains. They are mostly suited in situations where the expert is not readily available. As Sajja & Akerkar (2010), stated knowledge based systems applications are divided into two broad categories namely:

i. Pure knowledge based systems applications

Pure applications include research contributing in knowledge based systems and AI development techniques such as knowledge acquisition, knowledge representation, models of automated knowledge based systems development (knowledge engineering approaches, models and CASE tools for KBS), knowledge discovery and knowledge management types of tools.

ii. KBS for integrated development

The Knowledge based systems can be used for interpretation, prediction, diagnosis, design, planning, monitoring, debugging, repair, instruction, and control. Such advanced technology should be made available in urban and rural areas to utilize expert knowledge for holistic development. Such systems export knowledge in underdeveloped and remote area where expertise is rare and costly. Hence, knowledge based systems KBS should be at the primary consideration while designing the development plan for a nation. The share of AI/KBS systems in IT is improved significantly. In addition, today's KBS are easier to use, less expensive and integrate well with traditional technologies, so it can provide a fundamental technology to the majority of the applications for today's scenario. According to Sajja & Akerkar (2010), some example of knowledge based system in different dimensions can be outlined as follows:

Physical development: KBS for infrastructural planning, Small scale industries like agribusiness and cooperatives, energy planning and reuse**,** e-governance**,** irrigation management and supervision, communication and transportation, public distribution services, Special programmers like drought prone area planning, forestry, natural resource management, land use and land reform, network monitoring systems, resources and material management, river and land use management, soil health card for villagers, intelligent manufacturing and new product development, geographic property identification and measuring, Robotics and fly/drive by wire vehicle system **,** Pilot training and space training through virtual reality, Publication and printing media KBSs, loan passing system, fault diagnostic system are application of KBS for physical development.

Economical development: Employment exchange services, market reforms/information systems, new product development advisory, business selection advisory, tax planning system, knowledge based planning of agricultural products, knowledge based planning for agricultural inputs, knowledge based diagnosis for plants and animal diseases**,** crop land pattern matching system for agriculture, intelligent manufacturing**,** matching buyers and sellers agent in e-commerce, embedded KBS in the devises like fuzzy washing machine, robotic and intelligent sensors in manufacturing, KBS for potential risk identification in investments, software/product quality management, are some application areas of KBS in economic development.

Social development: Cultural information, tourism portal**,** identity/ration card, voters identification and election related systems, intelligent system to identify suitable beneficiaries for government/NGO schemes, Child and women health/nutrition systems, community health, e-learning education and training systems, knowledge based examination planning system, games and entertainment KBS, Language translation and tutoring are some application areas of KBS in social development.

Health improvement: Government schemes information system, diet planning system**,** disease diagnostic system, disease diagnostic system for cattle and live stock, patient monitoring system medical insurance, KBS monitoring in surgical process, KBS for guided neurosurgery.

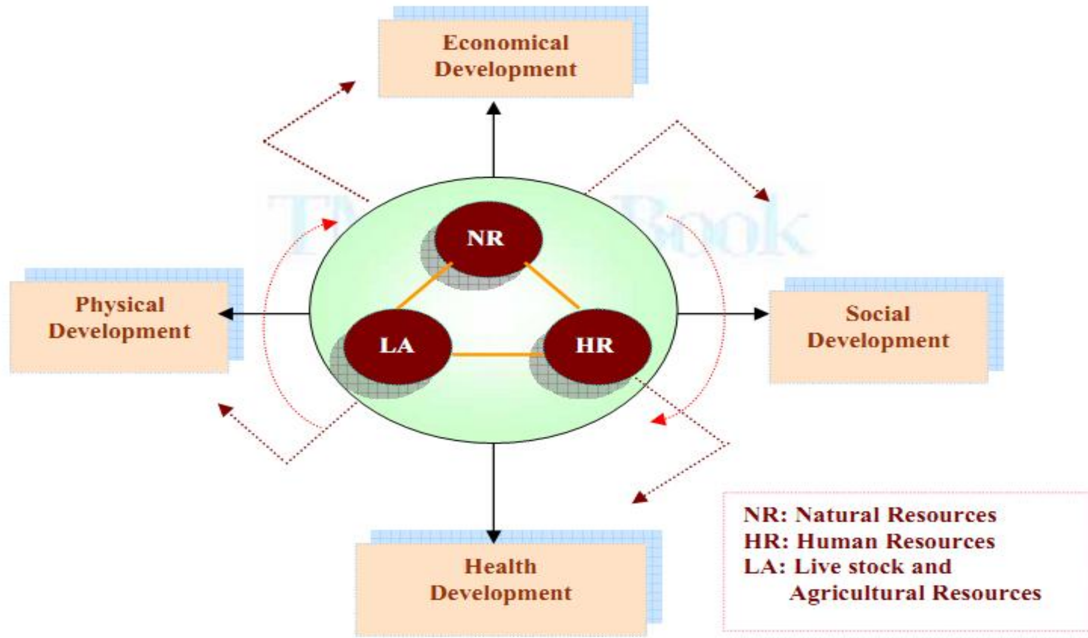


Figure 2.4 Dimensions of Development through Knowledge-Based Systems (Sajja and Akerkar, 2010)

2.1.9. Knowledge based system in agriculture

In agriculture, applications of expert system are mainly found in the area of diseases diagnosis and pest controls (Sarma *et al.*, 2009). In agriculture, expert systems unite the accumulated expertise of individual disciplines, e.g., plant pathology, entomology, horticulture and agricultural meteorology, into a framework that best addresses the specific, on-site needs of farmers (Prasad and Vinaya, 2006). In this sector expert systems are developed to diagnose the diseases and pests of various crops (Khan *et al.*, 2008).

In the nineties, several expert systems have also been developed in agricultural field. An agro forestry expert system was designed to support land use officials, research scientists, farmers, and other individuals interested in maximizing benefits gained from applying agro forestry management techniques in developing countries (Prasad and Vinaya, 2006).

The problems in agriculture are often multidisciplinary and very complex because of affecting complex events. Expert systems approaches will succeed with this kind of problems. It has many methods for uncertainty and reasoning using whatever on the hand. ES in Agriculture will help farmers and animal breeders make their decisions more efficiently and timely. Currently many people are forced to make decisions about agricultural activities without enough knowledge. Many of them have inadequate training about agriculture and needs to be managed.

Need of expert systems in agriculture

The need of expert systems for technical information transfer in agriculture can be identified by recognizing the problems in using the traditional system for technical information transfer, and by proving that expert systems can help to overcome the problems addressed, and are feasible to be developed. According to Prasad & Vinaya (2006), Zhu (2001) and Rafea *et al.* (1995), expert systems are needed in agriculture mainly to overcome the information transfer problems in which some of them are described as follow:

Static information: Examining the information stored and available in the agriculture domain revealed that this information is static and may not respond to the growers need. All extension documentations give general recommendations because there are many factors if taken into consideration; so many different recommendations should be included in the document. The problems already raised can to large extent be solved using expert systems to generate the information to the growers by using its knowledge base and reasoning mechanism acquired from human experts and other sources. The expert system generates the advice based on its knowledge base and its reasoning mechanism that are actually behind all developed extension documents, and more. Consequently, when a user enters the data of his/her plantation to the system, the appropriate advice is generated. Therefore expert system overcomes the problem of static information provided in extension documents.

Specialties integration: Most of the extension documents handle problems related to certain specialty: plant pathology, entomology, nutrition, or any other specialty. In real situations the problem may be due to more than one cause, and may need the integration of the knowledge behind the information included in the different extension documents and books. The knowledge acquisition process for building an expert system facilitates the integration of knowledge and experiences of different specialties. For example, an agricultural diagnostic expert system requires the integration of specialists in nutrition, plant pathology, entomology, breading, and production. Therefore, when a problem occurs, the system can help the user in identifying the cause of the problem in a much more efficient way than consulting a document that handles a specific problem.

Combination of more than one information source: Images may need sometimes an expert to combine other factors to reach an accurate diagnosis, and even if a diagnosis is reached, the treatment of the diagnosed disorder should be provided through extension document. Expert systems can be integrated with other information sources such as images bases and/or textual bases to make use of these sources. For example, images can be used for describing symptoms as it is very difficult and very confusing to describe them in words. Images can also be used for confirming the diagnosis of the cause of a certain disorder. Expert systems can also be integrated with textual data bases that may be the extension documents related to the specialty and/or commodity handled by an expert system. This textual data base can be used for explanation purposes of basic terms and operations. It can also be used to confirm the reached conclusion in some situations.

Updating: Changes in chemicals, their doses, and their effect on the environment should be considered. Updating this information in documents and distribute them takes long time. The same arguments can be made for audio tapes that are another form of extension documents but in voice instead of written words. Video tapes are more stable than other media as the information provided through the tape describes usually well established agricultural operations. However, if the tape includes information as what is commonly included in documents and audio tapes, this information should be updated. The updating problem is also found in expert systems. However, the knowledge base can be maintained more efficiently than maintaining manual documents. The problem of updating the versions in the field can be eliminated in case that the expert systems are stored on a central computer and accessed through a computer network. The undocumented experience and knowledge can be acquired and stored in the knowledge base of an expert system for a certain specialty and/or commodity.

Information unavailability: Information may not be available in any form of media. It is only available from human experts, extensionists, and/or experienced growers. In addition, the information transfer from specialists & scientists to extensionist and farmers represents a bottle neck for the development of agriculture on the national level. The current era is witnessing a vast development in all fields of agriculture. Therefore there is a need to transfer the information of experts in certain domain to the general public of farmers, especially that the number of experts in new technologies is lesser than their demand. This experience can be available to all growers using the system.

The feedback from the usage of the system can be used as a source of information when analyzed by researchers, the knowledge behind it can be identified, and the knowledge base can be updated continuously. Expert systems can also help in overcoming the problem of the relatively few numbers of experts relative to the demand from the growers. Expert systems technology can help to transfer the information of experts, and experienced growers to farmers through the extension system (Rafea *et al.,* 1995).

Usage areas of expert systems on agriculture

According to Robinson (1996), Expert systems are used in a wide range of areas in agriculture. Its main usage areas are:

Crop Management Advisors: These kinds of systems help the farmers by giving decision support on the process of growing a certain type of crop. Example an ES to generate fertilizer recommendations: This system deals with specific task “fertilization” in growing crops.

Livestock Management Advisors: Similar to crop growing advisors, this system gives integrated advices for animal breeders. Example: Application of conditional causality in an integrated knowledge based system for daily farms. The system has health, production and financial modules. It gives decision support for daily farm management tasks.

Planning system: Production planning systems with ES in agriculture, deals with identifying and suggesting projections, plans for future cropping activities. Example implementation is: CROPS: A whole farm crop rotation planning system to implement sustainable agriculture. Main purpose of the system is to obtain sustainable and profitable cropping plans which meet given production needs and various constraints.

Pest Management Systems: These systems help farmers to deal with harmful creatures with optimal management solutions. Such as an expert system for integrated pest management of apple orchards. The system helps the farmer first identifying the problem and then gives advice for taking actions.

Diagnostic Systems: Different from the pest management, diagnosis is concerned with any kind of disease in plants and crops. These tools are like the well known MYCIN. It works the same way. An adductive reasoning expert system shell for plant disorder diagnosis: It is a domain-specific generic tool for diagnosing plant diseases.

Conservation/Engineering Systems: Problems dealing with engineering solutions to conservation problems. A typical example is: Development and validation of an expert system for soil erosion control planning in Prince Edward Island: It is used for conserving soil by recommending the appropriate engineering solution to control soil erosion within typical cropping systems.

Process Control Systems: This system monitors some sensors and takes corrective actions using some instruments. Determination of greenhouse climate set points by SERRISTE: its function is to maintain certain conditions in a glass house for winter production of tomatoes.

Marketing Advisory Systems: Gives advices to farmers on marketing different products.

Cattle and GRAIN Marketing: Helps farmers to select different marketing alternatives for their cattle, and grain.

2.1.10. Knowledge based system in plant disease diagnosis

Identifying the plant diseases is not easy task; it needs experience and knowledge of plants and their diseases. Moreover, it requires accuracy in describing the symptoms of plant diseases. A person can depend on a system that posses experience and knowledge of experts and help users in identifying any type of disease, making the right decision and choosing the right treatment.

Using expert system technology in agriculture is not new. The expert system applied to the problems of diagnosing Soybean diseases developed by Michalski *et al.* (1983) is one of the earliest expert systems developed in agriculture. In 1991, serious efforts have been started in Egypt to develop crop management expert systems for different crops. A prototype for an expert system for cucumber seedlings productions has been developed. This prototype has six functions: seeds cultivation, media preparation, control environmental growth factors, diagnosis, treatment, and protection. An expert system for handling management of cucumber disorders is designed by (Rafea *et al.,* 1995). An expert system for apple orchid management which is implemented by Roach *et al. (*1985) is an expert system for apple orchid management. It advises growers about when and what to spray on their apples to avoid infestations. The system also provides advice regarding treatment of winter injuries, drought control and multiple insect problems. The system also provides advice regarding treatment of winter injuries, drought control and multiple insect problems (Prasad and Vinaya, 2006). Bethlehem (2010), developed

Knowledge Base System for Pepper Diseases Diagnosis. In this study the assessment was conducted in order to explore pest management practices of farmers. A survey was chosen for this purpose. The number of farmers to be included in the study was determined using single population proportion formula and simple random sampling used to select the individuals to be included in the survey. The survey questionnaire was used as data collection instrument for this study. The collected data was analyzed using weighted mean and mode. Additionally knowledge was acquired through individual interviews with experts and literature reviews were used. Semantic network were used to model the knowledge and production rules were created to represent the detailed knowledge. The researcher used prolog for implementation and the performance of the system was tested by test cases.

Yialouris and Sideridis (1996), developed an expert system for tomato. It handles the tomato disease identification problem. The US Department of Agriculture has developed an expert system for cotton crop management to provide appropriate management recommendations to cotton growers (Khan *et al.,* 2008). Another expert system “Dr. Wheat: A Web-based Expert System for Diagnosis of Diseases and Pests in Pakistani Wheat,” is also an expert system developed. The system is for the purpose of pest and disease control of Pakistani wheat. They had developed the system with web-based expert system using e2gLite shell (Sarma *et al.,* 2009).

2.1.11. Advantages of knowledge based systems

Knowledge based systems are more useful in many situations than the traditional computer. When expertise is to be stored for future use or when expertise is to be cloned or multiplied. More than one experts’ knowledge has to be grouped at one platform. With the proper utilization of knowledge, the knowledge based systems increase productivity, document rare knowledge by capturing scare expertise, and enhances problem solving capabilities in most flexible way. Such systems also document knowledge for future use and training. This leads to increased quality in problem solving process. Knowledge based systems offer several advantages over humans (Natural Intelligent systems). Some of the major advantages can be listed as follows:

- ✓ Knowledge-based systems provide efficient documentation of the important knowledge in a secured and reliable way.
- ✓ Knowledge based systems offer more than one expert knowledge in an integrated fashion.

- ✓ Typical information systems deal with data while knowledge based systems automate expertise and deal with knowledge (Sajja and Akerkar, 2010).

2.2.Coffee in Ethiopia

2.2.1. Introduction

Ethiopia is the source of several economically important cultivated crops around the world. Among these crops, the most important gift of Ethiopia is coffee known as Coffea arabica L., which had and still has a tremendous economic, social and spiritual impact on many people of different geographical locations, cultural backgrounds and psychological behaviors (Arega, 2006 and Getachew, 2010). Arabica coffee (Coffea arabica L.) is the most important cash crop that has been contributing a lion’s share to the Ethiopian economy. Although, it plays significant role in the economy of the country, the crop suffers from many production constraints.

2.2.2. History of coffee

The origins of the coffee crop can be traced back to the Ethiopian highlands for Coffea Arabica, and the forests of West and Central Africa for C. canephora (Robusta) (Waller *et al.*, 2007). The genus Coffea is endemic to Africa and a number of species are described in West, Central and East Africa. The genus Coffea (Rubiaceae) comprise 103 species but due to disease constraints and other factors such as yield, quality and growth habits, only two species are nowadays commercially grown worldwide, namely C. canephora (Robusta) in lowlands and C. arabica (Arabica) in highlands. Arabica coffee has a lower caffeine level than robusta, and arabica is an allotetraploid (2n =4x=44), while robusta is a diploid (2n =22. Both species of Coffea can either be grown at full sun, or under different levels of shade. Arabica coffee is grown in altitude ranges between 1400 and 1800 m and is cultivated under shade. This species originated from the province of Kaffa in Ethiopia and was distributed by Yemen traders all over the world during the 15th century (Hindorf and Omondi, 2011 and Vega *et al.*, 2009).

The significance of coffee in the world economy is staggering. It is grown in more than 10 million hectares in over 80 developing countries and approximately 20 million families depend on this plant for their subsistence (Vega *et al.*, 2009). Ethiopia is believed to be the primary centre of origin and genetic diversity for Arabica coffee (Coffea arabica L). Today, in a few remaining rain forests of South West and South East Ethiopia, coffee grows as an understory shrub in a large diversity of shade trees, shrubs and annual plants and has maintained its own genetic diversity as a natural gene bank. But even this natural resource is not free of diseases. It continues, however, to survive all attacks by pathogens and pests in a unique way under natural conditions. Therefore the description and occurrence of diseases will concentrate on experiences in the montane rainforests of Ethiopia (Hindorf and Omondi, 2011and Taye, 2011).

The majority of coffee production (90%) comes from the smallholders while the rest is produced by large scale producers (state farms and investors) (Abeyot *et al.*, 2011). The major coffee production systems include forest, semi-forest, garden and plantations. The forest ecosystem, which includes coffee forest (10%) and semi coffee forest production systems, occupies nearly 33% of land used for coffee production and contributes 25% of national coffee production. In this regard, the importance of rainforest conservation can be viewed against the background of manmade destruction or change in about 60% of the Ethiopian forests during the last thirty years. (Taye, 2011).

2.2.3. Economic, social and environmental considerations of Ethiopian coffee

Ethiopia is considered the birthplace of coffee. Coffea arabica, the aromatic and mild species of coffee used to produce the highest quality and priciest blends originated in the highland rainforests of south western Ethiopia. The country still retains a critical role as the genetic base of arabica coffee. Given the potential contribution to new varieties with increased yields, of higher quality and/or with disease resistance, its genetic diversity has considerable value, not just from an environmental perspective but from an economic one as well. For Ethiopia itself, coffee has enormous economic, social and environmental significance. Coffee is an emblematic product for the country, making up around half of its exports. It represents an important part of Ethiopia’s foreign exchange earnings, tax income and gross domestic product. It also employs 25 percent of the domestic labour force (María, 2008).

Economic value of wild coffee gene pool alone for world breeding purpose is estimated US$ 0.42- 1.46 billion. Significant contribution to the economy of the country Livelihood of about 16 million people in the coffee sector is determined by this commodity crop (Growers, (Growers, processors and marketing). Recent production potential: Ethiopia ranked among top ten coffee producing countries, 24.5 million bags during 2009/2010, 1st from Africa while 6th from the world (Brazil, Vietnam, Indonesia, Colombia and India) (Getu, 2011).

2.2.4. Coffee diseases and pests in Ethiopia

2.2.4.1.Major coffee diseases

Among the major factors limiting increased Coffee production worldwide are losses due to pests (insects, disease, nematodes and weeds), both indigenous and exotic and diseases. Coffea Arabia L. in Ethiopia is attacked by numerous diseases such as the Coffee Leaf Rust (CLR), Hemileia vastatrix, Coffee Berry Disease (CBD), Colletotrichum kahawae and Coffee Wilt Disease (CWD), Gibberella xylarioides(Fusarium xylarioides) (Arega, 2006 and Hindorf & Omondi, 2011). Insect pests are the most serious and the most numerous, with over 900 species having been recorded (Mitchell, 1985).

2.2.4.1.1. Coffee leaf rust

Coffee Leaf Rust (CLR) is one of the most important diseases of C. Arabica in the world. It devastated Arabica coffee plantations in Ceylon at the end of the 19th century and was responsible for its replacement with tea plantations. Despite effective fungicides and resistant varieties developed to control rust, yield reductions of 20% or more in various countries are still caused by the pathogen (Waller, 1982).

In Brazil, losses have been estimated to be about 30% and an annual loss of about 4500 tons of coffee was estimated in Kenya in the 1960s. The pathogen prefers a temperature range of 20–28 C, needs a leaf wetness period only during spore germination and penetrates with the germination hyphae into the stomata of the host. The fungus tolerates longer seasons without rainfall and spores are wind borne, only attacking leaves and needs no other host for completing the life cycle (Hindorf & Omondi, 2011). CLR was first reported in Ethiopia in 1934 (Sylvain, 1958) but the disease had existed for a long time in other countries without causing epidemics or eradications of certain varieties of C. Arabica. The long-term coexistence of coffee and rust coupled with the high genetic diversity of coffee populations and a high level of horizontal resistance might have kept the rust at low levels (Van der Graaff, 1981). Other factors such as the low average productivity associated with shade and the existence of biological agents such as the hyperparasite Verticillium lecanii, were also believed to play an important role in maintaining CLR at low levels. The occurrence of rust in the forest coffee populations varied significantly from season to season (Hindorf & Omondi, 2011).

The effect of shade on the occurrence of CLR could be shown in nursery experiments at the Jimma Agricultural Research Centre (JARC). All young coffee trees grown under the shade were infected more seriously with rust than in the non shaded sites. Comparing coffee from the different forest regions, the material from Bonga seemed to be more tolerant to rust than others (Girma *et al.*, 2008).

2.2.4.1.2. Coffee berry disease

Coffee Berry Disease **(**CBD) was first detected in 1922 in Kenya around Mt. Elgon, west of the Rift Valley. Soon after detecting the disease, losses of up to 75% were reported. At the beginning, the disease was related to the fungus C. coffeanum described from Brazil causing leaf spots on Arabica coffee. But the new disease in Kenya produced anthracnose like symptoms on green berries. From Kenya the disease spread to Angola in 1930, Zaire in 1937, Cameroon between 1955 and 1957, Uganda in 1959, Tanzania in 1964, Ethiopia in 1971 and Malawi in 1985. Until now the disease has been restricted to East, Central and South African coffee growing regions. In Ethiopia the disease occurred much later than in neighboring Kenya. After its first appearance in Sidamo the disease spread very quickly to nearly all growing coffee provinces until 1978 and caused remarkable losses (Hindorf & Omondi, 2011).

CBD is a major cause of crop loss of arabica coffee in Africa and a dangerous threat to production elsewhere. Apparently, the free movement of coffee plant materials from CBD infected areas has been the main factor in distribution of this disease throughout all important arabica growing areas in Africa. In Ethiopia yield losses of 51% at Melko and 81% at Wondo Genet due to CBD. The pathogen can infect all organs of the host: flower buds, leaves, fruits and the maturing bark. Infection takes place either early during flower bud formation causing some losses in flowers or remains latent in the inflorescence until the berries start to expand in growth. The outbreak of the disease with visible symptoms occurs during the expanding stage of berry development, producing sunken, black, anthracnose like lesions on the green pulp. The national average loss on local land races is estimated to be between 24 and 30%

The losses occur during early infestation by destroying the beans or by preventing proper wet and dry processing since the pulp cannot be removed completely, causing so called ‘‘stinkers’’ in the crop and reducing the quality. An intensive progress of the disease in the expanding stage of the berry development finally produces mummified berries with no economic value at all (Hindorf & Omondi, 2011). It is an anthracnose of green coffee berry, caused by the infection of a fungal pathogen Colletrichum kahawae. Largely, CBD causes 30% national average crop losses to total harvestable coffee yield every year in Ethiopia. At present, CBD has rapidly spread to all coffee growing areas of Ethiopia and still inflicting significant crop loss (up to 100% on susceptible land races) although the magnitudes vary from place to place and from time to time (Arega, 2006).

Fungicides such as Daconil and Delan were considered as promising chemicals against C. kahawae. However, later these products including Dyrene and Octave were banned for a number of side effects (Eshetu *et al.,* 2000). The high cost of pesticides, the appearance of fungicide resistant pathogen biotype and other social and health related problems of the conventional agriculture on the environment have increased interest in sustainable agriculture and biodiversity conservation. Additionally, millions of coffee farmers are facing problem not only with low coffee prices but also a growing interest in organically grown coffee across the globe. These problems make it essential to look for alternative strategies that can ensure competitive coffee production (Amsalu *et al.,* 2011).

2.2.4.1.3. Coffee wilt disease

The other important fungal disease of coffee, and probably the second most important disease next to CBD in Ethiopia, is CWD. Coffee Wilt Disease (tracheomycosis) is a vascular disease caused by the fungal pathogen, G. xylarioides (F. xylarioides) and results in a total death of the infected coffee trees. The disease has been a serious problem to the production of Robusta coffee in Congo and Uganda since the 1990s killing hundreds of trees. The first appearance on Arabica coffee in Ethiopia was reported in 1958. The disease occurred first on some large scale state farms near Gera. Infection mostly takes place at the imperfect stage penetrating through wounds into the base of the stem. The fungus blocks the water supply in the vascular system and causes a typical brown discoloration (Hindorf & Omondi, 2011).

The actual disease assessment indicated that the incidence varied from 45% at Gera to about 69% at Bebeka. The national incidence and severity of CWD in Ethiopia were 27.9% and 3%, in monitory terms it causes an estimate loss of more than 3.7 million US dollar annually. However, the incidence and severity varied from place to place in a range of 0-100% and 0-25%, respectively (Arega, 2006).

2.2.4.1.4. Brown eye spot disease

Brown eye spot, also referred to as coffee leaf spot, coffee eye spot, brown eye spot, berry blotch or berry spot disease of coffee, is caused by the fungus Cercospora coffeicola. It flourishes in warm, humid conditions and occurs in all of the coffee growing areas of the world. Although it is the most widespread disease of Coffea arabica, brown eye spot rarely causes yield losses on this coffee species but can cause defoliation in, and reduce the vigor of seedlings and young plants. In fact the disease appears to be more prevalent at lower altitudes and on Coffea canephora, possibly due to C. canephora being more susceptible. In eastern Africa brown eye spot disease is known to occur in Uganda and has also been reported in the Democratic Republic of Congo (DRC) (Rutherford, 2006).

2.2.4.2.Ethiopian coffee insect pests

Insect pests are among the number of factors considered to limit coffee production both in quality and in quantity (Million and Bayissa, 1986). Every part of the coffee tree roots, stems, leaves, flowers, berries and the seed in storage may all be attacked by insects in some coffee growing area (Wrigley, 1988). Pests of coffee include insects, mites, nematodes, mollusks, birds and mammals. Losses due to Coffee pests are estimated to be 13% worldwide (Nyambo and Masaba, 1997). Arabica coffee is preferred over all other species because of its superior quality and it would certainly have continued to be the exclusive producer of all coffee in the world (Herbert, 1985).

Coffee are ever green perennial crops grown in climates without sever extremes; consequently pests can survive from year to year, but fortunately the same applies to the parasitoids and predators of these pests (Wrigley, 1988). About 50 species of scales are known to infest the various parts of the Coffee tree. The most important are: Coccus viridis Green, or green scale which is yellowish green, and is found in all the tropical regions of the globe. General feeders such as Lepidoptera larvae eat the buds, scale insects and aphids by sucking the plant tissue and affect their development (Le Pelley, 1968 and Million 1987). Leaf miners infested plants have brown irregular blotches on the upper surface of leaves; the blotch mine is inhibited by a number of small white caterpillars. Mined leaves are usually shed prematurely (Hill, 1975). Their mining, which reduces the photosynthetic area of the leaf, causes same damage but the main losses of the production seem to be due to premature shedding of leaves (Singh, 1983).

Antestia bug (Antestiopsis spp.) is a major pest of Arabica coffee in the wetter regions of east Africa. Both nymphs and adults feed on the berries causing the young berries to drop and the production of soft or rotten beans by the bigger berries. When the Antestia infestations are high the growing points are also damaged, resulting into dense matted growth, such coffee trees results low yields of poor quality beans. They are sucking insects and by their habit of feeding transmit fungus. Infested berries develop dark brown patches. The bug also feeds on the follower buds. They also sometimes attack foliage (Singh, 1983).

Wellman (1961) also suggests that the bugs pierce the fruits, entering with their beaks into the endosperms of the seeds, and inject spore material into the coffee beans. The result of this feeding are the following types of damage: blackening of flower buds, fall of immature berries, rotting of the beans with in the berry of conversion of the substance of the bean into a soft paste; on the drying tables the parchment shows longitudinal brown streaks ("Zebra beans") and multiple branching and shortening of internodes.

Coffee berry borer (CBB) is a sever pest of Coffea species, of which C. canephora is the most preferred. Damage is caused by the females feeding on young berries, resulting in significant losses through premature falling. The bulk of the damage is on the endosperm of the mature bean, extensively damage or completely destroyed by the adult or larvae feeding and tunneling in it (Lan and Wintgens, 2004). As, Singh (1983) reported that this pest is the most serious pest of robusta of coffee and also damage Arabica plantation of lower altitudes but is uncommon above 1,500m. Coffee berry moth (Lepidoptera: Pyralidae) typical symptoms of attack are berry clusters in which the berries are webbed together and one or more is brown, dry and hollow (in the absence of berries the cater pillars may be found boring in the tips of green branches). If the caterpillar hatches out in the vicinity of every young berries it will graze them off but is too large to bore inside them. It is a minor pest of coffee, especially when it is grown without shade (Hill, 1975).

Coffee berry butterfly (Lepidoptera: Lycaenidae) single holes are bored into the sides or ends of large green berries turn brown and the edges of the holes bend up to form a distinct rim. Many affected berries are shed. The damaged berry is hollowed out and is clean inside, since the caterpillar pushes its excreta out through the entrance hole. Both beans are usually eaten. It is occasional sever outbreaks have occurred especially at higher altitudes (Hill, 1975).

Although Ethiopia is the homeland for Arabica Coffee and the environmental conditions are suitable for Coffee production, the average national yield is very low. Insect pests are among the factors considered to limit Coffee production in both quality and quantity. Over 47 species of insect pests are recorded on Coffee (Million and Bayissa, 1986, 1987). Among which Antestia bug, Antestiopsis intricate, A. facetoids and Coffee blotch miner, Leucoptera caffeinia, L.meyricki are the major ones inflicting considerable damage. On the other hand, insect pests such as Coffee berry borer, Hypothenemus hampei, Coffee thrips, Diarthrothrips coffeae, green scale, Coccus alpinus and Coffee cushion scale, Stictococcus formicarius, are potentially important pests (Esayas *et al.,* 2008). Insect pest problems are more pronounced in intensive coffee production system (plantation) compared to garden and semi forest coffee production systems mainly due to changes in cultural practices associated with the newly planted cultivars (Million, 1987).

In Ethiopia, most of the insect pests of Coffee have remained less important as opposed to many Coffee producing countries. One of the possible reasons is the existence of diverse natural enemies, which the population at low level mainly in the relatively undisturbed Coffee ecosystems, in which pest, and natural enemy balance is maintained (Crowe and Tadesse, 1984; Million and Bayissa, 1986 and Million, 2000). In addition, the genetic diversity of Arabica Coffee coupled with cultural practices with minimum or no input used by subsistence farmers could have contributed to the suppression of insect pests of Coffee (Tsegaye *et al.*, 2000). Nevertheless, if there are any adverse agronomic/farm practices that affect the natural biological balance between pest and their natural enemies, these minor pests can pose a serious problem to coffee industry (Esayas *et al.*, 2008)

2.2.4.2.1. Key coffee insect pests

Even these key pests are not always present at level capable of causing significant damage, but by virtue of their feeding habits and their ability to multiply, they are potentially damaging

(CGA, 1987). Among totally forty seven insect pests of coffee were reported only two insect pests Antestia bugs and Coffee leaf minor are the major insect pests (Esayas *et al*., 2008).

Antestia bug, Antestiopsis spp. There are 3 species of Antestiopsis in Ethiopia, namely A. intricate (Ghesquiere and Carayon), A. facetoides (Greated) and A. orbitalis Carayon. A. intricate is the most common bug found in all coffee growing areas except Hararghe, where only A. facetoides is found (Esayas et al., 2008). Weather factors, host plant, and natural enemies may be attributed for distribution and seasonal changes in population of the insect (Esayas *et al*., 2008).

In Ethiopia, Antestia bugs can cause about 9% berry fall (Mekuria *et al*., 1993), and up to 48% berry darkening (Million, 1987 and IAR, 1996a, 1996b). Mekasha (1993) reported that branches of coffee trees infested with four pairs of the bug caused the highest number of damaged Coffee flower bud (1.2), 54.1% of berry fall, 90.2% of bean damage, and the lowest yield (0.41kg/tree) of red cherry (Esayas *et al.*, 2008).

Coffee blotch leaf minor, Leucoptera spp. There are two species of Coffee blotch miner attacking Coffee leaves, namely, L. meyricki (Ghesquier) and L. caffeine Washbourn. The latter is the most important, commonly occurring in shaded Coffee. The former species is of minor importance in Ethiopia probably due to the fact that Coffee is grown under shade which is not conducive to the normal development of this species (Million, 1987), but it is the most damaging species in other Coffee growing countries such as Kenya, Tanzania and Uganda (Esayas *et al.*, 2008).

When the larvae hatches it feed inside a leaf just below the upper epidermis resulting in leaf damage (Crowe and Tadesse, 1984). Brownish blotch, covering on area ranging from a small spot up to three quarter of a leaf, is created depending up on the number of larva and size of leaf attacked (Million, 2000).

2.2.4.2.2. Potentially important insect pests

Coffee berry borer, Hypothenemus hampei (Ferrori) population had a marked seasonal variation both on dry left over and fallen berries. Moreover, weather factor showed a marked influence on its population dynamics (Esayas *et al.*, 2004). In Ethiopia it attacks only dry left over and fallen berries. Damage on green berries was almost negligible (< 1%) (Million, 2000; Esayas *et al.*, 2003). Coffee scale insects, out of the seven species of scale insects recorded on Coffee in Ethiopia, Coffee cushion scale, Stictococus formicarias Newstead and green scale, Coccus alpinus De Lotto are potentially important pests. Both species are also present in Jimma but at a low level of infestation (Million, 2000). The Coffee thrips, Diarthrothrips coffeae is the very small kidney shaped are laid in the tissue of the leaf. The yellow nymphs feed on the leaves and green berries. When fully grown, the nymph drops to the ground and update in the soil. When the brown adult thrips emerges, it flies back to the tree and continues to feed (Crowe and Tadesse, 1984). Coffee thrips Diarthrothrips coffeae Williams is one of the potentially important insect pests of Coffee. Thrips defoliated a large number of Coffee trees at both the Jimma and Tepi areas (IAR, 1972; 1997a).

2.2.4.2.3. Minor insect pests of coffee

Serpentine leaf minor, Cryphiomystis aletreuta (Meyrick) appears every year after the onset of the short rains affecting young leaves (Million, 2000). Serpentine leaf miner is a very common pest found in most Coffee growing areas. This insect is well suppressed by its natural enemies; however, it can easily build up to a damaging level in the absence of its natural enemies (Million, 1987). Coffee leaf skeletenizer, Leucoplema dehertyi (Warren) larvae feed on the underside of leaves, usually near the midrib eating everything except the veins and the upper epidermis, leaving irregular lace-like patches in the leaf (Crowe and Tadesse, 1984). Cocoa stem borer is becoming an important pest occurring in many Coffee growing regions of the country (IAR, 1996c). As, Million (1987) concluded among more than three species of fruit flies were available infesting Arabica Coffee in Ethiopia. Ceratitis rosa Karsch, C. capitata (Wiedemann) and Trirhithram cafeae Bezzi were the most frequently found and relatively abundant species.

CHAPTER THREE

DESIGN AND METHODOLOGY OF THE STUDY

3.1. Knowledge Engineering Methodology

The study was based on diseases and pests encountered in coffee plant in Ethiopia. The idea behind creating an expert system is that it can enable many people to benefit from the knowledge of one person i.e. the expert. Expert system simulates the judgment and behavior of a human that has expert knowledge and experience in a particular field. In an expert system development, knowledge base development is the most important part. The quality of an expert system depends on its knowledge base. Knowledge Base development with the help of domain specific expert in this system is developed with prolog programming language. The process of developing knowledge based system has a multi step process which aims at developing a domain specific knowledge base (Sarma *et al.*, 2010). The steps for developing knowledge base in this system are identification of the input problem, knowledge acquisition, knowledge modeling and representation of knowledge into the knowledge base.

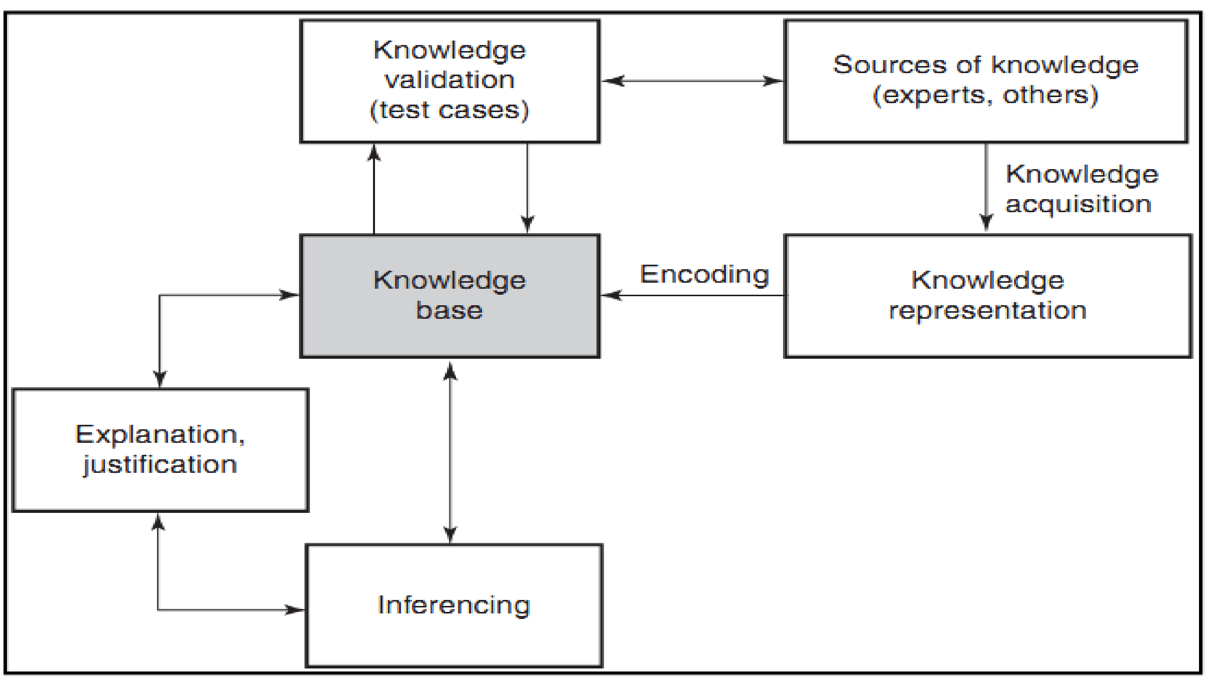


Figure 3.1 The process of knowledge engineering (Sarma *et al.*, 2010)

3.1.1. Identification of the input problem

To develop an expert system, first we need to identify the problem and understand the major characteristics of the problem that we have to solve in the expert system. The input problem for this system is regarding the diagnosis of diseases and pests in the coffee plant occurring during their life span.

3.1.2. Knowledge acquisition

Knowledge acquisition (KA) is the process of transferring knowledge from the knowledge source to knowledge engineer (or expert system builder) then encoding it into the knowledge base. Knowledge acquisition is considered as one of the most important phases in the expert system development life cycle (Hart, 1992).

The primary aspects that differentiate expert systems from conventional software programs are separation of the knowledge from the inference engine, user interface facilities, and the knowledge acquisition module. Experts gain knowledge through sensory contact, education and reasoning. However, an expert's knowledge is often unstructured, complicated and incomplete. Often experts cannot explain their knowledge not only because they cannot verbalize it, but also because they might not be aware of its relevancy to a particular problem. The performance of an expert system and the resources consumed in its construction are highly affected by the knowledge engineer and his/her communication capabilities. The knowledgebase is incrementally built through collaboration of the knowledge engineer and the domain expert(s). Communicating with an expert is time consuming and highly subjective. In addition, important concepts might be overlooked by both the expert and the knowledge engineer in any session. The knowledge engineer has the responsibility of choosing performance measures that can be used to ensure the consistency of the expert, and ensure that the right system is built right. Another concern of the knowledge engineer is to ensure that all the requirements for building an expert system are satisfied (Musam *et al.*, 1991).

The sources of knowledge in this system were primarily experts and secondly literatures were consulted to acquire the knowledge. Domain knowledge was obtained through individual interviews with experts in plant pathology and entomology, reviews of published research and coffee diseases and pest management guides. Basically structured interview was used to acquire knowledge of experts at the domain of the study; this is because of a structured interview is a systematic, goal oriented process. It forces organized communication between the knowledge engineer and the expert. The structure reduces the interpretation problems inherent in unstructured interviews and allows the knowledge engineer to prevent the distortion caused by the subjectivity of the domain expert (McGraw and Harbison-Briggs, 1989).

Therefore, interpersonal communication and analytic skills are important to come up with quality knowledge base. The knowledge of the various infestations was obtained from specific literature and symptom descriptions and the rules from domain experts. Two stages were iteratively done to implement this prototype. The first stage was the 'Domain Acquaintance', during which, the Knowledge Engineer, aiming to characterize the key problems, became familiar with the domain by studying books and papers related to coffee diseases and pests and identify appropriate, domain experts to be consulted. The second stage was the ''Meeting with the Experts'', during which, the expert system builder had meetings with the domain experts. The interviews with domain experts provided a lot of help in getting the idea of the extent of knowledge required to solve the problems. The experts were asked mainly the following questions, "which diseases and pests attack coffee in the country?", "mainly which parts of the coffee plant they attack?", "what are the symptoms of each disease and pest?", and "what are the basic treatments and preventions to be taken?" Initially disease/pests, symptoms and treatments were identified. This interview questioner is attached at appendix I. The following experts are interviewed.

No	Name	Status	Responsibility
1	Demelash Teferi	MSc	Plant pathologist
4	Sisay kindu	BSc	Entomology
2	Sisay Tsefaye	Diploma	Senior technical assistant in plant pathology
3	Tesfaye shimber	PhD	Coffee agronomy

Table 3.1 Profile of experts who participated in the knowledge acquisition

This iterative approach to KA was extremely effective and permitted a better understanding of the problem and its further representation. After the interviews with the experts and thorough review of the literature, the researcher summarized the information in the following table (Table 3.2). The table gives information about major diseases and insect pests observed, color of the insect, damage caused, and as well it gives information about the affected part of the coffee plant. The insect and disease diagnosis forms are formal modes of diagnosis based on the set of symptoms and conditions required to identify the insect or diagnose the disease. The insect pests are identified based on; mainly three considerations; physical structure or appearance of the insects (their color and shape), their feeding habit (which part of the plant they feed on), and the symptoms showed on the affected parts. And the diseases are indentified based on main symptoms caused due to their infection.

No	Insect pests observed	Colour of the pests	Major diseases observed	Symptoms of diseases appear on/ pests feeding habitat
1	Antestiabugs (Antestiopsis spp.)	dark brown with orange and white markings.	Coffee Wilt Disease (CWD) (Gibberella xylarioides)	green berries, flower buds and branches and stem
2	Coffee leaf minor (Leucoptera)	white moths	Coffee leaf rust (CLR) (Hemileia vastatrix)	Coffee Leaves
	Potentially important insect pests			
3	Coffee Berry borer (Hypothenemus hampei)	Blackish beetle	Coffee berry disease (CBD) (Colletotrichum kahawae)	green or ripe berries
			Minor disease	
4	Coffee Green Scale(Coccus alpinus)	yellowish to greenish color	Brown eye spot (Cercospora coffeicola)	feed on green wood(CGS) and leaves.
5	Coffee berry moth:	Reddish caterpillar larvae color	-	Coffee berries
6	Coffee stem borer	dark brown grayish in color	-	branches, stems

Table 3.2 Common diseases and pests of coffee elicited from the experts

More over the next two tables (table 3.3 and 3.4) are summarized with coffee disease and pests with their experts recommendations when observed.

Diseases	Recommendations
Coffee berry disease (Colletotrichum coffeanum)	○ Sanitation and crop hygiene ○ Shade management ○ Mulching ○ Pruning ○ Proper plant nutrition ○ Stem cleaning ○ Spray with recommended fungicide ○ Plant recommended resistant/tolerant varieties
Coffee leaf rust (Hemileia vastatrix)	▪ Removal of old unproductive trees ▪ Resistant varieties ▪ Sanitation and crop hygiene ▪ Shade management(should be regular) ▪ Mulching ▪ Pruning ▪ Clean weeding ▪ Spray with recommended fungicide
Coffee wilt (Trachomycosis)	▪ Uproot and burn infected plants as soon as symptoms appear. • Do not carry infected plants to distant places ▪ Do not drag infected plants across the field as this may spread the disease to new areas ▪ Scout the field regularly ▪ Disinfect (flame tools) and always begin farm operations from clean parts of the field. ▪ After uprooting allow up to 2 years rest before replanting on the same field

	▪ Establish new crop from disease free planting material ▪ Use resistant/tolerant plant material where available.
Brown eye spot	• control may be necessary for nursery plants by routine spraying with a protective, copper based fungicide Provision of adequate shade and nutrition can also be beneficial(partial shade)

Table 3.3 Coffee disease problems and recommended management practices

Pests	Recommendation
Antestia bugs (Antestiopsis spp)	○ Shade management by reducing size ○ Pruning and de suckering ○ Scouting ○ Conservation of indigenous natural enemies ○ Apply recommended insecticides at recommended dosage if necessary
Leaf miners (Leucopteraspp)	○ Sanitation and crop hygiene ○ Conservation of indigenous natural enemies ○ Shade management ○ Mulching ○ Pruning ○ Crop scouting ○ Spray with recommended insecticides if necessary
Coffee berry borer (CBB) (Hypothenemus hampei)	○ Conservation of indigenous natural enemies ○ Sanitation and crop hygiene ○ Shade management ○ Mulching

	○ Pruning ○ Burry infected berries as larvae can develop in fallen fruits ○ Regular harvesting
Green scale insects (Coccus viridis)	• Conservation of natural enemies • Curative spraying of solutions of ash, oil, soap, • kerosene or clay
Stem borers (Anthores spp)	• Sanitation and crop hygiene • Stem cleaning at least once a year • Uproot and bury badly damaged trees • Scouting for attacked trees • Pick and destroy the adults • Mechanical removal of larva by using hooks • Apply cooking oil or fat around borer holes to attract predatory ants • Insert cotton wool soaked with kerosene in borer holes • Paint the stem and branches with a paste out substance like lime • Apply recommended insecticides if necessary

Table 3.4 Coffee pests' problems and recommended management practices

3.2. Conceptual Knowledge Modeling

During the knowledge modeling phase, the specialist's knowledge (elicited by various techniques) is represented in a knowledge model. A knowledge model is a structured representation of knowledge using symbols to represent pieces of knowledge and the relationships between them. Knowledge models include symbolic character based languages such as logic, diagrammatic representations such as networks and ladders, tabular representation such as matrices and structured text such as hypertext. The generation and modification cycle of a knowledge model is an essential part of the knowledge modeling phase. The model helps to ensure that all stakeholders in a project understand the language and terminology being used and quickly conveys information for validation and modification where necessary. The knowledge models are also of great value during cross-validation with other specialists (Emberey *et al.*, 2007).

Models are used to capture the essential features of real systems by breaking them down into more manageable parts that are easy to understand and to manipulate. Models are very much associated with the domain they represent (Savolainen *et al.*, 1995). A model is a simplification of reality. Real systems are large entities consisting of interrelated components working together in a complex manner. Models help people to appreciate and understand such complexity by enabling them to look at each particular area of the system in turn. Models are used in systems development activities to draw the blueprints of the system and to facilitate communication between different people in the team at different levels of abstraction. People have different views of the system and models can help them understand these views in a unified manner (Booch *et al.*, 1999). During the knowledge acquisition stage, most of the knowledge is unstructured and often in tacit form. The knowledge engineer will try to understand both the tacit and the explicit part of the knowledge and then use simple visual diagrams to stimulate discussion amongst users and knowledge experts. The knowledge engineer then has to construct the conceptual model from what has been discussed during the knowledge acquisition stage. This communicates the knowledge to the information specialist who will transform the model into workable computer programs or codes. This approach is similar to that of software engineering where models are used to represent user requirements. The main difference here is that in knowledge engineering it is the modeling of knowledge and its related flows whereas software engineering models the information and process flow (Schreiber *et al.*, 1999).

The importance of knowledge modeling in knowledge management has been discussed by Wielinga *et al*. (1997). They argue that models are important for understanding the working mechanisms within a knowledge based system, such as: the tasks, methods, how knowledge is inferred, the domain knowledge and its schemas. Conceptual modeling is central to knowledge engineering (Schreiber *et al*. 1999). Modeling contributes to the understanding of the source of knowledge, the inputs and outputs, the flow of knowledge and the identification of other variables such as the impact that management action has on the organizational knowledge (Davenport and Prusak, 2000). As the paradigm has shifted from the transfer approach to the modeling approach, knowledge modeling has become an important aspect in the process of building knowledge base systems. With the modeling approach, systems development can be faster and more efficient through the reuse of existing models for different areas of the same domain. Therefore, understanding and selecting the modeling technique that is appropriate for different domains of knowledge will ensure the success of the knowledge base system being designed.

Decision tree are modeling tools that are used in a variety of different settings to organize and break down clusters of data decision tree is schematic tree shaped diagram used to determine a course of action and models the possible consequences of a series decisions in some situations (Lidtke and Sato, 2003).

In this work a decision tree is used in chapter four to model the acquired knowledge because this modeling tool helps to select the best of several alternatives courses of action and to clarify and find an answer to a complex problem. The structure allows users to take a problem with multiple possible solutions and displays it in a simple, easy to understand format that shows the relation between different decisions (Lau & Chan, 2004 and Podgorelec *et al.*, 2002).

To make the acquired knowledge reasonable for knowledge representation it is modeled using decision tree structures. In the context of this study decision tree is used to demonstrate clearly the diagnosis procedure of coffee diseases and pests which are implemented by using SWI Prolog in this chapter.

The model was built by the knowledge engineer based on information obtained during the interviews with experts and then reviewed with the domain expert. Decision tree was used to model the knowledge. The decision tree structures figure 4.1 are derived from the knowledge acquired from experts in the consultations of experts and secondary sources. These decision tree structures are the base for the prototype knowledge based system development. The prototype knowledge base system is developed based on the model presented in these decision tree structures. The prototype follows the same procedures presented in the decision tree to diagnosis coffee diseases and pests.

In the following decision tree figure 4.1 the core symptoms of each disease and pest which are the main indicators to identify the possible presence of the infections and to reach a better decision and the fundamental procedures during the diagnosis of coffee infections are structured. Figure 4.1 shows the decision tree for coffee disease and pests.

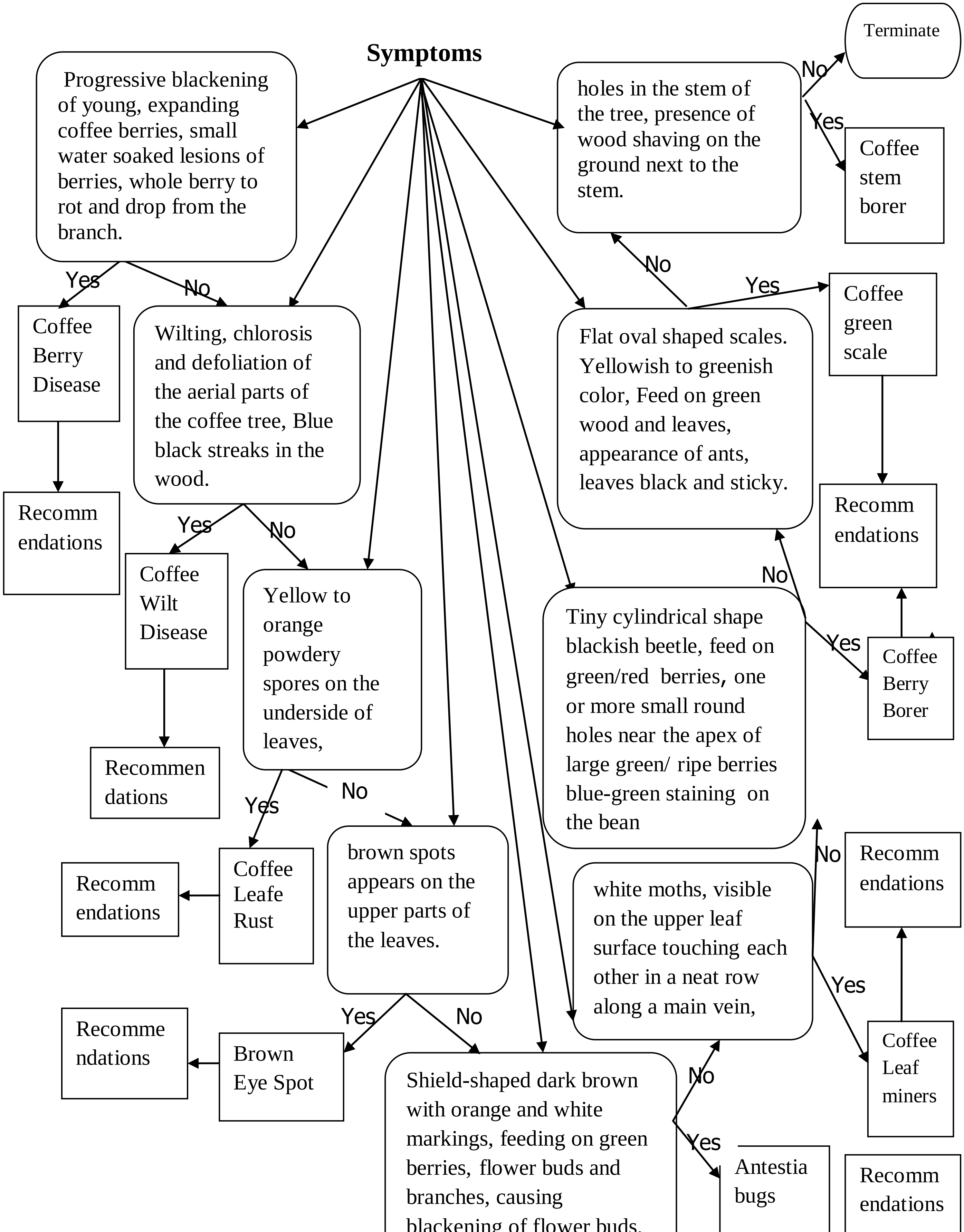


Figure 3.2 Decision tree for coffee disease and pests

3.2.1. System architecture

This system was designed with the progression of conceptual design that refined the systems' architecture. Of course, the conceptual design was essential to stabilize the architecture of KBSCDDT. Throughout design iterations, the design of KBSCDDT was expended into system architecture to ensure that it supported the disease and pests and treatments. The system architecture and the functional follow of the system is presented below.

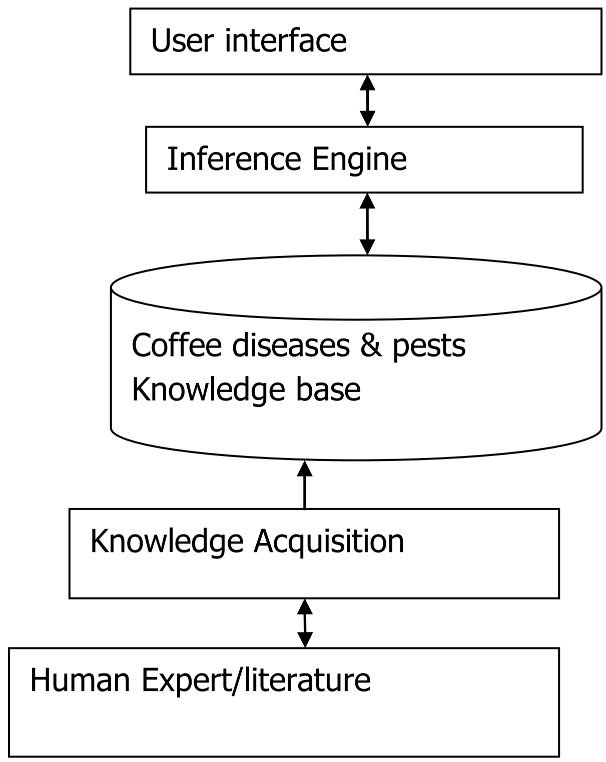


Figure 3.3 The architecture of coffee diseases and pests knowledge base system

CHAPTER FOUR

KNOWLEDGE BASE SYSTEM DEVELOPMENT

4.1. Introduction

The knowledge base system infers solution by running the knowledge base through inference engine, which is a software program that interacts with the user and processes the result from the rules and facts in the knowledge base. In the previous chapter (chapter three) the domain knowledge has been extracted from the experts and modeled using tree structure of decision tree knowledge modeling techniques. The Knowledge representation which was presented using IF_THEN representation technique, inferencing mechanism, development of the user interface and evaluation of the prototype knowledge base system for coffee diseases diagnosis and treatment (KBSCDDT) are discussed in this chapter.

A KBSCDDT is a knowledge base system that was designed to combine the best available knowledge regarding coffee disease and pest management to provide potential treatment information to farmers and non experts. From inputs describing how the symptom or the pest looks, it produces a pest or disease identification information plus the measure that needs to be taken. In this study common insect pests (Antestia bug, coffee blotch leaf miner, coffee berry borer, coffee green scale and coffee stem borer, coffee berry moth) and major diseases (coffee berry disease (CBD), coffee wilt disease (CWD), and coffee leaf rust (CLR) and brown eye spot) that were selected by the plant pathologists and entomologists at Jimma Agricultural Research center (JARC) were considered.

4.2. Representation of Knowledge

Knowledge representation (KR) is the problem of getting knowledge and expertise into the computer in a form that is easy to access and use in solving problems. In the representation of knowledge into knowledge base, the knowledge acquired from knowledge acquisition process is represented into structured form. There are many approaches for representing knowledge into the knowledge base. Knowledge based systems rely on knowledge from specific domains to provide solutions to specific problems. Knowledge engineers usually select the best ways of extracting and representing this knowledge, and the software to be used. To implement the diagnostic knowledge in a KBS, it must be formulated in a manner compatible with a computer representation.

Although different KR methodologies exist in developing knowledge based system for coffee diseases diagnosis and treatment the rule based KR is used because: the rule based knowledge representation has many advantages compared with other knowledge representation methodologies especially for such problems. This method is widely used because each rule is modular and contains a ‘‘chunk’’ of domain knowledge and experts are often able to express their heuristic knowledge in an IF-THEN format. It is the most common used methodology in agricultural expert systems. An additional advantage of rule based expert systems is their similarity to the human cognitive process. They are easy to understand and seem to effectively reflect the way our utility experts represent and diagnose problems. Another major advantage of this scheme is the visibility of the knowledge, especially because the designer of the expert system will not be the maintainer, which is the case in most software development projects. The designer has to exert extra effort to develop an understandable system to help the maintainers modify and update the system during its useful lifecycle (Mahamana *et al*., 2003). For such and the like advantages of production rule the real representation of this research is represented in the following tables using production rule.

IF : symptom appears on berry And progressive blackening of young, expanding coffee berries And small water soaked lesions of berries. And berries turn black and either drop or remain on the branch And berries dry, wrinkled and decayed with a hard skin,
THEN :Possible Disease Coffee berry disease (CBD)
TREATMENT: **Chemical control:** Use Chlorothanonil (Daconil) 75%WDG formulation at the rate of 4.4 kg/ha Use Chlorothanonil (Daconil 2787) 75%WDG formulation at the rate of 4.4 kg/ha Use Fuazinam (shirilan) 50%SC formulation at the rate of 1.1 kg/ha Use Cuprous oxide (Nordox) 75%WP formulation at the rate of 7.7% kg/ha Use Prochloraz/copper (Octave super)50%WP formulation at the rate of 6.5 kg/ha **Prevention:** Providing wide spacing Ensuring that trees are pruned appropriately. All berries including dried berries should be removed at the end of the cropping season o Sanitation and crop hygiene o Shade management o Mulching o Pruning o Proper plant nutrition

Table 4.1 Disease diagnosis form for coffee berry disease

IF : Symptom appears on stem, branch and leaf And Development of blue black discoloration of the wood, And blackening ('dieback') of the stem, spiral and drying of leaf on a coffee tree, And Yellowing, folding and inward curling of the leaves, And drying of the whole trees& become leafless.
THEN : Possible Disease Coffee wilt disease (CWD)
TREATMENT: affected trees and trees adjacent to affected trees should be uprooted and burnt, Clearing a strip of land, up to several hundred meters wide. **prevention** Allow two year fallow period before planting coffee at the affected plant station. Minimize any kind of wounding of coffee tress, for example Machete, hoe or slasher when weeding, wounding by goats Sterilize tools by flaming over fire (the metal part) Fertilize the remaining healthy trees with inorganic or in organic fertilizer or both.

Table 4.2 Disease diagnosis form for coffee wilt disease

IF :Symptoms Yellow to orange powdery spores on the underside of leaves
THEN :Possible Disease Coffee leave rust (CLR)
TREATMENT: Chemical control: Cuprous oxide 50% Cu WP applied at a rate of 3.8 kg per hectare, Cupric hydroxide 50% Cu WP applied at a rate of 3.8 kg per hectare, Cupric chloride 50% Cu WP applied at a rate of 7 kg per hectare, triazole fungicide Bayleton 25% EC sprayed at a rate of one liter per hectare. **Prevention :** ▪ Removal of old unproductive trees ▪ Resistant varieties ▪ Sanitation and crop hygiene ▪ Shade management(should be regular) ▪ Mulching ▪ Pruning ▪ Clean weeding

Table 4.3 Disease diagnosis form for coffee leaf rust disease

IF : Small brown spots appears on the upper parts of leaves; And the upper side of the leaf become reddish-brown or brown with a grayish centre; And dark brown, patch lesions on the coffee berries
THEN :Possible Disease Brown eye spot
TREATMENT: **Chemical:** Copper sprays such as the following will give control: Copper Cupravit (85% WP) 80 g/20 L water Copper oxychloride 80 g/20 L water Copper hydroxide 40 g/20 L water **Preventive** • Use partial shade for coffee seedlings grown ▪ Avoid over-watering. ▪ Maintain 50% shade cover. ▪ Space plant bags to allow air movement. ▪ Proper fertilizer application

Table 4.4 Disease diagnosis form for brown eye spot disease

IF : Shield shaped And dark brown with orange and white marking color And feeding on green berries, flower buds and branches And causing blackening of flower buds with no flower/fruit set. And attacked branches grow side shoots And rotting of the developing beans; And berries yield zebra pattern beans
THEN :Possible pest Antestia bugs (Antestiopsis spp)
TREATMENT: **Cultural control:** Pruning of coffee trees and tree regulation **chemical control:** 'use chlorpyrifos 48% EC(Dursban 4)(1.5 liter/ha). use cypermetrin(Nurelle D 25/369EC)(1.125 liter/ha). use cypermetrin(Fenom1`100EC)(0.8 liter/ha). use Lamadacyhaiotrin(5.0EC(karate))(0.4 liter/ha). use Fenitrothion(Sumithion 50%EC)(1.8 liter/ha). use Mlathion 50%EC(2.5 liter/ha). use Trichlorfon 95% SP(500g/ha). **Prevention** o Shade management by reducing size o Pruning and Scouting o Conservation of indigenous natural enemies

Table 4.5 Insect identification form for Antestia bugs

IF: Tiny cylindrical shape And blackish beetle color And feeding habitat on green/ ripe berries And one or more small round holes near the apex of large green or ripe berries And blue-green staining on the bean then CBB And berries rot, turn black and dry then falling to the ground
THEN :Possible pest **Coffee berry borer**
TREATMENT: **Chemical control** Thiodan 35%EC at the rate of 2 lt per hectare before the adult beetles get into the hardened bean. Within 4 to 5 months after blossom. **Cultural control** Destroy infested berries by burning Apply mulch to encourage natural enemies Hot water treatment to the infested crop before drying **Prevention:** Prune regularly Pick ripe berries regularly Removal of left over berries Proper drying of coffee

Table 4.6 Insect identification form for coffee berry borer

IF : white moths And visible on the upper leaf surface scattered in small groups touching each other in a neat row along a main vein. And cause irregular brown blotches on upper side of leaves, which when opened reveals many whitish caterpillars. And Attacked leaves are usually shed prematurely And blackening of flower buds
THEN:coffee Leaf blotch miners (Leucoptera)
TREATMENT: **Cultural control** Prune to keep the bush open but moderate shade is necessary The smoke causes the bugs to run to the centre of the tree where they can be picked up then collection of bugs can be successful in small plantations at last drop them in a container with a little kerosene to kill them. **Chemical** Selecron 720 Ec(1 lt/ha), Fenitrothion 50%(1 lt/ha), Dursban 4E (2lt/ha), Decis 2.5% Ec(250mls/ha)and by application of 30 grams of Furadan 5G (carbofuran) per tree during the beginning of the rains. Use of chemical is recommended when an average of 35 moths per mature tree. **Prevention** • Conservation of indigenous natural enemies ○ Sanitation and crop hygiene ○ Shade management ○ Mulching

Table 4.7 Insect identification form for coffee Leaf blotch miner

IF : small golden brown moth with a wingspan Scattered Berries are webbed together and by a darkened silk, One or more berries in a cluster appear brown dried and hollow; Boring in the tips of green branches
THEN :Possible Diagnosis Coffee berry moth:
TREATMENT: **cultural control** Hand picking of attacked berries should be feasible in small plots. Inside coffee tree, smoking by burning cow manure at night during full moon. Removing newly infested parts of trees attacked by the insect and burning them. **Chemical control** Fenitrothion50% ML, apply 50mls in 20l water/ha, Dursban 48%Ec, apply 1.5l/ha, Decis 2.5EC, apply 240mls/ha. Applied before larvae and caterpillars enter the berries.

Table 4.8 Insect identification form for Coffee berry moth

IF: flat oval shaped scales And yellowish to greenish color And feed on green wood and leaves, And usually appear as rows of flat oval green scales along main leaf vein and near tips of green shoots And produce large amounts of honeydew. And ants frequently appear And the sticky honeydew covers upper surface of the leaves And sooty mould develops on leaves. And causes leaves appear black and sticky.
THEN :Possible pest Coffee Green scale
TREATMENT: **Cultural control** ✓ Proper desuckering

- ✓ Use kerosene or clay

Chemical control

Apply 1 liter selecron 720 EC per ha

Prevention

- ✓ Cutting the branches touching the ground

Table 4.9 Insect identification form Coffee green scale

IF : dark brown grayish in color And has very long antenna And feed on the bark of branches, stems And cause round exit holes in the trunk And wood shaving extruding from the bark or from the roots just below soil level.
THEN :Possible pest Coffee stem borer
TREATMENT: **Cultural** • Uproot and bury badly damaged trees • Scouting for attacked trees • Pick and destroy the adults (from October/ to December • Mechanical removal of larva by using hooks • Apply cooking oil or fat around borer holes to attract predatory ants • Insert cotton wool soaked with kerosene in borer holes • Paint the stem and branches with a paste out substance like lime **Prevention** • Sanitation and crop hygiene • Stem cleaning at least once a year • Stem banding is effective against this pest.

Table 4.9 Insect identification form coffee stem borer

4.3. Implementation Software

There are many different tools to implement knowledge base systems. A KBS tool is a set of software instructions and utilities taken to be a software package designed to assist the development of knowledge-based systems. Personal computers, typical programming languages like java and framework like .NET can also be used in KBS development. These programming languages are general purpose and also being used to develop other application than AI applications. KBS shell with the readymade utilities of self learning; explanation and inference like Java Expert System Shell (JESS) are more specific and can also be useful to develop KBS. Tailor made KBS can be developed using programming languages like LISP and Prolog (Abraham, 2002)

In this paper the programming language PROLOG (PROgramming in LOGic) language is chosen to implement the designed KBS. This programming language represents knowledge in rules of the form ‘‘IF THEN...ELSE’’. This language has been applied to other agricultural implementations. It is a suitable language as it is more to English and it is easy to understand rather than using other programming languages such as C or C++ or Visual Basic. It provides a good inference engine mechanism that automatically matches facts against patterns in the rules then determines which rules are applicable. It is the best programming language to represent natural language in to formal language, and as well it is open source language (Sajja and Akerkar, 2010).

The knowledge represented using IF_THEN rules was used to construct the knowledge base of the system. The IF_THEN rules were converted to prolog code so that they can be easily inferred by the expert system shell. The implementation of the expert system shell uses backward chaining logic in its inferencing. Preliminary symptoms of diseases and insects were recognized. Subsequently, particular disease/pest corresponding to the symptoms and actions that need to be taken were identified. This process, proceeding from the end result through a logical of causal chain back to symptoms, was well suited to developing a backward chaining system. A user interacts with the system through dialogue. The system forwards successive questions to identify the diseases /insects occurrence and to recommend treatment. Based on the symptoms observed and fed to the system, the system displays disease/insects associated to the symptoms and appropriate actions that need to be taken. When asked for consultation the system will ask the existence of several symptoms associated with a particular disease/insect. Accordingly, a disease/insect associated to the symptoms fed, its description, treatment and prevention will be displayed to the user.

As indicated in the figure 4.1 below the system was designed in such a way that the user could easily understand and follow the steps. The system starts with asking questions related to the symptoms of the diseases and pests that affect the coffee plant. If one of the symptoms is not related to the types of disease/pests, the system will trace the possibility of other diseases /pests. If this is found, then the system will ask the next symptoms related to disease /pest. Sometimes, users might key in the wrong characters for YES or NO. Error checking will take place in the system for any input information and keep the previous data in the temporary memory until the user keys in the right character of YES or NO. Once the system matches all the questions concerning the symptoms with the data in the system, the system will then display the type of disease/pest, description for the indentified infections and suggested treatments plus prevention. The users could get more explanation if she or he didn't satisfied with the provided suggestions by replying Yes for the question "do you need more explanation?" The users could also repeat the procedure by just keying in 'YES' after the system asks, "Do you want to continue?"

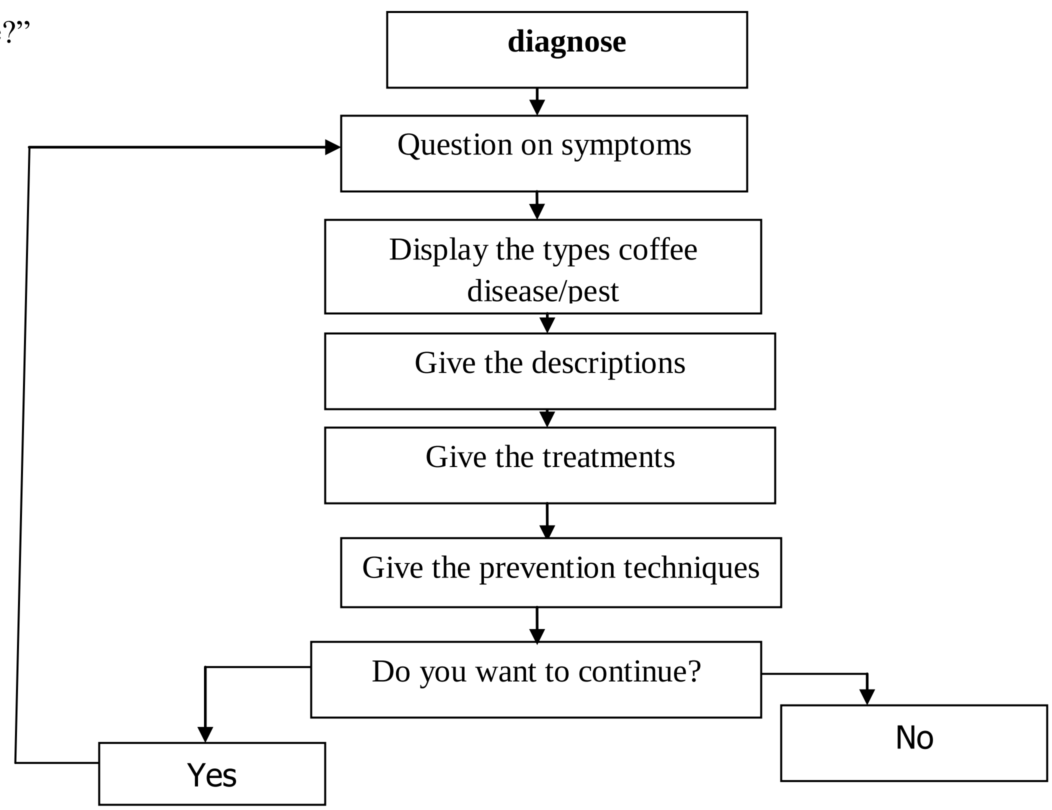


Figure 4.1 Functional follow of KBSCDDT system

4.4. User Interface

KBSCDDT used a simple user interface to display the information. When KBSCDDT identified a possible type of coffee disease/pest, the system would present descriptions and treatments and preventions of the disease/pests on the screen and the users can ask detail or more explanation if they did not satisfied with the provided suggestions in such away the users could observe it straight away. For example, when the type of disease/pest was identified, the typical disease/pest descriptions, treatments and prevention would appear on the computer screen and asked whether they need more explanation or not. The user could view different type of disease/pest problems, descriptions, and treatments for the coffee plant. The first page of the user interface welcomes users and describes what the system does as shown in the figure below figure 4.2

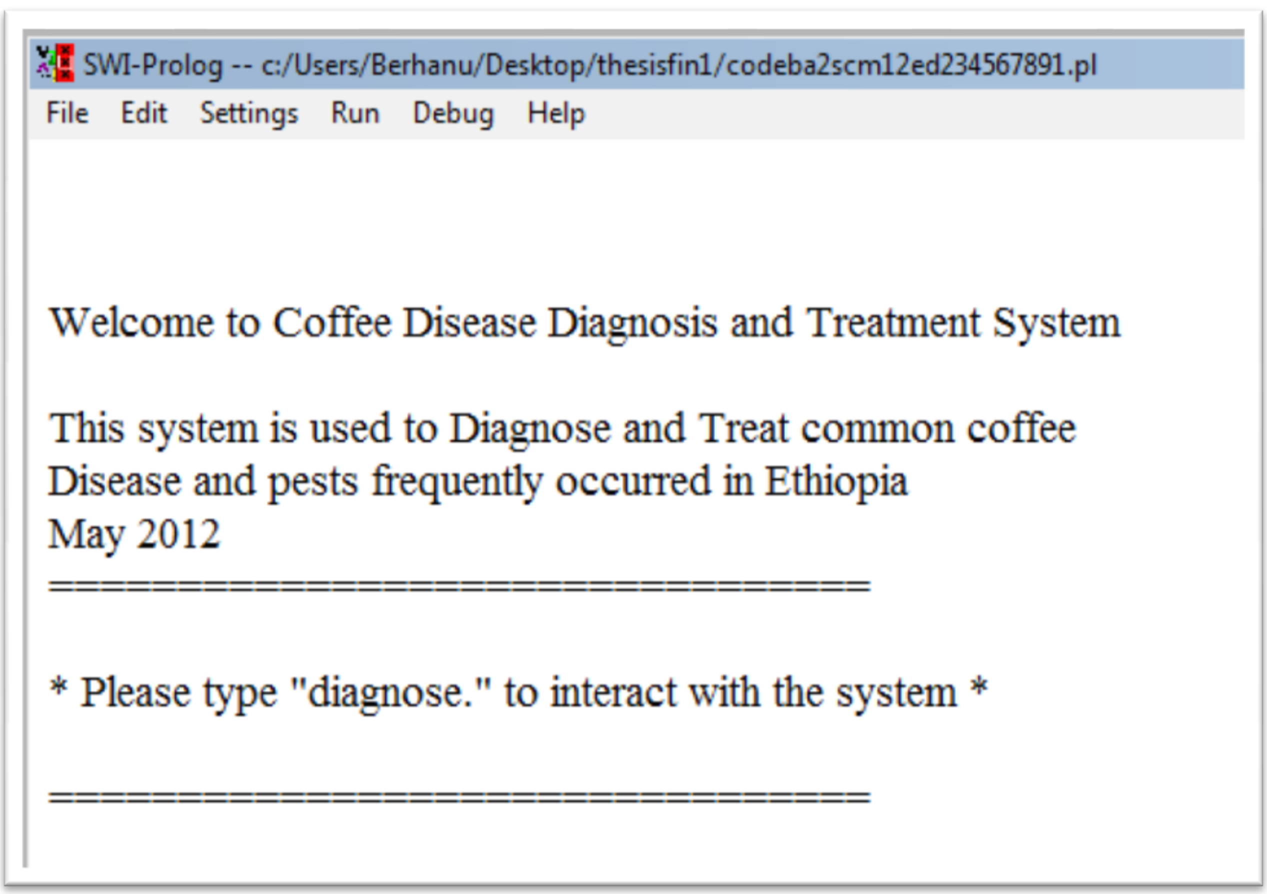
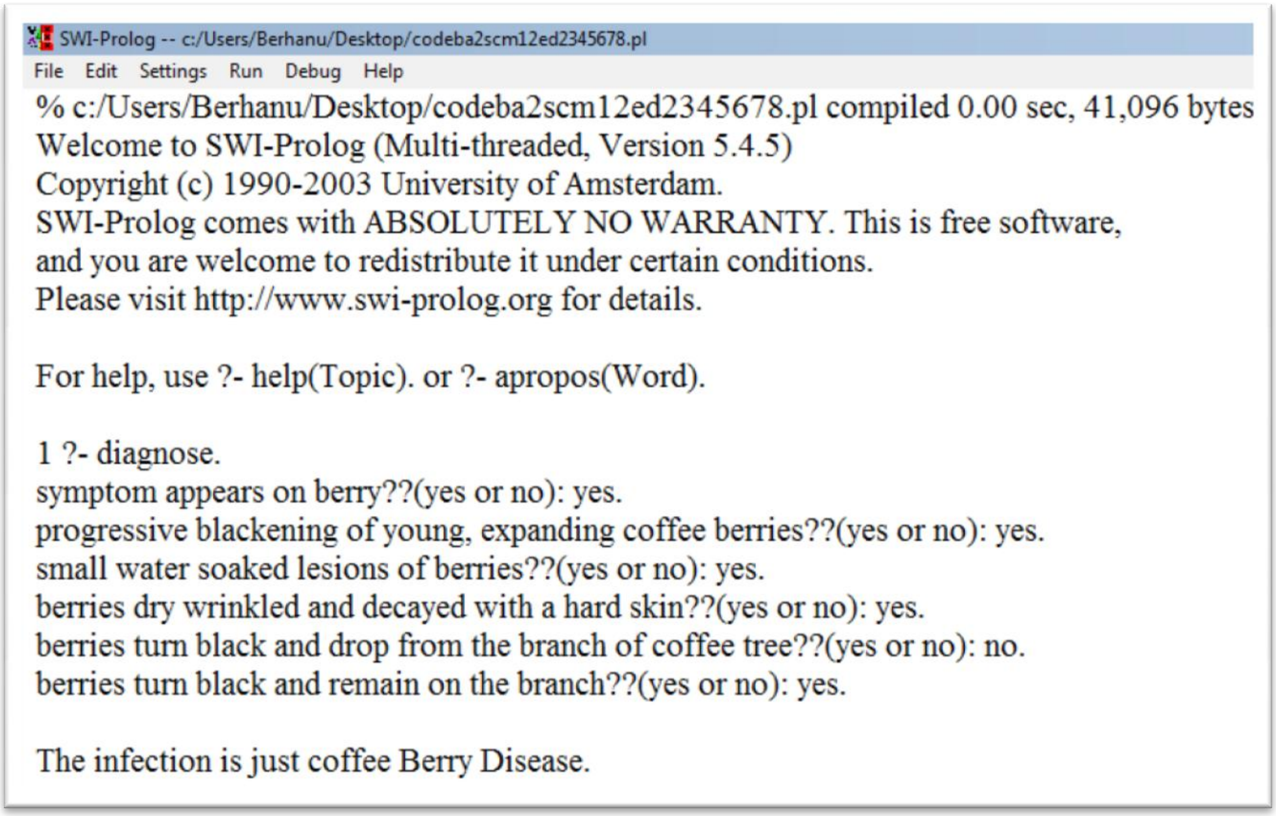


Figure 4.2 Welcoming windows of KBSCDDT user interface above

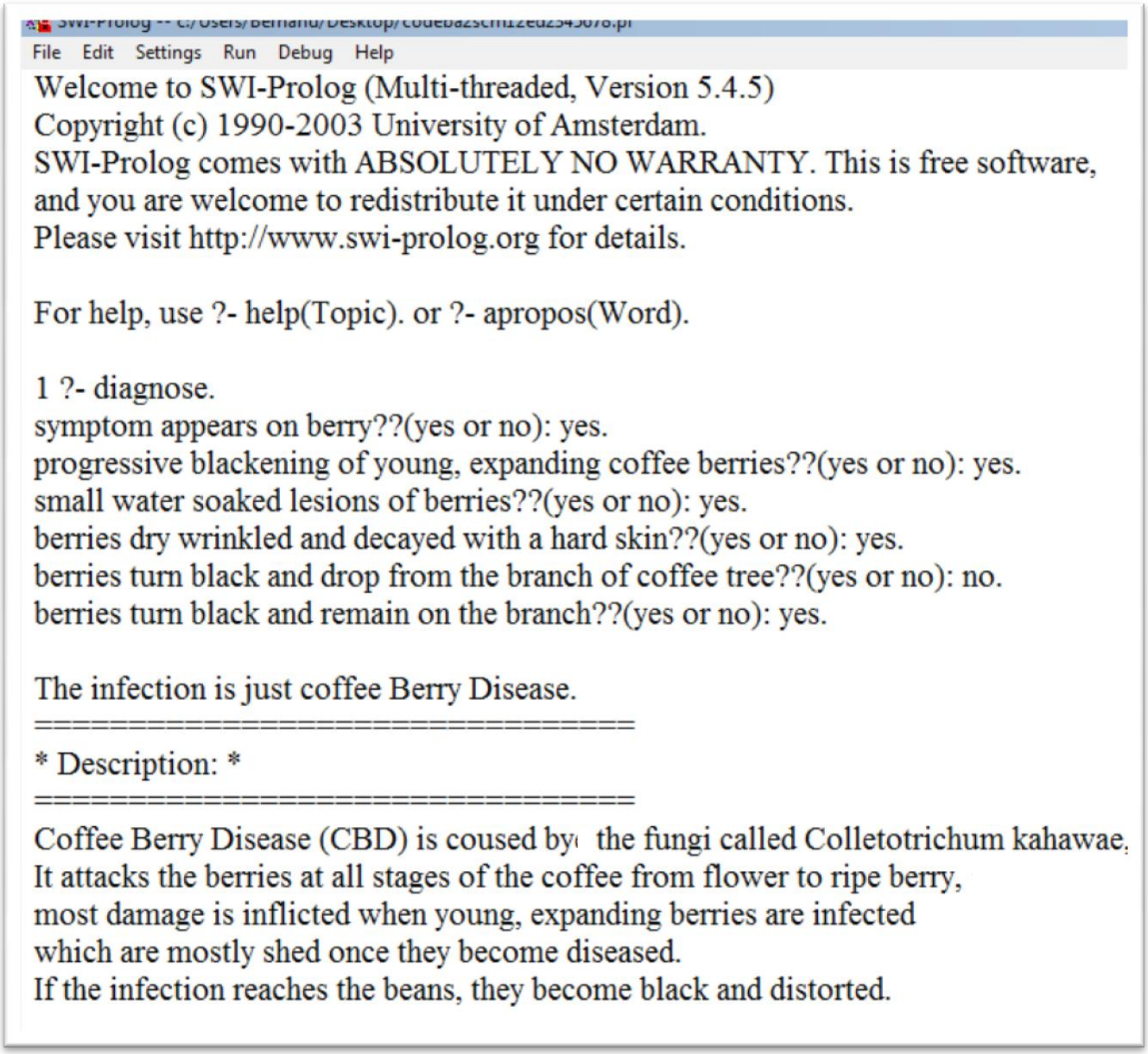
After the prototype displays the greeting page a user can interact directly with the system by typing “diagnose” followed by dot. As soon as a user types diagnose followed by dot the system gives gridline for users by providing options as (yes or no). The following figure shows the sample dialogue windows between the user and the system to identify the infections on coffee plant.



```
SWI-Prolog -- c:/Users/Berhanu/Desktop/codeba2scm12ed2345678.pl
File  Edit  Settings  Run  Debug  Help
% c:/Users/Berhanu/Desktop/codeba2scm12ed2345678.pl compiled 0.00 sec, 41,096 bytes
Welcome to SWI-Prolog (Multi-threaded, Version 5.4.5)
Copyright (c) 1990-2003 University of Amsterdam.
SWI-Prolog comes with ABSOLUTELY NO WARRANTY. This is free software,
and you are welcome to redistribute it under certain conditions.
Please visit http://www.swi-prolog.org for details.

For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- diagnose.
symptom appears on berry??(yes or no): yes.
progressive blackening of young, expanding coffee berries??(yes or no): yes.
small water soaked lesions of berries??(yes or no): yes.
berries dry wrinkled and decayed with a hard skin??(yes or no): yes.
berries turn black and drop from the branch of coffee tree??(yes or no): no.
berries turn black and remain on the branch??(yes or no): yes.

The infection is just coffee Berry Disease.
```

Figure 4.3 Sample dialogue windows between the user and the system to identify coffee infections.

After the system identifies the type of infection on coffee plant it provides the concerning description for the identified disease or pest. As indicated in the following window the indentified constraint based on user input from the dialogue is described in detail to better inform the user about the infection.

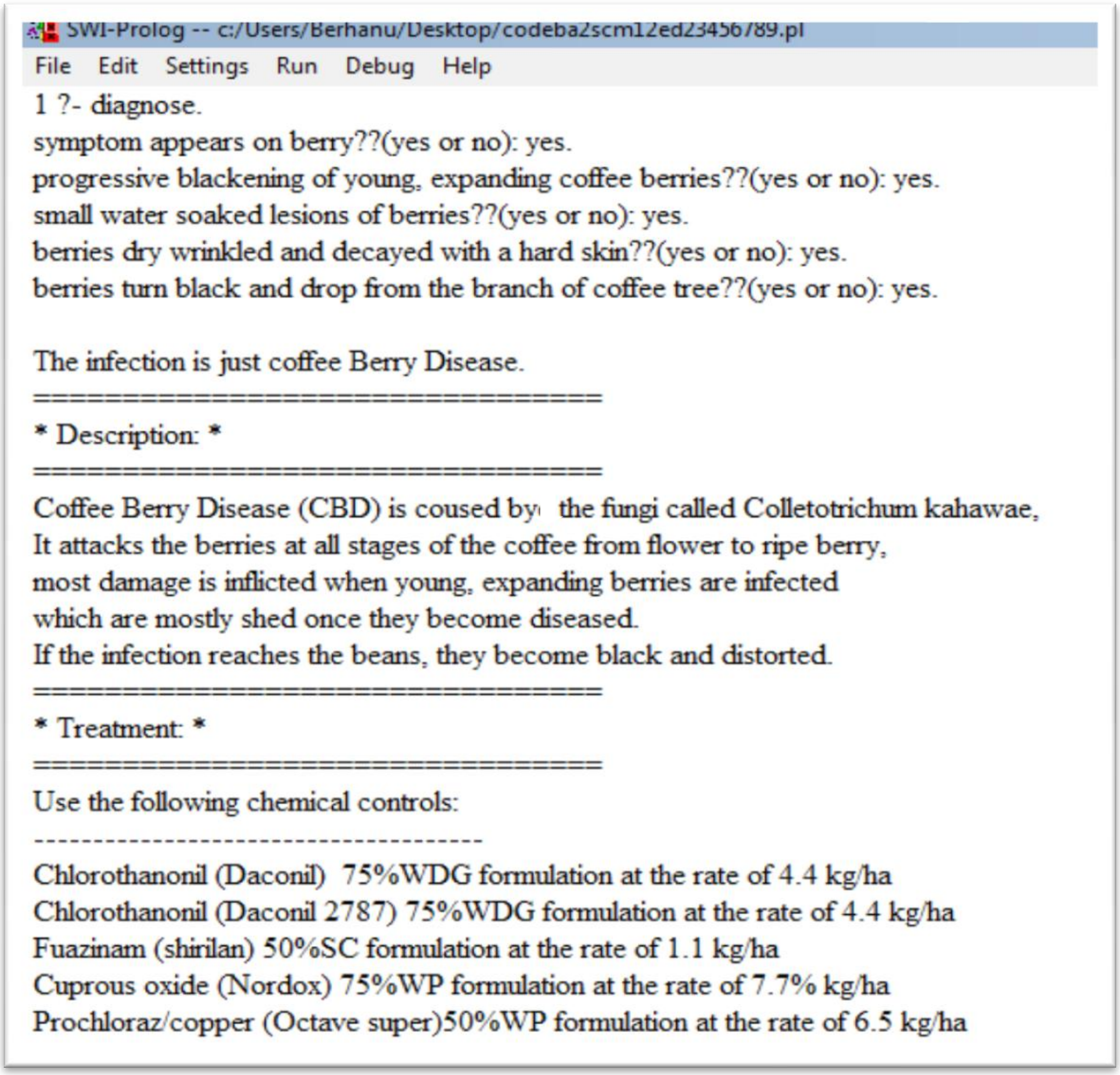


File Edit Settings Run Debug Help

```
Welcome to SWI-Prolog (Multi-threaded, Version 5.4.5)
Copyright (c) 1990-2003 University of Amsterdam.
SWI-Prolog comes with ABSOLUTELY NO WARRANTY. This is free software,
and you are welcome to redistribute it under certain conditions.
Please visit http://www.swi-prolog.org for details.

For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- diagnose.
symptom appears on berry??(yes or no): yes.
progressive blackening of young, expanding coffee berries??(yes or no): yes.
small water soaked lesions of berries??(yes or no): yes.
berries dry wrinkled and decayed with a hard skin??(yes or no): yes.
berries turn black and drop from the branch of coffee tree??(yes or no): no.
berries turn black and remain on the branch??(yes or no): yes.

The infection is just coffee Berry Disease.
=================================
* Description: *
=================================
Coffee Berry Disease (CBD) is coused by the fungi called Colletotrichum kahawae,
It attacks the berries at all stages of the coffee from flower to ripe berry,
most damage is inflicted when young, expanding berries are infected
which are mostly shed once they become diseased.
If the infection reaches the beans, they become black and distorted.
```

Figure 4.4 Sample dialogue window of the system's description for the identified disease.

After the constraint is identified and described well its recommended treatments are provided as it is presented in the following sample window.



```
SWI-Prolog -- c:/Users/Berhanu/Desktop/codeba2scm12ed23456789.pl
File  Edit  Settings  Run  Debug  Help
1 ?- diagnose.
symptom appears on berry??(yes or no): yes.
progressive blackening of young, expanding coffee berries??(yes or no): yes.
small water soaked lesions of berries??(yes or no): yes.
berries dry wrinkled and decayed with a hard skin??(yes or no): yes.
berries turn black and drop from the branch of coffee tree??(yes or no): yes.

The infection is just coffee Berry Disease.
===================================
* Description: *
===================================
Coffee Berry Disease (CBD) is coused by  the fungi called Colletotrichum kahawae,
It attacks the berries at all stages of the coffee from flower to ripe berry,
most damage is inflicted when young, expanding berries are infected
which are mostly shed once they become diseased.
If the infection reaches the beans, they become black and distorted.
===================================
* Treatment: *
===================================
Use the following chemical controls:
--------------------------------------
Chlorothanonil (Daconil)  75%WDG formulation at the rate of 4.4 kg/ha
Chlorothanonil (Daconil 2787) 75%WDG formulation at the rate of 4.4 kg/ha
Fuazinam (shirilan) 50%SC formulation at the rate of 1.1 kg/ha
Cuprous oxide (Nordox) 75%WP formulation at the rate of 7.7% kg/ha
Prochloraz/copper (Octave super)50%WP formulation at the rate of 6.5 kg/ha
```

Figure 4.5 Sample windows shows how it identified describe and threatened.

Next window with preventive mechanism information in addition to the above information is presented, it is shown as follow.

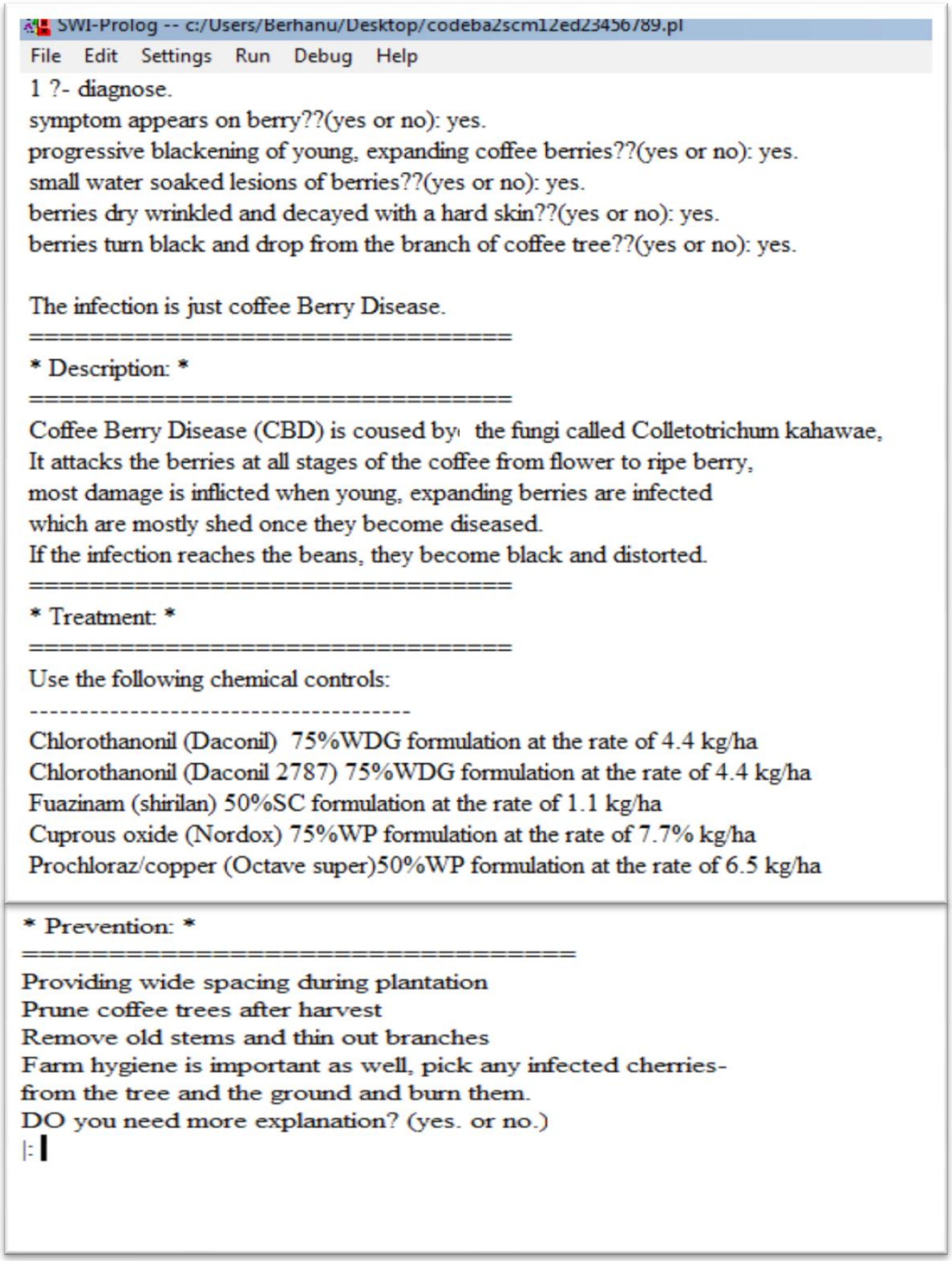


Figure 4.6 Sample window with identified infection and recommended information

Here if the users did not satisfied with the provided recommendation they can seek for additional more explanation.

4.5. System Evaluation

The developed system, KBSCDDT is tested and evaluated to check whether the objectives of the research are achieved or not. The evaluation and testing issue of the system is summarized by the question “does KBSCDDT give acceptable and accurate advisory service to diagnosis coffee with infection?” Visual interaction evaluation technique is used. In this research the visual interaction method is used to address user acceptance issue and helps to assess the performance of the system from user’s perspective. Visual interaction evaluation method allows the user to make comments while interacting with the system. Visual interaction helps to assess the performance of the system from user’s perspective. As discussed in the literature review chapter system evaluation is the basic issue for the application of successful and effective knowledge base system. To address the issue of user acceptance the researcher uses visual interaction along with close ended questionnaires.

Visual interaction evaluation method allows the domain expert to make comments by interacting with the system. It is used to evaluate the performance of the prototype from the users’ point of view. Similarly the questionnaires are helped to assess and evaluate the acceptability and applicability of the prototype in the domain area. Additionally, they are used to consider the attitude of the users about the prototype knowledge based system. These questioners are attached in appendix III.

For the purpose of user acceptance evaluation process, four domain experts from Jimma Agricultural Research Center (JARC) selected as system evaluators. These experts are selected purposively from plant pathologist and entomologist. All of the selected experts are working in the coffee disease and pests issue. Additionally, these experts have prior knowledge about the system during their involvement in the different stages of the prototype development. Before starting the evaluation process, the researcher gave explanation about the system. This explanation helped the experts to avoid the variation of awareness among them about the prototype knowledge based system. After the evaluators are interacting with the system by using test cases which have similar parameter with the rules in the prototype, they give their feedback on the questionnaires.

The questions are closed ended questions. Among them the first three questions are on the user interface design an aspect which is basic for users interface satisfaction. These questions assessed whether the user interface of the system is easy to use attractiveness and time efficiency of the system. The rest questions are used to evaluate the prototype's accuracy, adequacy, the problem solving ability and significance of the prototype knowledge based system in diagnosing coffee disease and pests. All these seven closed ended questions answered as excellent, very good, good, fair and poor. Therefore, for the ease of analyzing the relative performance of the system based on users evaluation the researcher assigned numbers for each criteria as excellent=5, very good= 4, good=3, fair=2, poor=1. The system evaluators give the value for each closed ended questions. The following table indicates the results obtained.

		Criterions					
No	Questions	Poor(1)	Fair(2)	Good(3)	v.good(4)	Excellent(5)	Average
1	The easiness of the system to use and interact with it is	0	0	0	2	2	4.5
2	Attractiveness of the system is	0	0	1	3	0	3.75
3	The efficiency of the system in time is	0	0	0	3	1	4.25
4	The accuracy of the system to reach the decision about coffee disease/pests identification.	0	0	1	1	2	4.25
5	The sufficiency of the knowledge does the system incorporate to diagnosis coffee disease and pests in its scope is	0	0	1	2	1	4.0
6	The accuracy of the	0	0	1	1	2	4.25

	system in providing the right treatment and recommendation for the identified disease or pest is						
7	How do you rate the significance of the system in the domain area?	0	0	0	3	1	4.25
		Total average					~4.18

Table 4.11 KBSCDDT user performance evaluation results

As shown in table above (table 4.11) 50% of the respondents rated easiness to use and interact with it as very good while the remaining 50% respond the same question as excellent. In the same way, for question ‘attractiveness of the prototype’ 25% of the respondents evaluated as good 75% of them as very good and none of them rate it as excellent. Similarly, 75% of the respondent rated the efficiency of time as very good and the remaining 25% of them as excellent. Additionally 25% of them responded as good, 25% of them as very good and the rest 50% as excellent for the criteria “system’s ability to identify type of infections”. Likewise for the criterion ‘adequacy of knowledge it contain ’ 25% of them respond as good, 50% of them rated as very good and the rest 25% as excellent. As well for the criterion ‘does it provide the right treatment and recommendation for the identified infection’ 25% of the respondents respond as good, 25% of them as very good and 50% of them rated as excellent. Lastly, concerning to the question related to the significance of the prototype 75% of the respondent evaluated as very good and the rest 25% as excellent. Based on the results obtained the overall average performance of the prototype with user’s point of view is 4.18 on a scale of 5. This result indicates that the overall average performance of the prototype knowledge based system is about 83.6%. This implies that the modeled prototype was performs well in making right decisions on the diagnosis of coffee infection.

4.6. Discussion

The evaluation and testing procedures help to address the question of user acceptance and accuracy of the prototype. Visual interaction and questionnaire methods are used to assess user's acceptance issues and applicability of the prototype. Based on the evaluation results obtained from visual interaction with closed ended questions none of the evaluators respond as poor or fair. On the other hand evaluators reply good four times (14.3%), very good fifteen times (53.6%) excellent nine times (32%) the following table summarizes the results obtained on close ended questions.

Respondents who respond as	Poor(1)	Fair(2)	Good(3)	Very good(4)	Excellent(5)	average
Total number	0	0	4	15	9	4.18
%age of 100%	0	0	14.3%	53.6%	32%	83.6%

Table 4.12 Users evaluation result summary on closed ended questions

As shown in the above table 4.12 the overall average user acceptance evaluation of the prototype knowledge based system is about 83.6%, this means the prototype is accepted by 83.6% of respondents. Therefore, above 83% of users are satisfied with the easiness, attractiveness, speed, accuracy, adequacy problem solving ability and the significance of the prototype knowledge based system in the domain area. This implies that the prototype modeled relevance and satisfactory domain knowledge in useful way and it performs well in making right decisions on the diagnosis of coffee infection.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Coffee is a well known commodity and this industry plays an important role in the Ethiopian economy. This subsector provides a source of coffee product which contributes to the national economy. However, coffee diseases and pests are a substantial source of monetary loss to planters and reduce the overall production of the crop. Disease outbreaks may severely limit the crop yield and result in considerable loss of investment. However, planters might face difficulties to consult these problems to expert due to the agriculture sites that are scattered in the rural area.

In any agricultural production system, accumulation and integration of related knowledge and information from many diverse sources play important role. Agriculture specialists and raw experiences are the common sources to provide information that the different stakeholders require for decision making to improve agricultural production. Agricultural specialists' assistance is not always available when the need arises for their help. Expert Systems will play a major role in resolving such problem and in dissemination and application of useful knowledge leading to economic growth and higher standards of living. In recent years, tools, technologies and applications of information technologies have emerged as efficient and effective measures for up gradation of the whole agricultural fields, ranging from scientific studies to farmers help. Integration of expert system as a powerful tool for the stakeholders of agricultural production has extensive potential. In agriculture, applications of expert system are mainly found in the area of diseases diagnosis and pest controls.

This paper has presented the architecture, design and development of an expert system for diagnosis of diseases and pests in the coffee plant. The knowledge base contains the knowledge about the different diseases and pests of coffee plant represented. Such system is especially useful for those farmers who are not getting the agricultural specialists at any time for their help to control the problems in their coffee plant. The system is an operational automatic identification tool that helps non experts to identify major disease and pests that frequently occur in coffee (insects pests, fungal diseases), and provides the appropriate description, treatments and prevention. The objective of this system was to serve as a diagnostic tool in coffee infections and it includes the most economically important diseases and insect pests that affect this crop. All the diagnostic knowledge is contained in a knowledge base. To implement the system prolog programming language was used and the knowledge is represented in the linguistic form of IF-THEN rules.

The inference engine analyzes specific information entered by the user to determine potential risks of outbreak for coffee crop diseases/pests common to Ethiopia. These potential outbreak risks are presented as identification, description and treatment and prevention. The system was evaluated using user interaction technique. By preparing questions for the experts in the domain to fill it about the overall performance of the system after they appropriately interact with the system, it was shown that the expert system agreed with human expert opinions in 83.6 percent of the decisions made. It also reviews about the ruled based expert system; modules and architecture, also state the advantages of rule based expert system. Beside, that the system that has been developed in agriculture were also mentioned in this research.

5.2. Recommendations

The system achieves its objectives by demonstrating the applicability of rule based system by developing a knowledge based system for diagnosis and treatment of major coffee diseases and pests with hopeful of performance and user acceptance. This thesis research is the promising study for further research works to fully implement the knowledge based system in the agricultural domain area. As a result the following recommendations are given based on the observed opportunities and uncover areas by this research. These recommendations are made for further investigations to fully implement the functionality of the prototype or to develop a new knowledge based system in the domain area.

- Due to the time limitation for the research, the study attempted to develop advisory knowledge based system for about four major fungi diseases and five major insect pests and the scope of the prototype is limited to identifying coffee infections and recommending fist line treatments and remedies however the scope of the knowledge based system should be expanded to include other infestations such as bacterial, viral diseases and mammal, birds pest and nematodes.

- This rule based system unable to learn from experience and do not operate with cases which have not matching facts in the rule base of the system. As a result the development of self learning system should be considered by using appropriate machine learning techniques like neural network, Bayesian networks, etc.
- To enhance the performance of the prototype knowledge based system the hybrid strategy approaches should be investigated which combines case based reasoning. The inclusion of case based reasoning helps the system to learn from documented experiences.

- In its present version, this system is a standalone one. For the future, it will be more attractive and effective if a Web-based version of it is developed that would make the diagnostic system accessible to anyone (particularly scattered users) with a computer and an Internet connection.
- It is proven that expert systems in agriculture helps a lot in increasing the crop production. But the system was in English language. By developing an expert system in agriculture in a mother tongue of a farmer, helps him/her to know the facts and truths in increasing the production.

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APPENDIXES

Appendix I

Interview questions

After introducing the objective of the study and requesting the respondents' participation in the study the interviewer records their answers for the following interview questions.

1. What coffee diseases and pests are identified in our country?
2. Which diseases and pests are having more economic importance?
3. How to recognize them or what are the key symptoms of the diseases?
4. What looks the feeding habitat of the pests?
5. What considerations do you use to identify particular coffee pests?
6. What are the treatments for each of the disease and pest?
7. What steps do you follow to diagnosis them?
8. What are the recommended actions to prevent them before their occurrence?

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Appendix II

Samples Rules from the knowledge base

disease('coffee Berry Disease'):-

symptom_appears_on_berry,

progressive_blackening_of_young_expanding_coffee_berries,

small_water_soaked_lesions_of_berries,

berries_dry_wrinkled_and_decayed_with_a_hard_skin,

berries_turn_black_and_drop_from_the_branch_of_coffee_tree;

berries_turn_black_and_drop_remain_on_the_branch.

disease('cofffe wilt disease'):-

check,

development_of_blue_black_discoloration_of_the_wood,

blackening_of_the_stem_spiral_and_drying_of_leaf_on_a_coffee_tree,

yellowing_folding_and_inward_curling_of_the_leaves,

drying_of_the_whole_trees_and_become_leaf_less.

disease('brown eye spot'):-

check,

small_chlorotic_spots_on_the_upper_parts_of_leaves,

the_upper_side_of_the_leaf_become_reddish-brown_or_brown_with_a_grayish_centre,

dark_brown_patch_lesions_on_the_coffee_berries.

disease('coffee leaf rust(CLR)'):-

check,

yellow_or_blotchy_orange_powdery_pustules_or_lesions_on_the_underside_of_coffee_leaves,

numerous_small_yellow_powdery_spores_on_the_leaves.

disease('Antestia bug'):-

check,

shield_shaped_and_dark_brown_orange_and_white_color_like_pest,

blackening_of_flower_buds_and_failing_to_flower,

sucking_of_young_fruits_causing_them_shrivel_rot_and_abortion,

rotting_of_the_developing_beans,

berries_yield_zebra_pattern_beans.

disease('Coffee Berry Borer'):-

check,

small_blackish_beetle_or_tiny_black_beetle,

smaller_round_holes_near_the_apex_of_large_green_or_ripe_berrie,

beans_with_a_distinctive_blue-green_staining,

berries_rot_and_fall,

berries_turn_black_and_dry_then_falling_to_the_ground.

disease('Coffee blotchleaf miner'):-

check,

tiny_moths_like,

brown_irregular_blotches_on_the_upper_surface_of_the_eaves, the_upper_surface_of_the_leaf_crack_open_revealing_a_small_white_caterpillar_in_a_fresh_mine,

leaves_change_color_to_brown.

disease('Green scale'):-

check,

immobile_green_insect,

feed_on_the_berries_by_sucking_the_plant_sap,

ants_are_often_to_be_found_in_the_vicinity_of_scale,

upper_surface_of_the_leaves_covered_with_spots_of_sticky,

transparent_honey_dew_and_often_black_mould_growing_on_the_honey_dew,

leaf_fall.

symptom_appears_on_berry:-ask('symptom appears on berry?').

progressive_blackening_of_young_expanding_coffee_berries:-ask('progressive blackening of young, expanding coffee berries?').

small_water_soaked_lesions_of_berries:-ask('small water soaked lesions of berries?').

berries_dry_wrinkled_and_decayed_with_a_hard_skin:-ask('berries dry wrinkled and decayed with a hard skin?').

berries_turn_black_and_drop_from_the_branch_of_coffee_tree:-ask('berries turn black and drop from the branch of coffee tree?').

berries_turn_black_and_drop_remain_on_the_branch:-ask('berries turn black and remain on the branch?').

development_of_blue_black_discoloration_of_the_wood:-ask('development of blue-black discoloration of the wood').

blackening_of_the_stem_spiral_and_drying_of_leaf_on_a_coffee_tree:-ask('blackening (‘dieback’) of the stem, spiral and drying of leaf on a coffee tree').

yellowing_folding_and_inward_curling_of_the_leaves:-ask('yellowing, folding and inward curling of the leaves').

drying_of_the_whole_trees_and_become_leaf_less:-ask('drying of the whole trees& become leafless').

small_chlorotic_spots_on_the_upper_parts_of_leaves:-ask('small chlorotic spots on the upper parts of leaves?').

the_upper_side_of_the_leaf_become_reddish-brown_or_brown_with_a_grayish_centre:-ask('the upper side of the leaf become reddish-brown or brown with a grayish centre?').

dark_brown_patch_lesions_on_the_coffee_berries:-ask('dark brown, patch lesions on the coffee berries?').

yellow_or_blotchy_orange_powdery_pustules_or_lesions_on_the_underside_of_coffee_leaves:-ask('Yellow or blotchy, orange powdery pustules, or lesions on the underside of coffee leaves').

numerous_small_yellow_powdery_spores_on_the_leaves:-ask('numerous small, yellow, powdery spores on the leaves').

shield_shaped_and_dark_brown_orange_and_white_color_like_pest:-ask('dark brown with orange and white marking color?').

blackening_of_flower_buds_and_failing_to_flower:-ask('feeding on green berries, flower buds and branches?').

sucking_of_young_fruits_causing_them_shrivel_rot_and_abortion:-ask('causing blackening of flower buds with no flower/fruit set?').

rotting_of_the_developing_beans:-ask('branches grow side shoots?').

berries_yield_zebra_pattern_beans:-ask('berries yield zebra pattern beans?').

small_blackish_beetle_or_tiny_black_beetle:-ask('small blackish beetle or tiny black beetle?').

smaller_round_holes_near_the apex_of_large_green_or_ripe_berries:-ask('smaller round holes near the apex of large green or ripe berries?').

beans_with_a_distinctive_blue-green_staining:-ask('beans with a distinctive blue-green staining?').

berries_rot_and_fall:-ask('berries rot and fall?').

berries_turn_black_and_dry_then_falling_to_the_ground:-ask('berries turn black and dry then falling to the ground?').

small_blackish_beetle_or_tiny_black_beetle:-ask('small blackish beetle or tiny black beetle?').

smaller_round_holes_near_the_apex_of_large_green_or_ripe_berrie:-ask('smaller round holes near the apex of large green or ripe berries?').

beans_with_a_distinctive_blue-green_staining:-ask('beans with a distinctive blue-green staining?').

berries_rot_and_fall:-ask('berries rot and fall?').

berries_turn_black_and_dry_then_falling_to_the_ground:-ask('berries turn black and dry then falling to the ground?').

tiny_moths_like:-ask('tiny moth like pest?').

brown_irregular_blotches_on_the_upper_surface_of_the_eaves:-ask('brown irregular blotches on the upper surface of the leaves?').

the_upper_surface_of_the_leaf_crack_open_revealing_a_small_white_caterpillar_in_a_fresh_mine:-ask('the upper surface of the leaf crack open revealing a small white caterpillar in a fresh mine?').

leaves_change_color_to_brown:-ask('leaves change color to brown?').

immobile_green_insect:-ask('immobile green insect?').

feed_on_the_berries_by_sucking_the_plant_sap:-ask('Feed on the berries by sucking the plant sap?').

ants_are_often_to_be_found_in_the_vicinity_of_scale:-ask('Ants are often to be found in the vicinity of scale?').

upper_surface_of_the_leaves_covered_with_spots_of_sticky:-ask('Upper surface of the leaves covered with spots of sticky?').

transparent_honey_dew_and_often_black_mould_growing_on_the_honey_dew:-ask('transparent honey dew and often black mould growing on the honey dew?').

leaf_fall:-ask('Leaf fall?')

Appendix III

Questionnaires to evaluate Knowledge based system for coffee diseases diagnosis and treatment

1. The easiness of the system to use and interact with it is

Poor ☐ fair ☐ good ☐ very good ☐ excellent ☐

2. Attractiveness of the system is

Poor ☐ fair ☐ good ☐ very good ☐ excellent ☐

3. The efficiency of the system in time is

Poor ☐ fair ☐ good ☐ very good ☐ excellent ☐

4. The accuracy of the system to reach the decision about the domain area.

Poor ☐ fair ☐ good ☐ very good excellent ☐

5. The sufficiency of the knowledge does the system incorporate to diagnosis coffee disease and pests is

Poor ☐ fair ☐ good ☐ very good ☐ excellent ☐

6. The accuracy of the system in providing the right treatment and recommendation for the identified disease or pest is

Poor ☐ fair ☐ good ☐ very good ☐ excellent ☐

7. How do you rate the significance of the system in the domain area?

Poor ☐ fair ☐ good ☐ very good ☐ excellent ☐

DECLARATION

I certify that this thesis to which it refers is the product of my own work and that any ideas or quotation from the work of other people, published or otherwise are fully acknowledged in accordance with the standard referring practices of the discipline.

Declared By:

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