Chapter 12: Fundamentals of Expert Systems

12.1 Opening Vignette:
CATS-1 at General Electric

The Problem

General Electric's (GE)

Top Locomotive Field Service Engineer was Nearing Retirement

Traditional Solution: Apprenticeship

Good Short-term Solution

BUT GE Wanted

- A more effective and dependable way to disseminate expertise
- To prevent valuable knowledge from retiring
- To minimize extensive travel or moving the locomotives

The Expert System Solution

- To MODEL the way a human troubleshooter works
  - Months of knowledge acquisition
  - 3 years of prototyping
- A novice engineer or technician can perform at an expert's level
  - On a personal computer
  - Installed at every railroad repair shop served by GE

12.2 (ES) Introduction

- ***Expert System*: from the term *knowledge-based expert system***
- **An *Expert System* is a system that employs human knowledge captured in a computer to solve problems that ordinarily require human expertise**
- **ES *imitate* the expert's reasoning processes to solve specific problems**

12.3 History of Expert Systems

1. Early to Mid-1960s

- One attempt: the General-purpose Problem Solver (GPS)

- General-purpose Problem Solver (GPS)
- A procedure developed by Newell and Simon [1973] from their Logic Theory Machine -
  - Attempted to create an "intelligent" computer
  - Predecessor to ES
  - Not successful, but a good start

2. Mid-1960s: Special-purpose ES programs

- **DENDRAL**
- **MYCIN**

- **Researchers recognized that the problem-solving mechanism is only a small part of a complete, intelligent computer system**
  - **General problem solvers *cannot* be used to build high performance ES**
  - **Human problem solvers are good only if they operate in a very *narrow domain***
  - **Expert systems must be constantly *updated* with new information**
  - **The complexity of problems requires a considerable amount of *knowledge about the problem area***

3. *Mid 1970s*

- Several Real Expert Systems Emerge
- Recognition of the Central Role of Knowledge
- AI Scientists Develop
  - Comprehensive knowledge representation theories
  - General-purpose, decision-making procedures and inferences

- **Limited Success Because**
  - Knowledge is Too Broad and Diverse
  - Efforts to Solve Fairly General Knowledge-Based Problems were Premature

BUT

- **Several *knowledge representations* worked**

Key Insight

- ***The power of an ES is derived from the specific knowledge it possesses, not from the particular formalisms and inference schemes it employs***

4. Early 1980s

- **ES Technology Starts to go Commercial**
  - **XCON**
  - **XSEL**
  - **CATS-1**
- **Programming Tools and Shells Appear**
  - **EMYCIN**
  - **EXPERT**
  - **META-DENDRAL**
  - **EURISKO**
- **About 1/3 of These Systems Are Very Successful and Are Still in Use**

Latest ES Developments

- Many tools to expedite the construction of ES at a reduced cost
- Dissemination of ES in thousands of organizations
- Extensive integration of ES with other CBIS
- Increased use of expert systems in many tasks
- Use of ES technology to expedite IS construction

- **The object-oriented programming approach in knowledge representation**
- **Complex systems with multiple knowledge sources, multiple lines of reasoning, and fuzzy information**
- **Use of multiple knowledge bases**
- **Improvements in knowledge acquisition**
- **Larger storage and faster processing computers**
- **The Internet to disseminate software and expertise.**

12.4 Basic Concepts of Expert Systems

- Expertise = kepakaran
- Experts
- Transferring Expertise
- Inferencing Rules
- Explanation Capability

Expertise

- **Expertise is the extensive, task-specific knowledge acquired from training, reading and experience**
  - **Theories about the problem area**
  - **Hard-and-fast rules and procedures**
  - **Rules (heuristics)**
  - **Global strategies**
  - **Meta-knowledge (knowledge about knowledge)**
  - **Facts**
- **Enables experts to be better and faster than nonexperts**

IS In Focus 12.2: Some Facts about Expertise

- Expertise is usually associated with a high degree of intelligence, but not always with the smartest person
- Expertise is usually associated with a vast quantity of knowledge
- Experts learn from past successes and mistakes
- Expert knowledge is well-stored, organized and retrievable quickly from an expert
- Experts have excellent recall

Experts

- Degrees or levels of expertise
- Nonexperts outnumber experts often by 100 to 1

Human Expert Behaviors

- Recognizing and formulating the problem
- Solving the problem quickly and properly
- Explaining the solution
- Learning from experience
- Restructuring knowledge
- Breaking rules
- Determining relevance
- Degrading gracefully (awareness of

Transferring Expertise

- **Objective of an expert system**
  - **To transfer expertise from an expert to a computer system and**
  - **Then on to other humans (nonexperts)**
- **Activities**
  - **Knowledge acquisition**
  - **Knowledge representation**
  - **Knowledge inferencing**
  - **Knowledge transfer to the user**
- **Knowledge is stored in a *knowledge base***

Two Knowledge Types

- **Facts**
- **Procedures (Usually Rules)**

Regarding the Problem Domain

Inferencing

- **Reasoning (Thinking)**
- **The computer is programmed so that it can make inferences**
- **Performed by the *Inference Engine***

Rules

- **IF-THEN-ELSE**
- **Explanation Capability**
  - **By the justifier, or explanation subsystem**
- **ES versus Conventional Systems (Table 12.1)**

TABLE 12.1 Comparison of Conventional Systems and Expert Systems

Conventional Systems	Expert Systems
Information and its processing are usually combined in one sequential program	Knowledge base is clearly separated from the processing (inference) mechanism (i.e., knowledge rules separated from the control)
Program does not make mistakes (programmers do)	Program may make mistakes
Do not (usually) explain why input data are needed or how conclusions are drawn	Explanation is a part of most ES
Require *all* input data. May not function properly with missing data unless planned for	Do *not* require all initial facts. Typically can arrive at reasonable conclusions with missing facts
Changes in the program are tedious	Changes in the rules are easy to accomplish
The system operates only when it is completed	The system can operate with only a few rules (as the first prototype)
Execution is done on a step-by-step (algorithmic) basis	Execution is done by using heuristics and logic
Effective manipulation of large databases	Effective manipulation of large knowledge bases
Representation and use of data	Representation and use of knowledge
Efficiency is a major goal	Effectiveness is the major goal
Easily deal with quantitative data	Easily deal with qualitative data
Use numerical data representations	Use symbolic knowledge representations
Capture, magnify and distribute access to numeric data or to information	Capture, magnify and distribute access to judgment and knowledge

12.5 Structure of Expert Systems

- Development Environment
- Consultation (Runtime) Environment

(Figure 12.2)

Three Major ES Components

- Knowledge Base
- Inference Engine
- User Interface

All ES Components

- Knowledge Acquisition Subsystem
- Knowledge Base
- Inference Engine
- User
- User Interface
- Blackboard (Workplace)
- Explanation Subsystem (Justifier)
- Knowledge Refining System

- Most ES do not have a Knowledge Refinement Component

(See Figure 12.2)

Knowledge Acquisition Subsystem

- Knowledge acquisition is the accumulation, transfer and transformation of problem-solving expertise from experts and/or documented knowledge sources to a computer program for constructing or expanding the knowledge base
- Requires a knowledge engineer

Knowledge Base

- **The knowledge base contains the knowledge necessary for understanding, formulating, and solving problems**

- **Two Basic Knowledge Base Elements**
  - **Facts**
  - **Special heuristics, or rules that direct the use of knowledge**

  - **Knowledge is the primary raw material of ES**
  - **Incorporated knowledge representation**

Inference Engine

- The ***brain*** of the ES
- The control structure or the rule interpreter
- Provides a methodology for reasoning

Inference Engine Major Elements

- Interpreter
- Scheduler
- Consistency Enforcer

User Interface

- **Language processor for friendly, problem-oriented communication**
- **NLP, or menus and graphics**

Blackboard (Workplace)

- Area of working memory to
  - Describe the current problem
  - Record Intermediate results
- Records Intermediate Hypotheses and Decisions
  1. Plan
  2. Agenda
  3. Solution

Explanation Subsystem (Justifier)

- **Traces responsibility and explains the ES behavior by interactively answering questions**
  - **Why?**
  - **How?**
  - **What?**
  - **(Where? When? Who?)**
- **Knowledge Refining System**
  - **– Learning for improving performance**

12.6 The Human Element in Expert Systems

- **Builder and User**
- **Expert and Knowledge engineer.**

- **The Expert**
  - **Has the special knowledge, judgment, experience and methods to give advice and solve problems**
  - **Provides knowledge about task performance**

The Knowledge Engineer

- **Helps the expert(s) structure the problem area by interpreting and integrating human answers to questions, drawing analogies, posing counterexamples, and bringing to light conceptual difficulties**

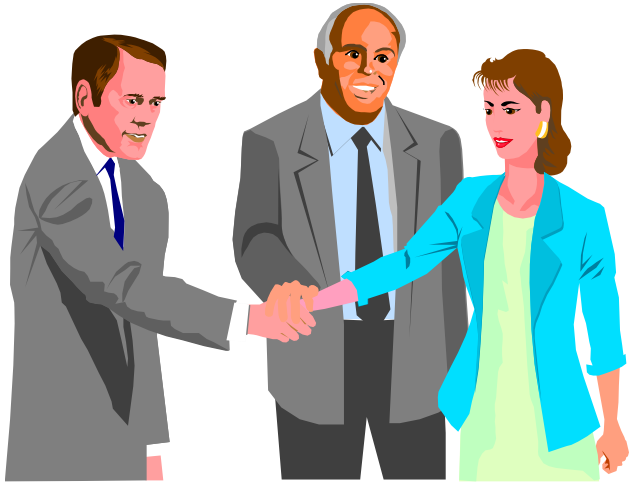
- **Usually also the System Builder**

The User

- **Possible Classes of Users**
  - **A non-expert client seeking direct advice - the ES acts as a *Consultant* or *Advisor***
  - **A student who wants to learn - an *Instructor***
  - **An ES builder improving or increasing the knowledge base - a *Partner***
  - **An expert - a *Colleague* or *Assistant***
- **The Expert and the Knowledge Engineer Should Anticipate Users' Needs and Limitations When Designing ES**

Other Participants

- System Builder
- Tool Builder
- Vendors
- Support Staff
- Network Expert



(Figure 12.3)

12.7 How Expert Systems Work

Major Activities of ES Construction and Use

- Development
- Consultation
- Improvement

ES Development

- Construction of the knowledge base
- Knowledge separated into
  - *Declarative* (factual) knowledge and
  - *Procedural* knowledge
- Construction (or acquisition) of an inference engine, a blackboard, an explanation facility, and any other software
- Determine appropriate knowledge representations

Participants

- **Domain Expert**
- **Knowledge Engineer and**
- **(Possibly) Information System Analysts and Programmers**

ES Shell

- **Includes All Generic Components of an ES**
- ***No* Knowledge**
  - **EMYCIN from MYCIN**
  - **RESOLVER (was EXSYS)**

Consultation

- **Deploy ES to Users (Typically Novices)**
- **ES Must be *Very Easy* to Use**

- **ES Improvement**
  - **By Rapid Prototyping**

12.8 An Expert System at Work

See text or do a demo in Resolver (Exsys)

12.9 Problem Areas Addressed by Expert Systems

- Generic Categories of Expert Systems (Table 12.2)
  - Interpretation systems
  - Prediction systems
  - Diagnostic systems
  - Design systems
  - Planning systems
  - Monitoring systems
  - Debugging systems
  - Repair systems
  - Instruction systems
  - Control systems
- Example in Human Resource Management (Table 12.3)

TABLE 12.2 Generic Categories of Expert Systems

Category	Problem Addressed
Interpretation	Inferring situation descriptions from observations
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observations
Design	Configuring objects under constraints
Planning	Developing plans to achieve goal(s)
Monitoring	Comparing observations to plans, flagging exceptions
Debugging	Prescribing remedies for malfunctions
Repair	Executing a plan to administer a prescribed remedy
Instruction	Diagnosing, debugging and correcting student performance
Control	Interpreting, predicting, repairing and monitoring system behaviors

TABLE 12.3 Expert Systems in Human Resource Management

Category					
Planning	• Employment requirement • Existing employment inventory • Strategic planning	→	**Planning ES** Eliminate any gaps that may exist between supply and demand	→	• Recruitment • Layoff • Overtime • Retirement • Dismissal
Interpretation, Design	• Organization and process chart • Characteristics of the job • Required behaviors • Employee characteristics	→	**Job Analysis ES** Fit each job into the total fabric of the organization	→	• Job description • Job specification
Design, planning prediction	• Employer's requirements • Candidates' performance • Recruiting goals • State of labor market • Status of possible inside recruits	→	**Recruitment ES** Distinguish between qualifications of potential applicants and desirable ones	→	• Methods of recruiting • Sources of recruits • Recruiting policies
Planning, design, interpretation, diagnosis	• Application blank • Personality and performance test • Physical examination • Selection criteria	→	**Selection ES** Most likely meet organization's standards of performance and increase the proportion of successful employees selected	→	• Selection ratio • Acceptance/Rejection
Design, planning monitoring, control	• Individual difference • Profit amount of organization • Contributions to meeting organizational goals	→	**Compensation ES** Meet all the criteria; equitable to employer and employee; incentive providing; and acceptable to the employee	→	• Methods of payment • Incentive form • Pay level • Pay structure • Rate ranges
Monitoring, interpretation, instruction, control	• Quality and quantity or work • Job knowledge • Personal qualities • Performance standards • Evaluation policies	→	**Performance Evaluation ES** Evaluate employee performance to meet with standards	→	• Salary adjustment • Promotion • Improvement of performance • Layoff • Transference
Debugging, instruction, control	• Organization's needs • Knowledge, skill, and ability needs to perform the job • Employee's needs, performance, and characteristics	→	**Training ES** Match the organization's objectives with the firm's human talent, structure, climate, and efficiency	→	• Determining training needs • Developing training criteria • Choosing trainers and trainees • Determining training type • Assignment, placement, and orientation follow-up
Monitoring, design, planning	• State of the economy • Goals of the bargaining parties • Public sentiment • Issues being discussed • Labor laws and regulation • Precedents in bargaining	→	**Labor-Management Relations ES** Negotiate with the union on the contract	→	• Contract • Lockout • Arbitration

(Source: Based on Byum, D. H. and E. H. Soh, "Human Resource Management Expert Systems Technology," *Expert Systems,* May 1994.

12.10 Benefits of Expert Systems

- **Major *Potential* ES Benefits**
  - **Increased Output and Productivity**
  - **Decreased Decision Making Time**
  - **Increased Process(es) and Product Quality**
  - **Reduced Downtime**
  - **Capture of Scarce Expertise**
  - **Flexibility**
  - **Easier Equipment Operation**
  - **Elimination of the Need for Expensive Equipment**

- **Operation in Hazardous Environments**
- **Accessibility to Knowledge and Help Desks**
- **Increased Capabilities of Other Computerized Systems**
- **Integration of Several Experts' Opinions**
- **Ability to Work with Incomplete or Uncertain Information**
- **Provide Training**
- **Enhancement of Problem Solving and Decision Making**
- **Improved Decision Making Processes**
- **Improved Decision Quality**
- **Ability to Solve Complex Problems**
- **Knowledge Transfer to Remote Locations**
- **Enhancement of Other CBIS**

  (provide intelligent capabilities to large CBIS)

Lead to

- Improved decision making
- Improved products and customer service
- A sustainable strategic advantage

- Some may even enhance the organization's image

12.11 Problems and Limitations of Expert Systems

- Knowledge is not always readily available
- Expertise can be hard to extract from humans
- Each expert's approach may be different, yet correct
- Hard, even for a highly skilled expert, to work under time pressure
- Users of expert systems have natural cognitive limits
- ES work well only in a narrow domain of knowledge

- **Most experts have no independent means to validate their conclusions**
- **The vocabulary of experts is often limited and highly technical**
- **Knowledge engineers are rare and expensive**
- **Lack of trust by end-users**
- **Knowledge transfer is subject to a host of perceptual and judgmental biases**
- **ES may not be able to arrive at conclusions**
- **ES sometimes produce incorrect recommendations**

Longevity of Commercial Expert Systems

(Gill [1995])

- Only about one-third survived five years
- Generally ES Failed Due to Managerial Issues
  - Lack of system acceptance by users
  - Inability to retain developers
  - Problems in transitioning from development to maintenance
  - Shifts in organizational priorities
- Proper management of ES development and deployment could resolve most

12.12 Expert System Success Factors

- **Two of the Most Critical Factors**
  - **Champion in Management**
  - **User Involvement and Training**
- **Plus**
  - **The level of knowledge must be sufficiently high**
  - **There must be (at least) one cooperative expert**
  - **The problem to be solved must be qualitative (fuzzy) not quantitative**
  - **The problem must be sufficiently narrow in scope**
  - **The ES shell must be high quality, and naturally store and manipulate the knowledge**

- A friendly user interface
- The problem must be important and difficult enough
- Need knowledgeable and high quality system developers with good people skills
- The impact of ES as a source of end-users' job improvement must be favorable. End user attitudes and expectations must be considered
- Management support must be cultivated.

- Need end-user training programs
- The organizational environment should favor new technology adoption

For Success

1. Business applications justified by strategic impact (competitive advantage)
2. Well-defined and structured applications

12.13 Types of Expert Systems

- Expert Systems Versus Knowledge-based Systems
- Rule-based Expert Systems
- Frame-based Systems
- Hybrid Systems
- Model-based Systems
- Ready-made (Off-the-Shelf) Systems
- Real-time Expert Systems

12.14 Expert Systems and the Internet/Intranets/Web

1. Use of ES on the Net
2. Support ES (and other AI methods)

Using ES on the Net

- To provide knowledge and advice to large numbers of users
- Help desks
- Knowledge acquisition
- Spread of multimedia-based expert systems (Intelimedia systems)

- Support ES and other AI technologies provide to the Internet/Intranet

(Table 12.4)

TABLE 12.4 Artificial Intelligence Contributions to the Internet

Technology	Application
Intelligent Agents	Assist Web browsing
Intelligent Agents	Assist in finding information
Intelligent Agents	Assist in matching items
Intelligent Agents	Filter E-mail
Intelligent Agents Expert Systems	Access databases, summarize information
Intelligent Agents	Improve Internet security
Expert systems	Match queries to users with "canned" answers to frequently asked questions (FAQ)
WWW Robots (spiders), Intelligent Agents	Conduct information retrieval and discovery, smart search engines ("metasearch")
Expert Systems	Intelligent browsing of qualitative databases
Expert Systems	Browse large documents (knowledge decomposition)
Intelligent Agents	Monitor data and alert for actions (e.g., looking for website changes), monitor users and usage

Summary

- Expert systems imitate the reasoning process of experts
- ES predecessor: the General-purpose Problem Solver (GPS).
  - Failed - ignored the importance of specific knowledge
- The power of an ES is derived from its specific knowledge
  - Not from its particular knowledge representation or inference scheme
- Expertise is a task-specific knowledge acquired from training, reading, and experience
- Experts can make fast and good decisions regarding complex situations

- **Most of the knowledge in organizations is possessed by a few experts**
- **Expert system technology attempts to transfer knowledge from experts and documented sources to the computer and make it available to nonexperts**
- **Expert systems involve knowledge processing, not data processing**
- **Inference engine provides ES reasoning capability**
- **The knowledge in ES is separated from the inferencing**
- **Expert systems provide limited explanation capabilities**
- **A distinction is made between a development environment (building an ES) and a consultation environment (using an ES)**

- **The major components of an ES are the knowledge acquisition subsystem, knowledge base, inference engine, blackboard, user interface and explanation subsystem**
- **The knowledge engineer captures the knowledge from the expert and programs it into the computer**
- **Although the major user of the ES is a nonexpert, there may be other users (such as students, ES builders, experts)**
- **Knowledge can be declarative (facts) or procedural**
- **Expert systems are improved in an iterative manner using a process called rapid prototyping**

- **The ten generic categories of ES: interpretation, prediction, diagnosis, design, planning, monitoring, debugging, repair, instruction and control**
- **Expert systems can provide many benefits**
- **Most ES failures are due to non-technical problems (managerial support and end user training)**
- **Although there are several limitations to using expert systems, some will disappear with improved technology**

- **ES success factors**
- **Expert systems can make mistakes**
- **Distinction between expert systems, and knowledge systems**
- **Some ES are ready-made**
- **Some expert systems provide advice in a real-time mode**
- **Expertise may be provided over the Internet / Intranets via ES**
- **ES and AI provide support to the Internet / Intranets**

CASE APPLICATION 12.1: Gate Assignment Display System (GADS)

Case Questions

1. Why is the gate assignment task so complex?
2. Why is GADS considered a real-time ES?
3. What are the major benefits of the ES over the manual system? (Prepare a detailed list.)
4. What measures were taken to increase the reliability of the system and why were they needed?

CASE APPLICATION 12.2: Expert System in Building Construction (EXSOFS)

CASE APPLICATION W12.1: DustPro--Environmental Control in Mines

APPENDIX 12-A: Expert Systems Cited in Chapter

System	Vendor (Developer)	Description
DENDRAL	Stanford University (Stanford, CA)	It infers the molecular structure of unknown compounds from mass spectral and nuclear magnetic response data. The system uses a special algorithm to systematically enumerate all possible molecular structures; it uses chemical expertise to prune this list of possibilities to a manageable size. Knowledge in DENDRAL is represented as a procedural code.
EURISKO	Stanford University (Stanford, CA)	It learns new heuristics and new domain-specific definitions of concepts in a problem domain. The system can learn by discovery in a number of different problem domains, including VLSI design. EURISKO operates by generating a device configuration, computing its input/output behavior, assessing its functionality and then evaluating it against other comparable devices.
META-DENDRAL	Stanford University (Stanford, CA)	It helps chemists determine the dependence of mass spectrometric fragmentation on substructural features. It does this by discovering fragmentation rules for given classes of molecules. META-DENDRAL first generates a set of highly specific rules that account for a single fragmentation process in a particular molecule. Then it uses the training examples to generalize these rules. Finally, the system reexamines the rules to remove redundant or System Vendor (Developer) Description incorrect rules.
STEAMER	U.S. Navy in cooperation with Bolt, Beranek, and Newman Inc. (Cambridge, MA)	It is an intelligent CAI that instructs Navy with personnel in the operation and maintenance of the propulsion plant for a 1078-class frigate. The system can monitor the student executing the boiler light-off procedure for the plant, acknowledge appropriate student actions, and correct inappropriate ones. The system works by tying a simulation of the propulsion plant to a sophisticated graphic interface program that displays animated color diagrams of plant subsystems. The student can manipulate simulated components like valves, switches, and pumps, and observe the effects on plant parameters, such as changes in pressure, temperature and flow. STEAMER uses an object-oriented representation scheme.

APPENDIX 12-B: Classic Expert Systems

- MYCIN
- X-CON

1. MYCIN

- To aid physicians in diagnosing meningitis and other bacterial blood infections and to prescribe treatment
- To aid physicians during a critical 24-48-hour period after the detection of symptoms, a time when much of the decision making is imprecise
- Early diagnosis and treatment can save a patient from brain damage or even death

Stanford Medical School in the 1970s by
Dr. Edward H. Shortliffe

MYCIN Features

- Rule-based knowledge representation
- Probabilistic rules
- Backward chaining method
- Explanation
- User-friendly system

2. XCON (Expert VAX System Configuration and Mass Customization)

- Digital Equipment Corp. (DEC) minicomputer system configuration
- Manually: Complex task, many errors, not cost effective
- Cost savings estimated at about $15 million / year
- Literature: Over $40 million / year later

APPENDIX 12-C: Typical Expert Systems Applications

Manufacturing/Engineering
Product design
Design analysis
Process planning
Assembly mgt.
Process control
Diagnosis & repair
Scheduling
Rostering
Simulation
Cost estimation
Configuration

Accounting and Finance
Credit analysis
Customer services
Loan eligibility
Banking help desk
Insurance underwriting
Auditing
Stock & commodity trading
Financial planning
Tax advising
Credit control

Transportation
Scheduling
Pricing
Yield management
Resource allocation

Marketing & Sales
Allocation of advertisement media
Market assessments
Salespersons' assignment
Account marketing
Product selection

Utilities & Telecommunications
Configuration
Real-time monitoring
Alarm analysis
Diagnosis
Network analysis
Marketing analysis
Marketing support
Back office operations
Scheduling
Billing Operations
Provisioning

Aerospace/DoD
Logistics
Manpower planning
Situation assessment
Diagnosis & repair
Inventory management
Seismic analysis
Tactical scheduling
Training
Munitions requirements

Business Services
Profit forecasting
Product selection
Data dictionary
Custom interfaces
Custom training
Custom software tools
Software requirements

Service Industry
For a list of applications in the service industry see Motiwalla and Gargaya [1992]