Chapter 14: Knowledge Representation

Once knowledge is acquired,
it must be organized for later use

14.1 Opening Vignette: Pitney Bowes Expert System Diagnoses Repair Problems and Saves Millions

The Situation

- Postage meter repair
- Varying levels of expertise, and less consistency in repairs
- Many parts changed unnecessarily

The G2 Solution

- Expert system G2 (Gensym Corp.) provides consistent advice to operators diagnosing and repairing 24,000 postage meters a year
- Supports 30 repair personnel
- Reduces repair time and unnecessary parts replacement
- Knowledge server: captured and distributes expert knowledge
- Graphic format to portray knowledge

G2 Benefits

- Over $1 million savings in two years (projected)
- Product cost reduced 23%
- Faster training and improved consistency
- Provides competitive advantage

14.2 Introduction

- A good knowledge representation 'naturally' represents the problem domain

- An unintelligible knowledge representation is wrong

- Most artificial intelligence systems consist of
  – Knowledge Base
  – Inference Mechanism (Engine)

- Knowledge Base
  - Forms the system's intelligence source
  - Inference mechanism uses to reason and draw conclusions
- Inference mechanism: Set of procedures that are used to examine the knowledge base to answer questions, solve problems or make decisions within the domain

- Many knowledge representation schemes
  - Can be programmed and stored in memory
  - Are designed for use in reasoning
- Major knowledge representation schemas:
  - Production rules
  - Frames

Knowledge Representation and the Internet

- Hypermedia documents to encode knowledge directly
- Hyperlinks Represent Relationships
- MIKE (Model-based and Incremental Knowledge Engineering
- Formal model of expertise: KARL Specification Language
- Semantic networks: Ideally suited for hypermedia representation
- Web-based Distributed Expert System (Ex-W-Pert

14.3 Representation in Logic and Other Schemas

- General form of any logical process (Figure 14.1)
- Inputs (Premises)
- Premises used by the logical process to create the output, consisting of conclusions (inferences)
- Facts known true can be used to derive new facts that also must be true

- **Symbolic logic: System of rules and procedures that permit the drawing of inferences from various premises**

- **Two Basic Forms of Computational Logic**
  - **Propositional logic (or propositional calculus)**
  - **Predicate logic (or predicate calculus)**

Propositional Logic

- **A proposition is a statement that is either <u>true</u> or <u>false</u>**
- **Once known, it becomes a premise that can be used to derive new propositions or inferences**
- **Rules are used to determine the truth (T) or falsity (F) of the new proposition**

- **Symbols represent propositions, premises or conclusions**

  Statement: A = The mail carrier comes Monday through Friday.

  Statement: B = Today is Sunday.

  Conclusion: C = The mail carrier will not come today.

- **Propositional logic: limited in representing real-world knowledge**

Predicate Calculus

- Predicate logic breaks a statement down into component parts, an object, object characteristic or some object assertion
- Predicate calculus uses variables and functions of variables in a symbolic logic statement
- Predicate calculus is the basis for Prolog (PROgramming in LOGic)
- Prolog Statement Examples
  - comes_on(mail_carrier, monday).
  - likes(jay, chocolate).

(Note - the period "." is part of the statement)

Scripts

Knowledge Representation Scheme Describing a Sequence of Events

- Elements include
  - Entry Conditions
  - Props
  - Roles
  - Tracks
  - Scenes

Lists

Written Series of Related Items

- **Normally used to represent hierarchical knowledge where objects are grouped, categorized or graded according to**
  - **Rank or**
  - **Relationship**

Decision Tables
(Induction Table)

Knowledge Organized in a Spreadsheet Format

- Attribute List
- Conclusion List
- Different attribute configurations are matched against the conclusion

Decision Trees

- Related to tables
- Similar to decision trees in decision theory
- Can simplify the knowledge acquisition process
- Knowledge diagramming is frequently more natural to experts than formal representation methods

O-A-V Triplet

- Objects, Attributes and Values
- O-A-V Triplet
- Objects may be physical or conceptual
- Attributes are the characteristics of the objects
- Values are the specific measures of the attributes in a given situation
- O-A-V triplets (Table 14.1)

Table 14.1 Representative O-A-V Items

Object	Attributes	Values
House	Bedrooms	2, 3, 4, etc.
House	Color	Green, white, brown, etc.
Admission to a university	Grade-point average	3.0, 3.5, 3.7, etc.
Inventory control	Level of inventory	14, 20, 30, etc.
Bedroom	Size	9 X 10, 10 X 12, etc.

14.4 Semantic Networks

- Graphic Depiction of Knowledge
- Nodes and Links Showing Hierarchical Relationships Between Objects
- Simple Semantic Network (Figure 14.2)
- Nodes: Objects
- Arcs: Relationships
  - is-a
  - has-a

- **Semantic networks can show *inheritance***
- ***Semantic Nets* - visual representation of relationships**
- **Can be combined with other representation methods**

14.5 Production Rules

- Condition-Action Pairs
  - IF this condition (or premise or antecedent) occurs,
  - THEN some action (or result, or conclusion, or consequence) will (or should) occur

  - IF the stop light is red AND you have stopped, THEN a right turn is OK

- **Each production rule in a knowledge base represents an *autonomous chunk* of expertise**
- **When combined and fed to the inference engine, the set of rules behaves synergistically**
- **Rules can be viewed as a simulation of the cognitive behavior of human experts**
- **Rules represent a *model* of actual human behavior**

Forms of Rules

- IF premise, THEN conclusion
  - IF your income is high, THEN your chance of being audited by the IRS is high
- Conclusion, IF premise
  - Your chance of being audited is high, IF your income is high

- Inclusion of ELSE
  - IF your income is high, OR your deductions are unusual, THEN your chance of being audited by the IRS is high, OR ELSE your chance of being audited is low
- More Complex Rules
  - IF credit rating is high AND salary is more than $30,000, OR assets are more than $75,000, AND pay history is not "poor," THEN approve a loan up to $10,000, and list the loan in category "B.”
  - Action part may have more information: THEN "approve the loan" and "refer to an agent"

Knowledge and Inference Rules

Common Types of Rules

- Knowledge rules, or declarative rules, state all the facts and relationships about a problem
- Inference rules, or procedural rules, advise on how to solve a problem, given that certain facts are known
- Inference rules contain rules about rules (metarules)
- Knowledge rules are stored in the knowledge base

Major Advantages of Rules

- Easy to understand (natural form of knowledge)
- Easy to derive inference and explanations
- Easy to modify and maintain
- Easy to combine with uncertainty
- Rules are frequently independent

Major Limitations of Rules

- Complex knowledge requires many rules
- Builders like rules (hammer syndrome)
- Search limitations in systems with many rules

- **Major Characteristics of Rules (Table 14.2)**

Table 14.2 Characteristics of Rule Representation

	First Part	Second Part
Names	Premise → Antecedent → Situation → IF →	Conclusion Consequence Action THEN
Nature	Conditions, similar to declarative knowledge	Resolutions, similar to procedural knowledge
Size	Can have many IFs	Usually one conclusion
Statements	AND statements	All conditions must be true for a conclusion to be true
	OR statements	If any of the OR statement is true, the conclusion is true

14.6 Frames

Definitions and Overview

- **Frame**: Data structure that includes all the knowledge about a particular object
- Knowledge organized in a hierarchy for diagnosis of knowledge independence
- Form of *object-oriented programming* for AI and ES.

- Each Frame Describes One Object
- Special Terminology (Table 14.3)

Table 14.3 Terminology for Frames

Default	Instantiation
Demon	Master frame
Facet	Object
Hierarchy of frames	Range
If added	Slot
If needed	Value (entry)
Instance of	

- **Provide a concise, structural representation of knowledge in a natural manner**
- **Frame encompasses complex objects, entire situations or a management problem as a single entity**
- **Frame knowledge is partitioned into slots**
- **Slot can describe declarative knowledge or procedural knowledge**

- **Major Capabilities of Frames (Table 14.4)**

- **Typical frame describing an automobile (Figure 14.3)**

- **Hierarchy of Frames: Inheritance**

Table 14.4 Capabilities of Frames

Ability to clearly document information about a domain model; for example, a plant's machines and their associated attributes
Related ability to constrain the allowable values that an attribute can take on
Modularity of information, permitting ease of system expansion and maintenance
More readable and consistent syntax for referencing domain objects in the rules
Platform for building a graphic interface with object graphics
Mechanism that will allow us to restrict the scope of facts considered during forward or backward chaining
Access to a mechanism that supports the inheritance of information down a class hierarchy

14.7 Multiple Knowledge Representation

Knowledge Representation *Must* Support

- Acquiring knowledge
- Retrieving knowledge
- Reasoning

Considerations for Evaluating a Knowledge Representation

- Naturalness, uniformity and understandability
- Degree to which knowledge is explicit (declarative) or embedded in procedural code
- Modularity and flexibility of the knowledge base
- Efficiency of knowledge retrieval and the heuristic power of the inference procedure

- **No single knowledge representation method is ideally suited by itself for all tasks (Table 14.5)**
- **Multiple knowledge representations: each tailored to a different subtask**
- **Production Rules and Frames works well in practice**
- **Object-Oriented Knowledge Representations**
  - **Hypermedia**

TABLE 14.5 Advantages and Disadvantages of Different Knowledge Representations

Scheme	Advantages	Disadvantages
Production rules	Simple syntax, easy to understand, simple interpreter, highly modular, flexible (easy to add to or modify)	Hard to follow hierarchies, inefficient for large systems, not all knowledge can be expressed as rules, poor at representing structured descriptive knowledge
Semantic networks	Easy to follow hierarchy, easy to trace associations, flexible	Meaning attached to nodes might be ambiguous, exception handling is difficult, difficult to program
Frames	Expressive power, easy to set up slots for new properties and relations, easy to create specialized procedures, easy to include default information and detect missing values	Difficult to program, difficult for inference, lack of inexpensive software
Formal logic	Facts asserted independently of use, assurance that all and only valid consequences are asserted (precision), completeness	Separation of representation and processing, inefficient with large data sets, very slow with large knowledge bases

14.8 Experimental Knowledge Representations

- **Cyc**
- **NKRL**
- **Spec-Charts Language**

The Cyc System

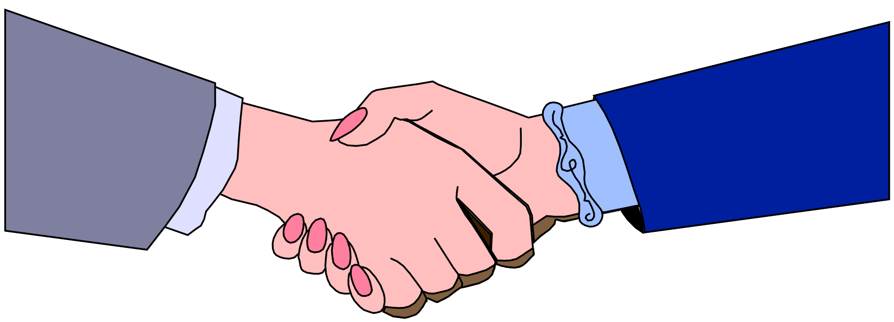
- Attempt to represent a substantial amount of common sense knowledge
- Bold assumptions: intelligence needs a large amount of knowledge
- Need a large knowledge base
- Cyc over time is developing as a repository of a consensus reality - the background knowledge possessed by a typical U.S. resident
- There are some commercial applications based on portions of Cyc

NKRL

- **Narrative Knowledge Representational Language (NKRL)**
- **Standard, language-independent description of the content of narrative textual documents**
- **Can *translate* natural language expressions directly into a meaningful set of templates that represent the knowledge**

Knowledge Interchange Format (KIF)

To Share Knowledge and Interact



The Spec-Charts Language

- **Based on Conceptual Graphs: to Define Objects and Relationships**
- **Restricted Form of Semantic Networks**
- **Evolved into the Commercial Product - STATEMATE**

14.9 Representing Uncertainty: An Overview

Dealing with Degrees of Truth, Degrees of Falseness in ES

- **Uncertainty**
  - When a user cannot provide a definite answer
  - Imprecise knowledge
  - Incomplete information

Uncertainty

Several Approaches Related to Mathematical and Statistical Theories

- **Bayesian Statistics**
- **Dempster and Shafer's Belief Functions**
- **Fuzzy Sets**

Uncertainty in AI

Approximate Reasoning, Inexact Reasoning

Relevant Information is Deficient in One or More

- Information is partial
- Information is not fully reliable
- Representation language is inherently imprecise
- Information comes from multiple sources and it is conflicting
- Information is approximate
- Non-absolute cause-effect relationships exist

- Can include ***probability*** in the rules
- IF the interest rate is increasing, THEN the price of stocks will decline (80% probability)

Summary

- The two main parts of any AI system: knowledge base and an inferencing system
- The knowledge base is made up of facts, concepts, theories, procedures and relationships representing real-world knowledge about objects, places, events, people and so on
- The inference engine (thinking mechanism) uses the knowledge base, reasoning with it

- To build the knowledge base, a variety of knowledge representation schemes are used: logic, lists, semantic networks, frames, scripts and production rules
- Propositional logic uses symbols to represent and manipulate premises, prove or disprove propositions and draw conclusions
- Predicate calculus: a type of logic to represent knowledge as statements that assert information about objects or events, and apply them in reasoning

- **Semantic networks: graphic depictions of knowledge that show relationships (arcs) between objects (nodes); common relationships: is-a, has-a, owns, made from**
- **Major property of networks: inheritance of properties through the hierarchy**
- **Scripts describe an anticipated sequence of events; indicate participants, actions, setting**
- **Decision trees and tables: used in conjunction with other representation methods. Help organize acquired knowledge before coding**

- **Production rules: IF-THEN statement**
- **Two rule types: declarative (describing facts) and procedural (inference)**
- **Rules: easy to understand; inferences can be easily derived from them**
- **Complex knowledge may require thousands of rules; may create problems in both search and maintenance. Some knowledge cannot be represented in rules**

- **Frame: holistic data structure based on object-oriented programming technology**
- **Frames: composed of slots that may contain different types of knowledge representation (rules, scripts, formulas)**
- **Frames: can show complex relationships, graphic information and inheritance concisely. Modular structure helps in inference and maintenance**
- **Integrating several knowledge representation methods is gaining popularity: decreasing software costs and increasing capabilities**

- **Experimental knowledge representations focus on expressing general knowledge about the world, and specialized languages that incorporate graphs and logic**
- **Knowledge may be inexact and experts may be uncertain at a given time**
- **Uncertainty can be caused by several factors ranging from incomplete to unreliable information**

Questions for the Opening Vignette

1. What was the purpose of the Pitney Bowes ES?
2. Why was a rule-based knowledge representation appropriate?
3. Would a frame-based knowledge representation work? Why or why not?
4. What were the benefits of the ES? What potential disadvantages can you determine?
5. Check the literature for other ES for diagnosis and compare what you find to the description in the Opening Vignette.

Group Exercises

1. Have everyone in the group consider the fairly ‘easy’ task of doing laundry. Individually, write down all the facts that you use for sorting clothes, loading the washer and dryer, and folding the clothes. Compare notes. Are any members of the group better at the task than others. For simplicity, leave out details like ‘go to the laundromat.’ Code the doing laundry facts in a rule-base. How many exceptions to the rules did you find?