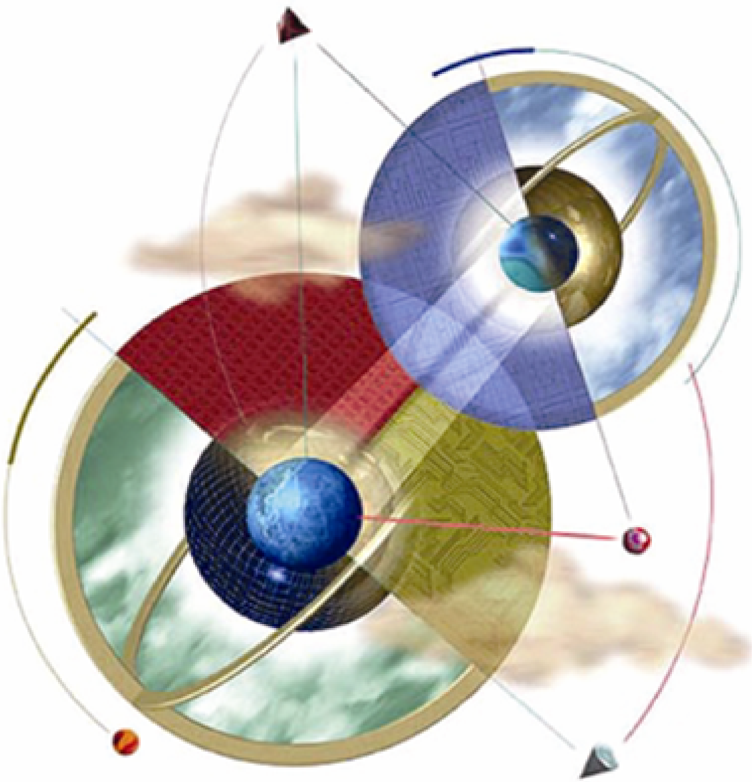


Chapter 2: The Representation of Knowledge

Expert Systems: Principles and Programming, Fourth Edition

What is the study of logic?

- Logic is the study of making inferences – given a set of facts, we attempt to reach a true conclusion.
- An example of informal logic is a courtroom setting where lawyers make a series of inferences hoping to convince a jury / judge .
- Formal logic (symbolic logic) is a more rigorous approach to proving a conclusion to be true / false.

Why is Logic Important

- We use logic in our everyday lives – “should I buy this car”, “should I seek medical attention”.
- People are not very good at reasoning because they often fail to separate word meanings with the reasoning process itself.
- Semantics refers to the meanings we give to symbols.

The Goal of Expert Systems

- We need to be able to separate the actual meanings of words with the reasoning process itself.
- We need to make inferences w/o relying on semantics.
- We need to reach valid conclusions based on facts only.

Knowledge vs. Expert Systems

- Knowledge representation is key to the success of expert systems.
- Expert systems are designed for knowledge representation based on rules of logic called inferences.
- Knowledge affects the development, efficiency, speed, and maintenance of the system.

Arguments in Logic

- An argument refers to the formal way facts and rules of inferences are used to reach valid conclusions.

- The process of reaching valid conclusions is referred to as logical reasoning.

How is Knowledge Used?

- Knowledge has many meanings – data, facts, information.
- How do we use knowledge to reach conclusions or solve problems?
- Heuristics refers to using experience to solve problems – using precedents.
- Expert systems may have hundreds / thousands of micro-precedents to refer to.

Epistemology

- Epistemology is the formal study of knowledge .
- Concerned with nature, structure, and origins of knowledge.

Categories of Epistemology

- Philosophy
- A priori
- A posteriori
- Procedural
- Declarative
- Tacit

A Priori Knowledge

- “That which precedes”
- Independent of the senses
- Universally true
- Cannot be denied without contradiction

A Posteriori Knowledge

- “That which follows”
- Derived from the senses
- Now always reliable
- Deniable on the basis of new knowledge w/o the necessity of contradiction

Procedural Knowledge

Knowing how to do something:

- Fix a watch
- Install a window
- Brush your teeth
- Ride a bicycle

Declarative Knowledge

- Knowledge that something is true or false
- Usually associated with declarative statements
- E.g., "Don't touch that hot wire."

Tacit Knowledge

- Unconscious knowledge
- Cannot be expressed by language
- E.g., knowing how to walk, breath, etc.

Knowledge in Rule-Based Systems

- Knowledge is part of a hierarchy.
- Knowledge refers to rules that are activated by facts or other rules.
- Activated rules produce new facts or conclusions.
- Conclusions are the end-product of inferences when done according to formal rules.

Expert Systems vs. Humans

- Expert systems infer – reaching conclusions as the end product of a chain of steps called inferencing when done according to formal rules.
- Humans reason

Expert Systems vs. ANS

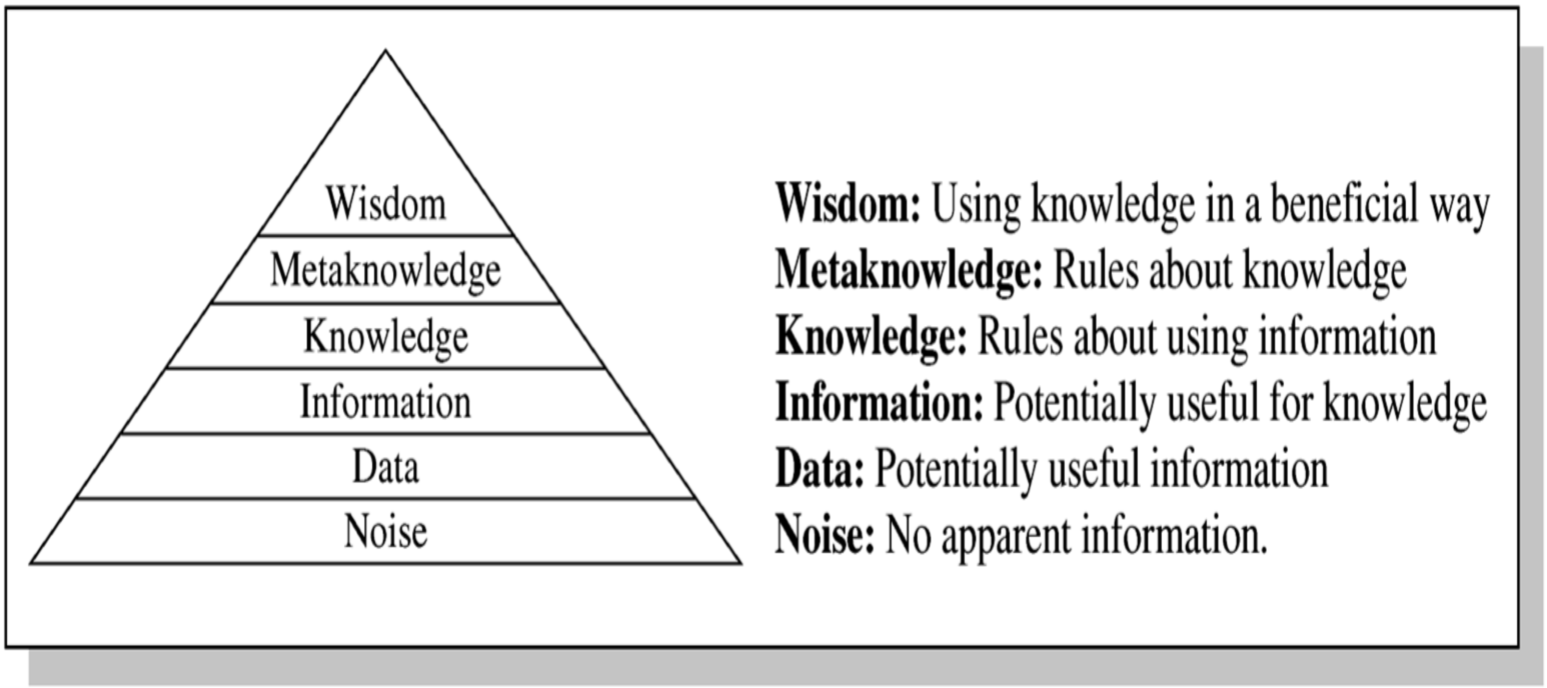
- ANS does not make inferences but searches for underlying patterns.

- Expert systems
  - **Draw inferences using facts**
  - **Separate data from noise**
  - **Transform data into information**
  - **Transform information into knowledge**

Metaknowledge

- Metaknowledge is knowledge about knowledge and expertise.
- Most successful expert systems are restricted to as small a domain as possible.
- In an expert system, an ontology is the metaknowledge that describes everything known about the problem domain.
- Wisdom is the metaknowledge of determining the best goals of life and how to obtain them.

Figure 2.2 The Pyramid of Knowledge

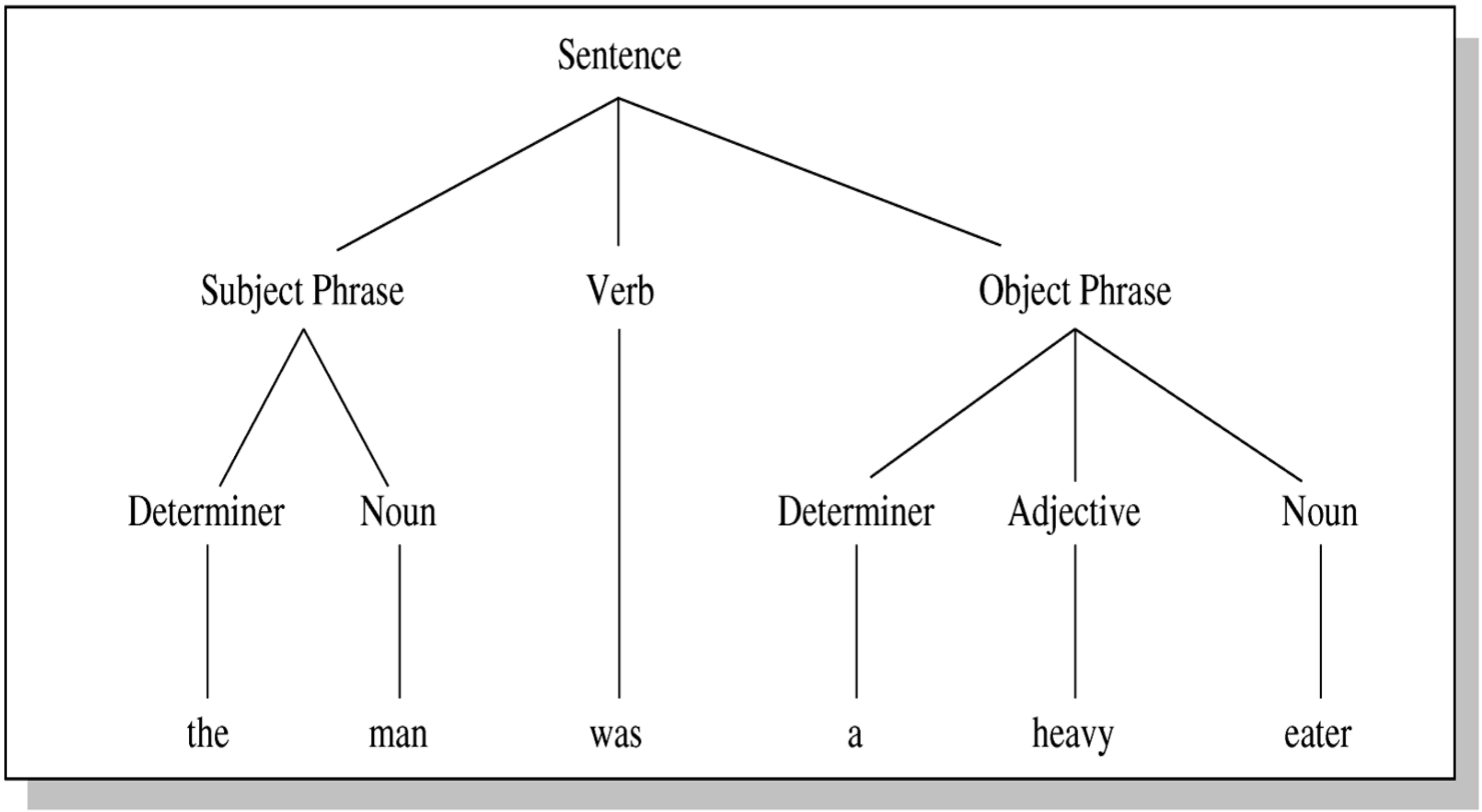


Productions

A number of knowledge-representation techniques have been devised:

- Rules
- Semantic nets
- Frames
- Scripts
- Logic
- Conceptual graphs

Figure 2.3 Parse Tree of a Sentence



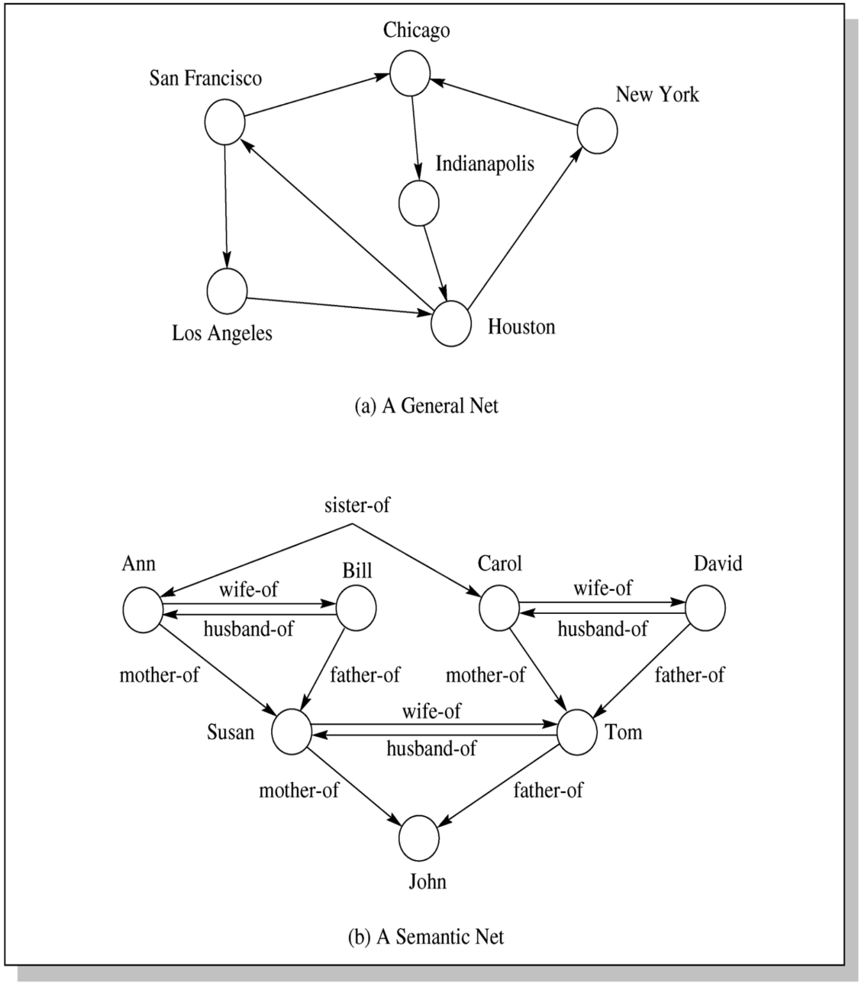
Semantic Nets

- A classic representation technique for propositional information
- Propositions – a form of declarative knowledge, stating facts (true/false)
- Propositions are called "atoms" – cannot be further subdivided.
- Semantic nets consist of nodes (objects, concepts, situations) and arcs (relationships between them).

Common Types of Links

- IS-A – relates an instance or individual to a generic class
- A-KIND-OF – relates generic nodes to generic nodes

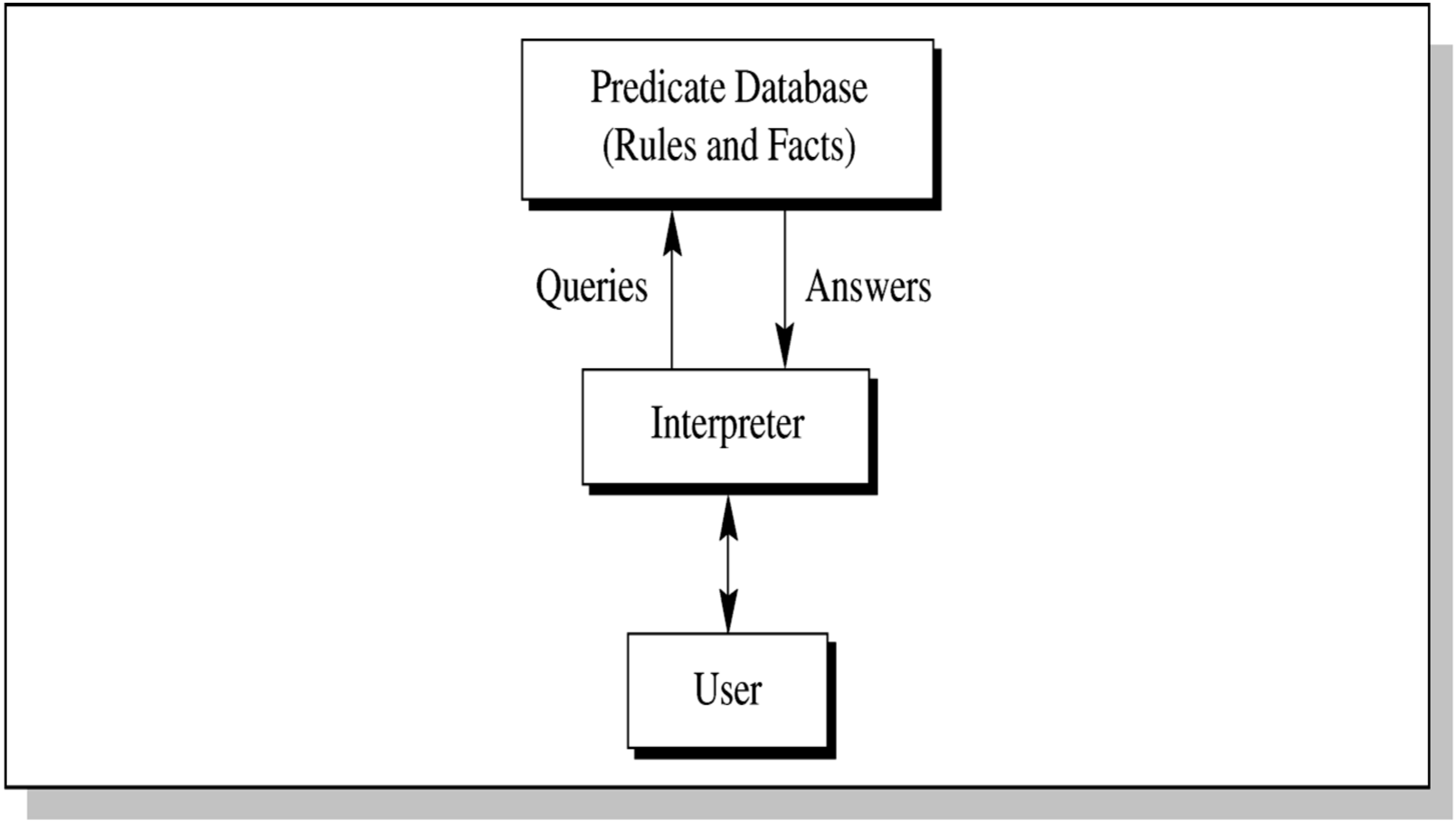
Figure 2.4 Two Types of Nets



(a) A General Net

(b) A Semantic Net

Figure 2.6: General Organization of a PROLOG System



PROLOG and Semantic Nets

- In PROLOG, predicate expressions consist of the predicate name, followed by zero or more arguments enclosed in parentheses, separated by commas.
- Example:

mother(becky,heather)

means that becky is the mother of heather

PROLOG Continued

- Programs consist of facts and rules in the general form of goals.
- General form: `p:- p1, p2, …, pN`
  `p` is called the rule's head and the p_i represents the subgoals
- Example:

```
spouse(x,y) :- wife(x,y)
```

`x` is the spouse of `y` if `x` is the wife of `y`

Object-Attribute-Value Triple

- One problem with semantic nets is lack of standard definitions for link names (IS-A, AKO, etc.).
- The OAV triplet can be used to characterize all the knowledge in a semantic net.

Problems with Semantic Nets

- To represent definitive knowledge, the link and node names must be rigorously defined.
- A solution to this is extensible markup language (XML) and ontologies.
- Problems also include combinatorial explosion of searching nodes, inability to define knowledge the way logic can, and heuristic inadequacy.

Schemata

- Knowledge Structure – an ordered collection of knowledge – not just data.
- Semantic Nets – are shallow knowledge structures – all knowledge is contained in nodes and links.
- Schema is a more complex knowledge structure than a semantic net.
- In a schema, a node is like a record which may contain data, records, and/or pointers to nodes.

Frames

- One type of schema is a frame (or script – time-ordered sequence of frames).
- Frames are useful for simulating commonsense knowledge.
- Semantic nets provide 2-dimensional knowledge; frames provide 3-dimensional.
- Frames represent related knowledge about narrow subjects having much default knowledge.

Frames Continued

- A frame is a group of slots and fillers that defines a stereotypical object that is used to represent generic / specific knowledge.
- Commonsense knowledge is knowledge that is generally known.
- Prototypes are objects possessing all typical characteristics of whatever is being modeled.
- Problems with frames include allowing unrestrained alteration / cancellation of slots.

Logic and Sets

- Knowledge can also be represented by symbols of logic.
- Logic is the study of rules of exact reasoning – inferring conclusions from premises.
- Automated reasoning – logic programming in the context of expert systems.

Figure 2.8 A Car Frame

Slots	Fillers
manufacturer	General Motors
model	Chevrolet Caprice
year	1979
transmission	automatic
engine	gasoline
tires	4
color	blue

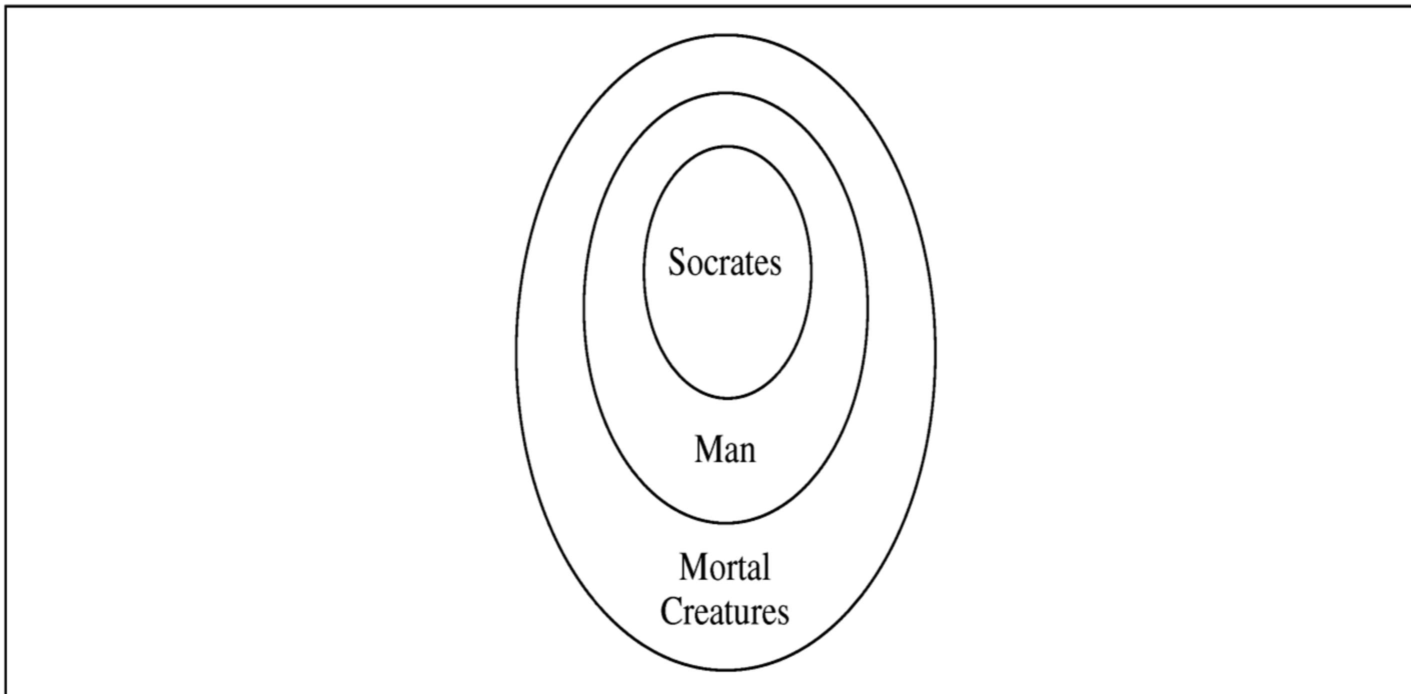
Forms of Logic

- Earliest form of logic was based on the syllogism – developed by Aristotle.
- Syllogisms – have two premises that provide evidence to support a conclusion.
- Example:
  - Premise: *All cats are climbers.*
  - Premise: *Garfield is a cat.*
  - Conclusion: *Garfield is a climber.*

Venn Diagrams

- Venn diagrams can be used to represent knowledge.
- Universal set is the topic of discussion.
- Subsets, proper subsets, intersection, union , contained in, and complement are all familiar terms related to sets.
- An empty set (null set) has no elements.

Figure 2.13 Venn Diagrams



Syllogism 三段論法

Premise: All men are mortal
Premise: Socrates is a man
Conclusion: Socrates is mortal

Only the **form** is important.

Premise: All **X** are **Y**
Premise: **Z** is a **X**
Conclusion: **Z** is a **Y**

Categorical Syllogism

- Syllogism: a valid deductive argument having two premises and a conclusion.

major premise:	All M are P
minor premise:	All S is M
Conclusion:	All S is P

M middle term
P major term
S minor term

Categorical Statements

Form	Schema	Meaning
A	All S is P	universal affirmative
E	No S is P	universal negative
I	Some S is P	particular affirmative
O	Some S is not P	particular negative

Figure	1	2	3	4
Major Premise	M P	P M	M P	P M
Minor Premise	S M	S M	M S	M S

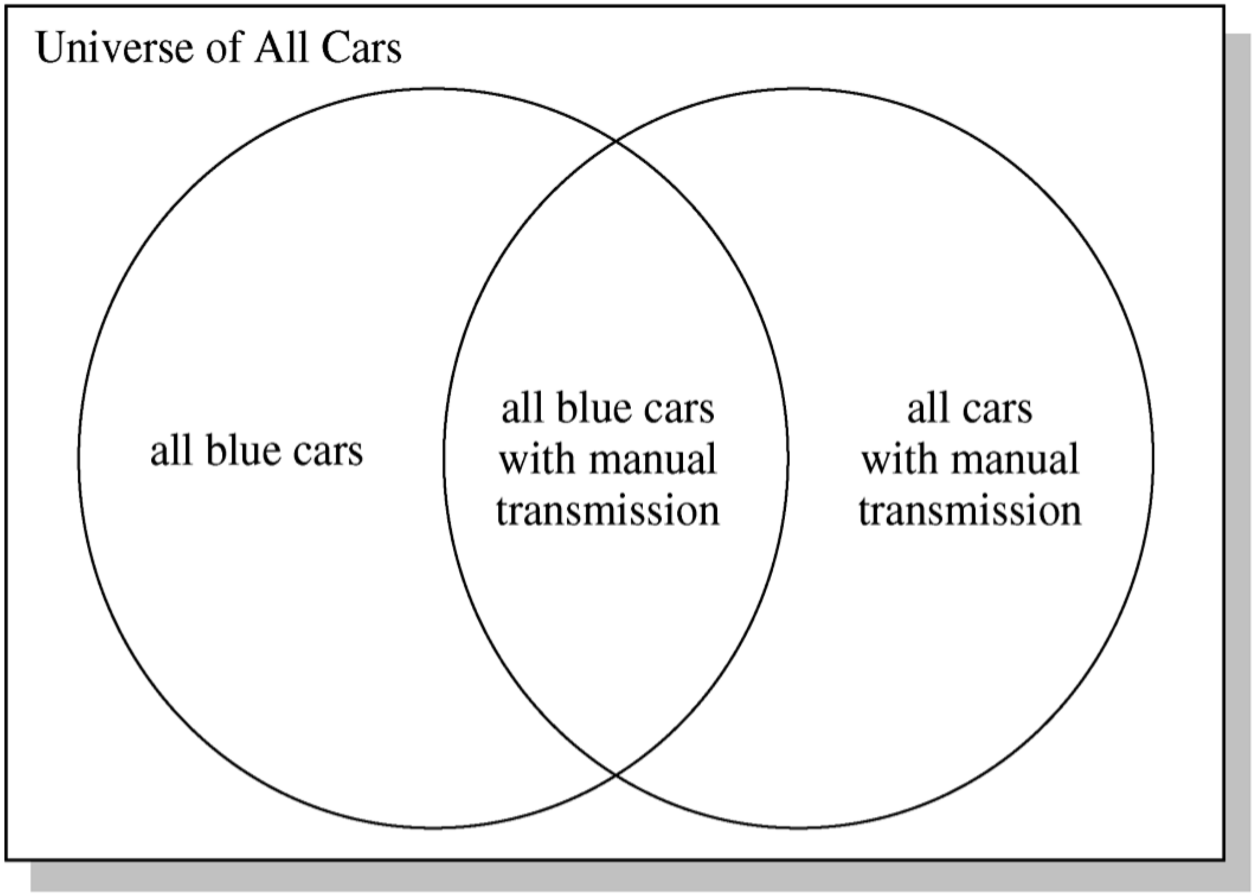
Mood

AAA-1	EAE-1	IAI-4
`All M is P`	`No M is P`	`Some P is M`
`All S is M S`	`All S is M`	`All M is S`
`All S is P`	`No S is P`	`Some S is P`

Propositional Logic

- Formal logic is concerned with syntax of statements, not semantics.
- Syllogism:
  - All goons are loons.
  - Zadok is a goon.
  - Zadok is a loon.
- The words may be nonsense, but the form is correct – this is a “valid argument.”

Figure 2.14 Intersecting Sets



Boolean Logic

- Defines a set of axioms consisting of symbols to represent objects / classes.
- Defines a set of algebraic expressions to manipulate those symbols.
- Using axioms, theorems can be constructed.
- A theorem can be proved by showing how it is derived from a set of axioms.

Features of Propositional Logic

- Concerned with the subset of declarative sentences that can be **classified as true or false**.
- We call these sentences "statements" or "**propositions**".
- Paradoxes – statements that cannot be classified as true or false.
- Open sentences – statements that cannot be answered absolutely.

Features Continued

- Compound statements – formed by using logical connectives (e.g., AND, OR, NOT, conditional, and biconditional) on individual statements.

- Material implication – $p \rightarrow q$ states that if p is true, it must follow that q is true.

- Biconditional – $p \leftrightarrow q$ states that p implies q <u>and</u> q implies p.

Features Continued

- Tautology – a statement that is true for all possible cases.
- Contradiction – a statement that is false for all possible cases.
- Contingent statement – a statement that is neither a tautology nor a contradiction.

Truth Tables

Table 2.4 Truth Table of the Binary Logical Connectives

p	q	$p \wedge q$	$p \vee q$	$p \rightarrow q$	$p \leftrightarrow q$
T	T	T	T	T	T
T	F	F	T	F	F
F	T	F	T	T	F
F	F	F	F	T	T

Table 2.5 Truth Table of Negation Connectives

p	$\sim p$
T	F
F	T

Rule of Inference

- Modus ponens, way assert

  direct reasoning, law of detachment

  assuming the antecedent

- Modus tollens, way deny

  indirect reasoning, law of contraposition

  assuming the antecedent

Modus Ponens

If there is power, the computer will work

There is power

The computer will work

A → B   p, p ->q;   q

A

B

Modus tollens

$p \rightarrow q$

$\sim q$

$\sim p$

conditional p -> q

converse q -> p

inverse ~p -> ~q

contrapositive

~q -> ~p

Formal Logic Proof

Chip prices rise only if the yen rises.
The yen rises only if the dollar falls and
  if the dollar falls then the yen rises.
Since chip prices have risen,
  the dollar must have fallen.

$C \rightarrow Y$	C = chip prices rise
$(Y \rightarrow D) \wedge (D \rightarrow Y)$	Y = yen rises
C	D = dollar falls

\-------------------------

D

Formal Logic Proof

$C \rightarrow Y$

$(Y \rightarrow D) \wedge (D \rightarrow Y)$

C

D

1. $C \rightarrow Y$		premise
2. $(Y \rightarrow D) \wedge (D \rightarrow Y)$		premise
3. C		
4. $Y == D$	2	Equivalence
5. $C \rightarrow D$	1	Substitution
6. D	3,5	modus ponens

Resolution

Normal form

- Conjunctive normal form

  (P1vP2v…)^(Q1vQ2…)^…(Z1vZ2…)

- Kowalski clausal form

  A1, A2, …., An → B1, B2, …., Bm

- Horn clause

  A1, A2, …., An → B

Method of Contradiction

A v B

A v ~B

A

(AvB)^(Av~B)

A v (B^~B)

A

Forward Reasoning

T: $A \rightarrow B$

$B \rightarrow C$ ➔ **CONCLUSION**?

$C \rightarrow D$

A

Resolve by modus ponens

Backward Reasoning

What if T is very large?

T may support all kinds of inferences

which have nothing to do with

the proof of our goal

Combinational explosion

➔ Use **Backward Reasoning**

Resolution Refutation

- To refute something is to prove it false
- Refutation complete:

  Resolution refutation will terminate in a finite steps if there is a contradiction
- Example: Given the argument

  A → B

  B → C

  C → D

  A → D

Example

A → B
B → C
C → D

A → D

To prove that A → D is a **theorem** by resolution refutation:

1. A → D equ ~A v D   convert to disjunction form
2. ~(~A v D) equ A ^ ~D   negate the conclusion
3. 3. A → B equ ~A v B
4. B → C equ ~B v C
5. C → D equ ~C v D
4. (~A v B) ^ (~B v C) ^ (~C v D) ^ A ^ ~D   resolution
5. => nil   **false**

Method of Contradiction

A v B
A v ~B

A

(AvB)^(Av~B)
A v (B^~B)
A

Propositional Logic

- Symbolic logic for manipulating proposition
- Proposition, Statement, Close sentence:

  a sentence whose truth value can be determined.
- Open Sentence: a sentence which contains variables
- Combinational explosion
- Can not prove argument with quantifiers

Predicate Logic

- Predicates with arguments

  on-top-of(A, B)

- Variables and Quantifiers

  Universal $(\forall x)(\text{Rational}(x) \rightarrow \text{Real}(x))$

  Existential $(\exists x)(\text{Prime}(x))$

- Functions of Variables

  $(\forall x)(\text{Satellite}(x)) \rightarrow (\exists y)(\text{closest}(y, \text{earth}) \wedge \text{on}(y,x))$

  $(\forall x)(\text{man}(x) \rightarrow \text{mortal}(x))$

  ^ man(Socrates)

  => mortal(Socrates)

Universal Quantifier

- The universal quantifier, represented by the symbol ∀ means “for every” or “for all”.

$$(\forall x)\ (x \text{ is a rectangle} \rightarrow x \text{ has four sides})$$

- The existential quantifier, represented by the symbol ∃ means “there exists”.

$$(\exists x)\ (x - 3 = 5)$$

- Limitations of predicate logic – *most* quantifier.

First Order Predicate Logic

- Quantification not over predicate or function symbols
- No MOST quantifier, (counting required)
- Can not express things that are sometime true

  => Fuzzy Logic

Syllogism in Predicate Logic

Type	Scheme	Predicate Representation
A	All S is P	$(\forall x)(S(x) \rightarrow P(x))$
E	No S is P	$(\forall x)(S(x) \rightarrow \sim P(x))$
I	Some S is P	$(\exists x)(S(x) \wedge P(x))$
A	Some S is not P	$(\exists x)(S(x) \wedge \sim P(x))$

Rule of Universal Instantiation

$(\forall x)p(x) \Rightarrow p(a)$

p: any proposition or propositional function

a: an instance

Formal Proof

$(\forall x)(H(x) \to M(x))$	All men are mortal
$H(s)$	Socrates is a man
$\Rightarrow$ $M(s)$	=> Socrates is mortal

1.	$(\forall x)(H(x) \to M(x))$	premise
2.	$H(s)$	
3.	$H(s) \to M(s)$	universal instantiation
4.	4. $M(s)$	2,3 modus ponens

Well-formed Formula

1. An atom is a formula
2. If F and G are formula, then ~(F), (FvG),
3. (F^G),(F->G), and (F<->G) are formula
3. If F is a formula, and x is a free variable in F, then ($\forall$x)F and ($\exists$x)F are formula
4. Formula are generated only by a finite number of applications of 1,2 and 3

Summary

- We have discussed:
  - Elements of knowledge
  - Knowledge representation
  - Some methods of representing knowledge
- Fallacies may result from confusion between form of knowledge and semantics.
- It is necessary to specify formal rules for expert systems to be able to reach valid conclusions.
- Different problems require different tools.