CIS 7414x Expert Systems

Lecture 2: Knowledge representation and methods of inference

Yuqing Tang

gclogo bclogo

Doctoral Program in Computer Science
The Graduate Center
City University of New York
ytang@cs.gc.cuny.edu

cunylogo

September 15th, 2010

Outline

Expert systems

Expert system = Knowledge base + Inference engine

- Knowledge base contains facts about objects in the chosen domain and their relationships
  - Knowledge base can also contains concepts, theories, practical procedures, and their associations
- The inference mechanism is a set of procedures that are used to examine the knowledge based in an orderly manner to answer questions, solve problems, or make decisions within the domain

Overview of knowledge representation and methods of inference

Knowledge representation

- Logic
  - Propositional logic
  - Predicate logic
- Production rules
- Semantic networks/web
- Frames
- Probability (next meeting)

Methods of inference

- Reasoning with logic
- Inference with rules
  - Forward chaining
  - Backward chaining
- The inference tree
- Inference with frames
- Probabilistic inferences (next meeting)

Outline

Knowledge representation

Two general types

- Those that support analysis, e.g. semantic networks, scripts, lists, decision trees, and decision tables
- Those that are used in actual coding, e.g. production rules, frames, and probabilistic networks

Outline

General form of logical process

- Premises: First, information is given, statements are made, or observations are noted
- Inferences: The premises are used by the logical process to create the output which consists of conclusions, called *inferences*
- Symbolic logic (formal logic) is the logical process that can be achieved by manipulating the symbols of representation without the need to refer to their semantics
  - Propositional logic
  - Predicate logic

Propositional Logic

- Formal logic is concerned with syntax of statements, not semantics.
- Propositional logic uses symbols (e.g. letters) to represent various propositions, premises, or conclusions
- Syllogism:
  Statement: A = The mail carrier comes on Friday.
  Statement: B = Today is Friday.
  Statement: C = The mail carrier comes today.
- The words may be nonsense, but the form is correct – this is a *valid* argument.
- To form more complex premises, two or more propositions can be combined using logical connectives: AND, OR, NOT, IMPLIES, EQUIVALENT and so on

Features of Propositional Logic I

- 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 of Propositional Logic II

- 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 and q implies p.

Features of Propositional Logic III

- 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 of connectives

Table 2.4 Truth Table of the Binary Logical Connectives

p	q	$p \wedge q$	$p \vee q$	$p \to q$	$p \leftrightarrow q$
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

Predicate Logic

- In predicate logic, a proposition is divided into two parts
  - the predicate (or assertion),
  - the arguments (or objects)
- Predicate logic allows to break a statement down into component parts
  - an object,
  - characteristic of an object, or
  - some assertion about an object

Example

$$Human(socrates)$$
$$Human(x)$$
$$Mortal(x)$$
$$\forall_x Human(x) \rightarrow Mortal(x)$$
$$\exists_x Human(x)$$

Outline

Production rules

Example

- IF the stoplight is red AND you have stooped, THEN a right turn is okay.
- IF the client uses purchase requisition forms AND the purchase orders are approved and purchasing is segregated from receiving, accounts, payable, AND inventory records, THEN there is strongly suggestive evidence (90 percent probability) that controls to prevent unauthorized purchases are adequate.

Production rules

- Production rules are in the form of condition-action pairs:
  "IF this *condition* (or premises or antecedent) occurs, THEN some action (or result, or conclusion, or consequence) will (or should) occur."
- Ideally, each production rule implements an autonomous chunk of expertise that can be developed and modified independently of other rules
- Production systems are composed of
  - production rules
  - working memory, and
  - a control
- Rules can be used as descriptive tools for problem-solving heuristics, replacing a more formal analysis of the problem
  - incomplete but useful guides to make search decisions
- Rules can be viewed as simulation of the cognitive behavior of human experts

Forms of production 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 by the IRS 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, ELSE your chance of being audited is low.
- Complex rules: IF your income is high AND salary is more than $\$30,00$, OR assets are more than $\$75,000$, AND pay history is not "poor", THEN approve a loan up to $\$10,000$, and list the load in catgory "B".
  The action part may include additional information: THEN "approve the load" and "refer to an agent".

Knowledge and inference rules

- Knowledge *declarative rules* state all the facts and relationships about a problem.
- Inference *procedural rules* advise on how to solve a problem given certain facts are known.

Example (Knowledge declarative rules)

- IF international conflict begins THEN the price of gold goes up.
- IF inflation rate declines THEN the price of gold goes down
- IF the international conflict lasts more than seven days and IF it is in the Middle East THEN buy gold.

Example (Inference procedural rules)

- IF the data needed is not in the system THEN request it from the user.
- IF more than one rule applies THEN deactivate any rules that add no new data.

Advantages and limitations of rules

Advantages

- Rules are easy to understand
- Inference and explanations are easily derived
- Modifications and maintenance are relatively easy
- Uncertainty is easily combined with rules
- Each rule is usually independent of all others

Limitations

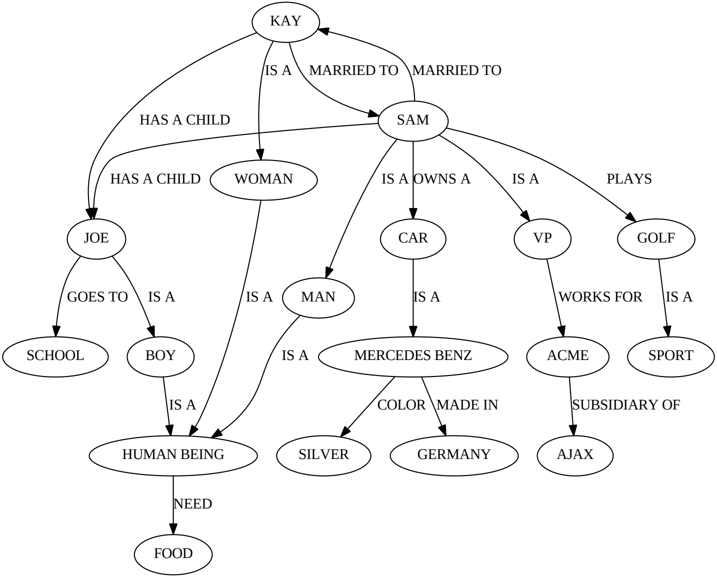
- Complex knowledge requires many, many rules: creating problems in using and maintaining the systems
- Builders likes rules: preventing the choices of more appropriate representation
- Systems with many rules may have a search limitation in the control program: difficulty in evaluating rule-based systems and making inferences

Outline

Semantic networks/web

- Nodes represent objects and descriptive information about those objects
  - Objects can be any physical item such as a book, car, desk, a person, and etc.
  - Nodes can also be concepts, events, or actions, Netwon's law, election, building house, and etc.
  - Attributes of an object can also be used as nodes, e.g. color, size, class, age, and etc.
- Links show the relationship between various objects and descriptive factors
  - Common links are of "IS-A", "HAS-A", "A-KIND-OF", etc.
- Inheritance is a useful feature of semantic network
  - Various characteristics of some nodes can inherit the characteristics of others

Semantic network example



Object, Attributes, and Values

- Objects, attributes, and values, the O-A-V triplet
- O-A-V can be used as a common way to represent knowledge
- The O-A-V triplet can be used to characterize all the knowledge in a semantic net.

Advantages and limitations

Advantages

- Flexibility in adding new nodes and links
- The visualization is easy to understand
- Inheritance
- Similarity to that of human information storage
- Ability to reason and create definition statements between nonlinked nodes
- XML/RDF standards for definition of nodes and relationships

Limitations

- Inheritance has difficulty with exceptions
- The perception of the situation can place relevant facts at inappropriate points
- Procedural knowledge is difficult to represent

Outline

Frames

- A frame is a data structure that includes all the knowledge about a particular object (an application OOP to expert systems)
- A frame groups values that describe one object
- The knowledge is partitioned into slots
- A slot can describe declarative and procedural knowledge

A car frame

Figure 2.8 A Car Frame

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

Outline

Overview

- Reasoning with logic
- Inferences with rules
- Inference tree
- Inference with frames
- Probabilistic inferences

Categories of reasoning

- Deductive reasoning uses general premises are used to obtain a specific inference
- Inductive reasoning uses a number of established facts or premises to draw some general conclusions.
- Analogical reasoning assumes that when a question is asked, the answer can be derived by analogy
- Formal reasoning involves syntatic manipulations of data structures to deduce new facts, following prescribed rules of inferences
- Procedural numeric reasoning uses mathematical models or simulation to solve problems
- Generalization and abstract can be successfully used with both logical and semantic representation of knowledge
- Metalevel reasoning

Outline

Reasoning with Logic

- Truth tables
- Modus Ponens: $\frac{A, A \to B}{B}$
- Modus Toolens: $\frac{\neg B, A \to B}{A}$
- Resolution: $\frac{A \vee B, A \vee \neg B}{A}$

More inference rules

1. Law of Detachment
$$\begin{array}{l} p \to q \\ \underline{p \qquad} \\ \therefore q \end{array}$$

2. Law of the Contrapositive
$$\begin{array}{l} \underline{p \to q} \\ \therefore \sim q \to \sim p \end{array}$$

3. Law of Modus Tollens
$$\begin{array}{l} p \to q \\ \underline{\sim q \qquad} \\ \therefore \sim p \end{array}$$

4. Chain Rule (Law of the Syllogism)
$$\begin{array}{l} p \to q \\ \underline{q \to r} \\ \therefore p \to r \end{array}$$

5. Law of Disjunctive Inference
$$\begin{array}{l} p \lor q \\ \underline{\sim p \qquad} \\ \therefore q \end{array} \qquad\qquad \begin{array}{l} p \lor q \\ \underline{\sim q \qquad} \\ \therefore p \end{array}$$

Outline

Forward chaining

- Rules:
  - rule 1: IF $P(x) \wedge Q(x)$ THEN $R(X)$
  - rule 2: IF $R(x)$ then $K(x)$
  - rule 3: IF $P(x) \wedge K(x)$ then $T(x)$
- Query: $T(a)$?
- Initial working memory: $WM_0 = \{P(a), Q(a)\}$
- Step 1: rule 1 is matched, update $WM_1 = \{P(a), Q(a), R(a)\}$
- Step 2: rule 2 is matched, update $WM_2 = \{P(a), Q(a), R(a), K(a)\}$
- Step 2: rule 3 is matched, update $WM_3 = \{P(a), Q(a), R(a), K(a), T(a)\}$
- Answer: yes since $T(a)$ is found in the working memory
- This is naive; the Rete algorithm [Perlin, 1990] is more efficient and see [Doorenbos, 1995, Chapter 2] for a comprehensive description

Backward chaining

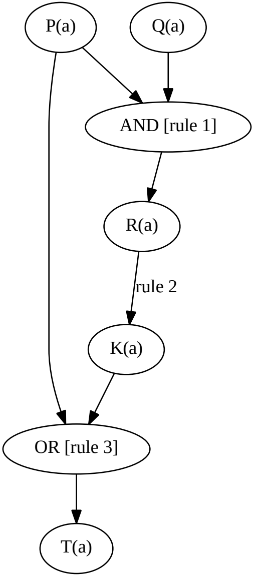
- Rules:
  - rule 1: IF $P(x) \wedge Q(x)$ THEN $R(X)$
  - rule 2: IF $R(x)$ then $K(x)$
  - rule 3: IF $P(x) \wedge K(x)$ then $T(x)$
- Query: $T(a)$?
- Initial assertion base: $WM_0 = \{P(a), Q(a)\}$
- Initial goals: $Goals_0 = \{T(a)\}$
- Step 1: rule 3 is matched, update $Goals_1 = \{P(a), K(a)\}$
- Step 2: rule 2 is matched, update $Goals_2 = \{P(a), R(a)\}$
- Step 3: rule 1 is matched, update $Goals_3 = \{P(a), Q(a)\}$;
- Answer: yes, since $Goals_3$ matches the facts in the assertion base

Backward chaining (another view)

- Rules:
  - rule 1: IF $P(x) \wedge Q(x)$ THEN $R(X)$
  - rule 2: IF $R(x)$ then $K(x)$
  - rule 3: IF $P(x) \wedge K(x)$ then $T(x)$
- Query: $T(a)$?
- Initial assertion base: $WM_0 = \{P(a), Q(a)\}$
- Initial goals: $Goals_0 = \{T(a)\}$
- Step 1: rule 3 is matched, update $Goals_1 = \{P(a), K(a)\}$
- Step 2: rule 2 is matched, update $Goals_2 = \{P(a), R(a)\}$
- Step 3: rule 1 is matched, update $Goals_3 = \{P(a), Q(a)\}$;
- WM maintanence for step 3: $Goals_3 \subseteq WM_0$, update the working memory: $WM_1 = \{P(a), Q(a), R(a)\}$
- WM maintanence for step 2: $Goals_2 \subseteq WM_1$, update the working memory: $WM_2 = \{P(a), Q(a), R(a), K(a)\}$
- WM maintanence for step 1: $Goals_3 \subseteq WM_2$, update the working memory: $WM_3 = \{P(a), Q(a), R(a), K(a), T(a)\}$
- Answer: yes, since $T(a)$ is found in the assertion base.

Outline

An inference AND-OR tree



- rule 1: IF $P(x) \wedge Q(x)$ THEN $R(X)$
- rule 2: IF $R(x)$ then $K(x)$
- rule 3: IF $P(x) \vee K(x)$ then $T(x)$

The inference AND-OR tree

- The inference tree provides a schematic view of the inference process
- Premises and conclusions are shown as nodes
- Branches connect the premises and conclusions
- The operators *AND* and *OR* are used to reflect the structure of rules

Outline

Inference with frames

- The slots provides a mechanism for a kind of reasoning called expectation-driven-processing
- Empty slots can be filled subject to certain conditioning, with data that confirm the expectations
- Slot values can be filled by default specifications
- With frames, it is easy to make inferences about new objects, events, or situations
- Reasoning frames can be executed by
  - Using rules
  - Employing hierarchical reasoning

Outline

Summary

- Knowledge representation
  - Logic
  - Production rules
  - Semantic networks/web
  - Frames
  - Probability (next meeting)
- Methods of inference
  - Reasoning with logic
  - Inference with rules
    - Forward chaining
    - Backward chaining
  - The inference tree
  - Inference with frames
  - Probabilistic inferences (next meeting)

Acknowledgments

Lecture 2 is composed of the instructor's own understanding and materials from [Giarratano and Riley, 2005, Chapter 2, Chapter 3] and [Turban and Frenzel, 1992, Chapter 5, Chapter 6] with the instructor's own interpretations. The instructor takes full responsibility of any mistakes in the slides.

References I

beamericonarticle Robert B. Doorenbos.
Production Matching for Large Learning Systems.
PhD thesis, 1995.

beamericonarticle Joseph C. Giarratano and Gary Riley.
Expert systems : principles and programming.
Thomson Course Technology, c2005., October 2005.

beamericonarticle Mark Perlin.
Topologically traversing the rete network.
Appl. Artif. Intell., 4(3):155–177, 1990.

beamericonarticle Efraim Turban and Louis E. Frenzel.
Expert Systems and Applied Artificial Intelligence.
Prentice Hall Professional Technical Reference, 1992.