UNIT-III: Knowledge Representation and Reasoning Under Uncertainty

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1. Knowledge Representation Issues

Knowledge representation is a core area of artificial intelligence. It concerns how knowledge about the world, relationships, facts, and rules are encoded so that machines can reason, learn, and make decisions.

Issues in Knowledge Representation

- **Expressiveness vs. Efficiency:** The challenge is to represent complex information compactly without sacrificing ease of inference.
- **Completeness:** Capturing all relevant knowledge needed for reasoning and decision-making.
- **Consistency:** Ensuring the knowledge base doesn't have contradictions.
- **Context Sensitivity:** Properly encoding knowledge that can change meaning based on context.
- **Scalability:** Making sure the system works efficiently even as the amount of knowledge grows.
- **Reasoning Mechanisms:** Supporting deduction (provable truth), induction (generalization), and abduction (explanatory inference).

Refer: GeeksforGeeks: Knowledge Representation in AI

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2. Predicate Logic and Logic Programming

Predicate logic (specifically, First-Order Logic) is a formal way to represent facts and relationships.

First Order Logic (FOL) Components

- **Constants:** Fixed objects (e.g., John, Paris).
- **Variables:** Placeholders for any object.
- **Predicates:** Properties or relations (e.g., Loves(x, y)).
- **Functions:** Map objects to other objects.
- **Quantifiers:** Universal (∀), Existential (∃).
- **Logical Connectives:** ∧ (and), ∨ (or), ¬ (not), → (implies).

Example Statements:

- Man(Marcus) "Marcus is a man."
- Loyal(Marcus, Caesar) "Marcus is loyal to Caesar."
- ∀x (Man(x) → Mortal(x)) "All men are mortal."

Refer: Mahesh Huddar — Predicate Logic Example Video
Refer: GeeksforGeeks: Knowledge Representation in First Order Logic

Logic Programming

Logic programming (e.g., Prolog) uses predicate logic for rules and queries.

- **Propositional Logic**: Uses only true/false variables.
- **Inference Rules**: Modus ponens, resolution, unification.

Resolution in Predicate Logic:
Refer: Mahesh Huddar — Resolution to Prove Predicate Facts
Refer: Proof by Resolution Example

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3. Semantic Nets, Frames, and Inheritance

Semantic Networks

Semantic networks represent knowledge as nodes (concepts) and edges (relationships).

- **Nodes:** Concepts (Animal, Dog, Cat)
- **Edges:** Relationships ("is-a", "has-part", "friend-of")

Common types:

- **Definitional Networks:** Hierarchical, for classification.
- **Assertional Networks:** For specific facts and attributes.
- **Implicational, Executable:** For inferring new facts and sequences.

Example:

- "Dog is a mammal"
- "Rex is a Dog"
- "Rex has brown fur"

Refer: Mahesh Huddar — Knowledge Representation Using Semantic Nets
Refer: GeeksforGeeks: Semantic Networks in AI

Frames and Inheritance

Frames are structured records for stereotypical situations.
Origin by Minsky, they are similar to objects in OOP.

- **Frame:** Template with slots (attributes) and facets (constraints).
- **Inheritance:** Child frames inherit slots from parent frames, override as needed.

Example:

- **Person (Frame):**
  - Name
  - Age (Default: 30, Range: 0–120)
  - Address
- **Book (Frame):**
  - Title: "To Kill a Mockingbird"
  - Author: "Harper Lee"
  - Procedures: CheckAvailability, UpdateRecord

Refer: GeeksforGeeks: Frames in AI
Refer: Lecture 8: Semantic Networks and Frames - YouTube

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4. Constraint Propagation

Constraint propagation iteratively refines the choices of variable assignments by applying constraints.

- **Narrowing domains:** As variables are assigned, constraints restrict possible values for others.
- **Propagation:** If X ≠ Y, and Y=2, then X cannot be 2.
- **Application:** Sudoku, scheduling, graph coloring.

Refer: GeeksforGeeks: Constraint Propagation in AI

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5. Representing Knowledge Using Rules

Rule-based systems use IF-THEN production rules, enabling deduction.

Rule Example:
IF Temperature > 38 THEN Fever.

Rules-Based Deduction Systems

- **Forward Chaining (Data-Driven):** Start with facts, deduce new ones.
- **Backward Chaining (Goal-Driven):** Start with goal, check which facts/rules support it.

- **Forward Chaining:**
  - Start with data, repeatedly apply rules to produce new facts until goal is reached.
- **Backward Chaining:**
  - Start with goal, work backward to identify necessary supporting facts.

Refer: GeeksforGeeks: Forward and Backward Chaining in Rule-Based Systems
Refer: Rule Based System in AI
Refer: Mahesh Huddar — Resolution and Inference Rules

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6. Reasoning Under Uncertainty

Real-world AI rarely has perfect knowledge—uncertainty must be handled probabilistically.

Review of Probability

- **Random variables:** Each state/outcome has a probability.
- **Conditional probability:** Probability of A given B, P(A|B).
- **Joint probability:** P(A ∩ B).

Bayes' Theorem:

$$P(A|B) = \frac{P(B|A) \times P(A)}{P(B)}$$

Refer: GeeksforGeeks: Bayes' theorem in Artificial intelligence
Refer: Mahesh Huddar — Probabilistic Reasoning and Bayes Rule

Bayesian Networks

Graphical models for representing dependencies via nodes and edges.

- Used for diagnosis, prediction, reasoning under uncertainty.

Refer: Bayesian Belief Network Example — Mahesh Huddar

Dempster-Shafer Theory

A generalization of Bayesian probability, allows "degrees of belief" for sets/hypotheses.

- **Belief (support):** Lower bound on probability based on evidence directly supporting hypothesis.
- **Plausibility:** Upper bound—how much evidence "might" support hypothesis.
- **Combination rule:** Allows fusing evidence from multiple sources.

Refer: Dempster-Shafer Theory — Wikipedia
Refer: Dempster Shafer Theory — PPT

Example: Reasoning with Bayes' Theorem

Suppose a medical test has:

- Sensitivity = 0.95 (probability it detects disease if present)
- Specificity = 0.90 (probability it correctly reports negative if disease absent)

$$P(\text{Disease}|\text{Positive Test}) = \frac{P(\text{Positive Test}|\text{Disease}) \cdot P(\text{Disease})}{P(\text{Positive Test})}$$

You can update your belief about the patient based on test result and prior probability.

References

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