Knowledge Representation in Artificial Intelligence

1. Knowledge Representation and Mappings
Definition
Knowledge representation (KR) refers to the formalization of knowledge in a way that enables a computer system to process, reason, and make decisions based on it. It involves encoding information about the world into a format that machines can understand and manipulate.
Purpose

Facilitates reasoning and decision-making by providing a structured way to store and retrieve knowledge.

Enables machines to interpret and understand complex information.

Mappings

Real-world to Symbolic Representation:

Translates real-world entities (e.g., objects, events) into symbolic forms (e.g., variables, predicates).

Example: Representing "It is raining" as a proposition RR.

Symbolic to Computational Representation:

Encodes symbols into data structures (e.g., graphs, logical formulas) that computers can process.

Example: Representing relationships between objects using a graph structure.

2. Approaches to Knowledge Representation
1. Logical Representation

Uses formal logic (e.g., Propositional Logic, Predicate Logic) to represent knowledge.

Example: "If it rains, the ground is wet" is represented as R→WR→W.

Advantages: Precise and unambiguous.

Disadvantages: Limited expressiveness for uncertain or incomplete knowledge.

2. Semantic Networks

A graphical representation where nodes represent objects or concepts, and edges represent relationships.

Example:

```
[Dog] --(is-a)--> [Animal]
[Dog] --(has)--> [Tail]
```

Advantages: Intuitive and easy to visualize.

Disadvantages: Limited ability to represent complex relationships.

3. Frames

A structured representation using slots (attributes) and fillers (values).

Example: A "Car" frame:

```
Frame: Car
  Slot: Color
    Filler: Red
  Slot: Model
    Filler: Sedan
```

Advantages: Effective for hierarchical and structured knowledge.

Disadvantages: Rigid structure may not handle dynamic changes well.

4. Rule-Based Systems

Uses "if-then" rules to represent knowledge.

Example: "If temperature > 30°C, then turn on the fan."

Advantages: Simple and effective for expert systems.

Disadvantages: Scalability issues with large rule sets.

5. Probabilistic Representations

Uses probability theory to handle uncertainty.

Example: Bayesian Networks.

Advantages: Suitable for uncertain and incomplete knowledge.

Disadvantages: Computationally intensive.

3. Issues in Knowledge Representation

Expressiveness:

The ability of a representation to capture complex real-world knowledge.

Example: Predicate Logic is more expressive than Propositional Logic.

Efficiency:

The computational complexity of reasoning with the representation.

Example: Semantic networks are efficient for simple queries but may struggle with complex inferences.

Ambiguity:

Handling vague or uncertain information.

Example: Probabilistic representations are better suited for ambiguous data.

Scalability:

The ability to handle large amounts of knowledge.

Example: Rule-based systems may become inefficient as the number of rules grows.

4. Semantic Nets
Structure

Nodes: Represent objects or concepts.

Edges: Represent relationships (e.g., "is-a", "has-a").

Example
[Bird] --(is-a)--> [Animal]
[Bird] --(has)--> [Wings]
Advantages

Intuitive and easy to visualize.

Effective for representing hierarchical relationships.

Disadvantages

Limited expressiveness for complex relationships.

Difficult to represent negation or disjunction.

5. Frames
Structure

A frame is a collection of slots (attributes) and fillers (values).

Example: A "Person" frame:

```
Frame: Person
  Slot: Name
    Filler: John
  Slot: Age
    Filler: 30
```

Advantages

Effective for representing structured, hierarchical knowledge.

Easy to add default values and constraints.

Disadvantages

Rigid structure may not handle dynamic changes well.

Limited ability to represent complex relationships.

6. Propositional Logic (PL)
Syntax

Basic elements: Propositions (e.g., PP, QQ).

Logical connectives: ∧∧ (AND), ∨∨ (OR), ¬¬ (NOT), →→ (IMPLIES).

Semantics

Truth tables define the meaning of logical expressions.

Key Concepts

Tautology: A statement that is always true (e.g., P∨¬PP∨¬P).

Validity: A statement that is true under all interpretations.

Well-Formed Formula (WFF): A syntactically correct logical expression.

Inference using Resolution

A rule of inference used in automated theorem proving.

Example: Resolving P∨QP∨Q and ¬P∨R¬P∨R to infer Q∨RQ∨R.

7. Predicate Logic (First-Order Predicate Logic - FOPL)
Syntax

Constants, variables, predicates, and quantifiers (∀∀, ∃∃).

Example: ∀x(Human(x)→Mortal(x))∀x(Human(x)→Mortal(x)).

Semantics

Interpretation of predicates and quantifiers over a domain.

Quantification

Universal (∀∀): "For all."

Existential (∃∃): "There exists."

Rules of Inference

Modus Ponens, Universal Instantiation, Existential Generalization.

Unification

Finding a substitution that makes two logical expressions identical.

Resolution Refutation System

A proof technique that uses resolution to derive a contradiction.

8. Bayes' Rule and Its Use
Bayes' Rule
P(A∣B)=P(B∣A)⋅ P(A)P(B)P(A∣B)=P(B)P(B∣A)⋅ P(A)

P(A∣B)P(A∣B): Posterior probability.

P(B∣A)P(B∣A): Likelihood.

P(A)P(A): Prior probability.

P(B)P(B): Evidence.

Use

Updating probabilities based on new evidence.

Applications: Spam filtering, medical diagnosis.

9. Bayesian Networks
Definition

A graphical model representing probabilistic relationships among variables.

Structure

Nodes: Random variables.

Edges: Conditional dependencies.

Example

[Rain] --> [Wet Grass]
[Sprinkler] --> [Wet Grass]
Reasoning

Inference using conditional probability tables (CPTs).

10. Reasoning in Belief Networks
Types of Reasoning

Causal Reasoning: From causes to effects.

Diagnostic Reasoning: From effects to causes.

Intercausal Reasoning: Between causes of a common effect.

Algorithms

Exact Inference: Variable Elimination.

Approximate Inference: Monte Carlo methods.