Knowledge Representation & Planning

Reasoning, Representation, Inference, Propositional Logic & Predicate Logic

1. Knowledge Representation

1.1 Meaning of Knowledge Representation

In Artificial Intelligence, **knowledge** refers to facts, concepts, relationships, rules, and assumptions about the real world.
Knowledge Representation (KR) is the technique of **encoding this human knowledge into a formal structure so that a computer system can understand it, store it, and reason with it**.

📌 Humans understand knowledge in natural language, but computers require **formal, structured representations**.

👉 Example:

- Human statement: *"All doctors are educated."*
- Machine needs a **formal logical form** to reason about it.

1.2 Why Knowledge Representation is Important

Knowledge Representation is required because:

1. AI systems must **store information**
2. AI systems must **reason logically**
3. AI systems must **derive new conclusions**
4. AI systems must **solve problems and make decisions**

Without KR, an AI system becomes a **data storage machine**, not an intelligent system.

1.3 Properties of a Good Knowledge Representation

1. **Representational Adequacy**
   Ability to represent all necessary knowledge.
2. **Inferential Adequacy**
   Ability to derive new knowledge from existing knowledge.
3. **Inferential Efficiency**
   Ability to perform reasoning efficiently.
4. **Acquisitional Efficiency**
   Ease of adding, modifying, or removing knowledge.

2. Reasoning in Artificial Intelligence

2.1 What is Reasoning?

Reasoning is the process of **drawing conclusions from known facts using logical rules**.

📌 Reasoning allows AI to go **beyond stored facts** and generate **new knowledge**.

2.2 Types of Reasoning

2.2.1 Deductive Reasoning

Deductive reasoning starts with **general rules** and applies them to **specific cases**.
If the premises are true, the conclusion is **always true**.

Example:

Statement 1: All humans are mortal
Statement 2: Socrates is a human

Conclusion: Socrates is mortal

Explanation:

- The first statement is a **general rule**
- The second statement applies the rule to a specific object (Socrates)
- The conclusion logically follows

This type of reasoning is **commonly used in logic-based AI systems**.

2.2.2 Inductive Reasoning

Inductive reasoning moves from **specific observations** to a **general conclusion**.

Example:

- Student 1 scored well after using AI tools
- Student 2 scored well after using AI tools
- Student 3 scored well after using AI tools

Conclusion: Using AI tools improves performance

Explanation:

- The conclusion is **probable**, not guaranteed
- Future observations may contradict it

Used in **machine learning and data analysis**.

2.2.3 Abductive Reasoning

Abductive reasoning is used to find the **most likely explanation** for an observation.

Example:

- Observation: Laptop is not turning on
- Possible explanation: Battery is dead

Explanation:

- Conclusion is **not certain**
- It is the **best possible explanation**

Used in **diagnosis systems**.

3. Inference

3.1 Meaning of Inference

Inference is the mechanism by which **new facts are derived from existing facts using reasoning rules**.

👉 Inference is the **engine** of reasoning.

3.2 Types of Inference Mechanisms

3.2.1 Forward Chaining (Data-Driven Inference)

- Starts with known facts
- Applies inference rules
- Moves forward until a conclusion is reached

Example:
Facts:
It is raining
Rule:
IF it is raining → roads are wet

Inference Process:

1. Known fact: It is raining
2. Rule condition matches the fact
3. Apply the rule
4. Derive new fact: Roads are wet

📌 Used in **expert systems**.

3.2.2 Backward Chaining (Goal-Driven Inference)

- Starts with a goal
- Works backward to find supporting facts

Example:

Goal: Are roads wet?

Steps:

1. Check rules that conclude "roads are wet"
2. Rule found: IF raining → roads are wet
3. Check if "raining" is true
4. If true, goal is satisfied

📌 Used in **diagnostic systems**.

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Topics:

1. Propositional Logic
2. Predicate Logic (First Order Logic)
3. Logical Reasoning

1. Propositional Logic:

Deals with simple statements that are either **True or False**.
It treats each statement as a whole and does not look inside it.

Example:
P: It is raining

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2. Predicate Logic (First Order Logic):

Deals with **objects, properties, and relationships**.
It uses variables and words like **all** or **some**.

Example:
Student(Ram)
$\forall x$ Student(x) → Intelligent(x)

1. PROPOSITIONAL LOGIC

1.1 Introduction (Expanded Explanation)

According to Rich & Knight, logic provides a **formal language** for:

- Representing knowledge
- Expressing relationships between facts
- Drawing new conclusions through inference

Propositional Logic (PL) is the most basic logical representation system.

It deals with:

- Simple declarative statements
- Statements that are either TRUE or FALSE
- No internal structure inside the statement

Example:

- “It is raining”
- “The road is wet”

In propositional logic, these are treated as atomic symbols:
P = It is raining
Q = The road is wet

The internal meaning of P is not analyzed. It is treated as a black box with a truth value.

👉 Important idea from Rich & Knight:
Propositional logic focuses on the truth relationships between statements, not their internal content.

1.2 Basic Elements (Expanded)

1. Propositions

A proposition must:

- Be declarative
- Have definite truth value

Valid propositions:

- 5 > 3 (True)
- India is in Asia (True)
- 2 + 2 = 5 (False)

Not propositions:

- Close the door! (command)
- What is your name? (question)

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2. Logical Connectives (With Meaning)

Logical connectives allow building complex sentences.

Negation (¬P)

Reverses truth value.

If P = True → ¬P = False
If P = False → ¬P = True

Conjunction (P ∧ Q)

True only when both are true.

Truth Table:

P	Q	P ∧ Q
T	T	T
T	F	F
F	T	F
F	F	F

Disjunction (P ∨ Q)

True when at least one is true.

Implication (P → Q)

"If P then Q"

Important interpretation:

- It does NOT mean causation
- It only defines truth-functional relationship

False only when:
P = True and Q = False

Example:
P: It rains
Q: Road is wet

If it rains but road is not wet → rule violated → False

Biconditional (P ↔ Q)

True when both have same truth value.

Represents logical equivalence.

1.3 Knowledge Representation in PL (Expanded Example)

Consider knowledge:

1. If it rains, roads are wet. (P → Q)
2. It rains. (P)

We infer:
Q (Road is wet)

This inference is called **Modus Ponens**.

Logical form:

(P → Q)
P
Therefore Q

This is the foundation of rule-based systems.

1.4 Additional Example (Resolution Based)

Knowledge:

1. P → Q
2. Q → R
3. P

Goal: Prove R

Convert implications:

1. ¬P ∨ Q
2. ¬Q ∨ R

Given P

Using resolution:

From (¬P ∨ Q) and P → derive Q
From (¬Q ∨ R) and Q → derive R

Thus R is true.

This shows how automated reasoning works.

1.5 Limitations of Propositional Logic (Deeper View)

Propositional Logic cannot express:

- "All students are intelligent"
- "Some dogs are black"
- "Ram loves Shyam"

Because:

- No variables
- No quantifiers
- No relationships between objects

Each statement must be separately represented.

Thus, we move to Predicate Logic.

2. PREDICATE LOGIC (FIRST ORDER LOGIC – FOL)

2.1 Introduction (Expanded)

Predicate Logic increases expressive power by introducing:

- Objects
- Properties
- Relations
- Quantifiers

It allows representation of **structured knowledge**.

Unlike PL, FOL understands internal structure.

Example:

In PL:
P = “Ram is intelligent”

In FOL:
Intelligent(Ram)

Now the system knows:

- Intelligent is a property
- Ram is an object

This makes reasoning more powerful.

2.2 Components (Deep Explanation)

Constants

Represent specific objects.

Ram, Delhi, 5

Variables

Represent arbitrary objects.

x, y, z

Used with quantifiers.

Predicates

Represent properties or relations.

Human(x)
Loves(Ram, Sita)
Greater(5,3)

Predicates define relationships between objects.

Functions

Map object → object

FatherOf(Ram)
Square(5)

Example:
FatherOf(Ram) = Shyam

2.3 Quantifiers (Deep Explanation)

Universal Quantifier (∀)

Statement applies to all objects in domain.

∀x (Human(x) → Mortal(x))

Meaning:
For every x,
if x is human then x is mortal.

This expresses general knowledge.

Existential Quantifier (∃)

At least one object exists.

∃x (Student(x) ∧ Intelligent(x))

Meaning:
There exists at least one student who is intelligent.

2.4 Classical Example (Step-by-Step Inference)

Knowledge Base:

1. ∀x (Human(x) → Mortal(x))
2. Human(Socrates)

Goal: Mortal(Socrates)?

Step 1: Universal Instantiation
From (1):

Human(Socrates) → Mortal(Socrates)

Step 2: Modus Ponens
Since Human(Socrates) is true

Therefore:
Mortal(Socrates)

This demonstrates deductive reasoning in FOL.

2.5 More Complex Example

Knowledge:

1. ∀x (Bird(x) → CanFly(x))
2. Bird(Tweety)

Conclusion:
CanFly(Tweety)

But if we add:

3. Penguin(Tweety)
4. Penguin(x) → Bird(x)
5. Penguin(x) → ¬CanFly(x)

Now reasoning becomes non-trivial(મહત્વપૂર્ણ અને ઊંડાણ ધરાવતું / સામાન્ય કે સ્પષ્ટ ન હોય તેવું).

This introduces:

- Conflicting rules
- Need for more advanced reasoning

This leads toward non-monotonic reasoning (advanced topic).

2.6 Why FOL is More Powerful

FOL allows:

- Representation of general rules
- Compact knowledge base
- Reusable rules
- Automated theorem proving

This is why most classical AI systems use FOL as foundation.

3. LOGICAL REASONING

3.1 What is Logical Reasoning?

Logical reasoning is the systematic process of deriving conclusions from known premises using inference rules.

In AI, reasoning is used for:

- Problem solving
- Theorem proving
- Planning
- Expert systems
- Question answering

3.2 Types of Reasoning (Expanded with Examples)

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1. Deductive Reasoning

General → Specific
Conclusion is logically certain.

Example:

1. $\forall x\,(Student(x) \rightarrow Smart(x))$
2. Student(Ram)

Conclusion:
Smart(Ram)

This is guaranteed true.

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2. Inductive Reasoning

Specific → General

Observed:
Crow1 is black
Crow2 is black
Crow3 is black

Conclusion:
All crows are black

Not logically guaranteed.

Used in machine learning.

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3. Abductive Reasoning

Inference to best explanation.

Fact:
Grass is wet.

Possible causes:
Rain
Sprinkler

System chooses most plausible explanation.

Used in:

- Medical diagnosis
- Fault detection