UNIT - III

Logic and Knowledge Representation

→ First-order Logic :-

- Representation
- Syntax & Semantics of FOL
- Using FOL logic
- Knowledge Engineering in FOL

→ Inference in FOL :-

- Propositional vs First-order Inference
- Unification & Lifting
- Forward chaining
- Backward chaining
- Resolution

FOL (First Order Logic) → It is Powerful framework

→ Also called as First Order Predicate logic (or) Predicate logic

~~Knowledge repre~~

→ We use 2 techniques, to represent Knowledge:

- Propositional Logic (or)
- Predicate Logic

→ Result of Propositional logic is True or False

-but not both Simultaneously

ex: 2 is an even

→ Inorder to represent complex sentences or Natural language sentences Propositional logic is not sufficient.

ex: x is an even number.

→ We require Predicate logic to represent the complex sentences

→ Predicate logic is an extension ~~of~~ to Proposition logic.

~~*Representation~~

Components of Predicate logic

1. Objects (or) Constants (names): 5, John

2. Variables: x, y

3. Predicates: represents relationship b/w the objects.

ex: John loves Sophy ⇒ loves (John, Sophy)

John = object, loves = Predicate, Sophy = object

4. Quantifiers:

① Universal Quantifier (∀): for all, for every, for each, everything, Anything, for any.

(ii). Existential Quantifier ($\exists$):

There exists, for some, for atleast one, there exists some.

5. Connectives:

$\wedge$ (AND), $\vee$ (OR), $\neg$ (negation), conditional ($\rightarrow$),

biconditional ($\leftrightarrow$).

* Representation of FOL

→ FOL creates a powerful set of ontological commitments i.e

- Properties, objects, functions, relations

Properties: It is used to differentiate one object with another (eg: big, small)

Objects: Items with separate identities (names)

Functions: One type of relation

Relations: relation exists b/w objects.

* Representation of FOL

→ It means writing real-world knowledge in the form of logical statements.

→ It is used to represent objects, their properties, and relationships b/w them.

→ It helps to AI agents to understand & make decisions.

→ It is more powerful than propositional logic.

→ It is a way to represent knowledge about the world using:

- objects
- properties
- Relations
- Rules.

Elements	Representation	Meaning
Constants	Ram, India	Specific things
Variables	x, y	General things
Predicates	Student(x), Loves(Ram, Pizza)	properties or relations
Functions	FatherOf(x)	Maps input to object
Quantifiers	$\forall$, $\exists$	Show quantity
Connectives	$\wedge, \vee, \rightarrow, \neg, \Leftrightarrow$	Logical symbol

Quantifiers

- $\forall x \rightarrow$ universal Quantifier (for all)

Ex: $\forall x$ Human$(x) \rightarrow$ Mortal (x)

(All humans are mortal)

- $\exists x \rightarrow$ Existential Quantifier (there exists)

ex: $\exists x$ Animal$(x) \wedge$ wild (x)

(Some animals are wild)

Connectives

Symbol	Meaning	Example.
$\wedge$	AND	$A \wedge B$
$\vee$	OR	$A \vee B$
$\rightarrow$	Implies	$A \rightarrow B$
$\sim$	NOT	$\sim A$
$\Leftrightarrow$	Iff	$A \Leftrightarrow B$

Examples

Statement	FOL Representation
①. Ravi is a student	Student(Ravi)
②. All humans are mortal	$\forall x$ Human$(x) \rightarrow$ Mortal(x)
③. Some birds can fly	$\exists x$ Bird$(x) \wedge$ Fly(x)
④. Ram loves ice cream	Loves(Ram, iceCream)
⑤. Rani is mother of Ravi	MotherOf(Ravi)

* Syntax and Semantics of FOL

Syntax

* Same as Representation

Semantics

→ Semantics = Meaning of FOL Statements

Term	Meaning	Example
Domain	Set of all objects	{Ram, Ravi, Cat}
Interpretation	Assigning meaning to constants, functions, Predicates	Student (Ram) = True
Truth value	Stmt is True or False depending on interpretation	$\forall x$ Student(x) → True or False

Example:

Let domain = {Ram, Ravi}

Let Student(Ram) = True
Student (Ravi) = False

Then:

- $\forall x$ Student (x) — False
- $\exists x$ Student (x) — False

* Using FOL Logic

→ It means converting English sentences (facts, rules) into FOL statements.

→ It helps AI to store knowledge

Steps to use FOL Logic

1. Identify constants
2. Identify variables
3. Define predicates (properties or relations)
4. Use quantifiers ($\forall, \exists$)
5. Use connectives ($\wedge, \vee, \sim, \rightarrow, \leftrightarrow$)

Examples

English Sentence	FOL logic
1. Ram is a student	Student(Ram)
2. All humans are mortal	$\forall x$ Human$(x) \rightarrow$ Mortal(x)
3. Some animals are wild	$\exists x$ Animal$(x) \wedge$ Wild(x)
4. If it rains, the ground is wet	Rains$(x) \rightarrow$ Wet(Ground)
5. Every person has a mother	$\forall x \exists y$ Mother(y, x)
6. Ravi loves pizza	Loves(Ravi, Pizza)

Benefits of using FOL

→ Helps to represent complex knowledge.

→ useful in :- NLP
- Expert Systems
- Planning.

→ More expressive than propositional logic.

⇒ Converts real-world facts to logic

⇒ Uses tools constants, variables, predicates, quantifiers.

* Knowledge Engineering

→ It is the process of building a knowledge base for an AI System.

→ In FOL, this means collecting facts, rules & relationships and expressing them FOL Logic.

⇒ Used in expert systems, chatbots, planners etc.

→ It means constructing (building knowledge for an AI system,

→ In FOL, we represent facts and rules using logic.

ex: All humans are mortal

$\forall x \; Human(x) \rightarrow Mortal(x)$

Steps

1. Define the problem : what should the system solve?
   → what is actual ~~prob~~ issue?
2. Choose the vocabulary :
   constants, predicates, functions.
   - Decide

ex: - constant : Ravi
   - Predicate : HasFever(x)

3. Write FOL sentences :
- convert knowledge into FOL Logic
ex: $\forall x$ HasFever(x) $\rightarrow$ Sick(x)

4. Add Facts : Substitute x value.
ex: HasFever(Ravi)

5. Ask questions / queries :
ex: Is Ravi Sick ?

6. Use Inference to get answers : (use logic)
- System applies logic & gives output.

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ex: ① If a person has fever and cough, they have flu"

②. constants : Ravi, Doctor
Predicate : HasFever(X), HasCough(x), HasFlu(x)

③. $\forall x$(HasFever(x) $\wedge$ HasCough(x)) $\rightarrow$ HasFlu(x)

④. • HasFever (Ravi)
• HasCough (Ravi)

⑤. ~~Step~~ Does Ravi have flu ?

⑥. Yes

Uses
- Robots
- Expert Systems
- Chatbots
- Game logic

* Inference in FOL

→ Inference means deriving new facts from known facts and rules.

→ It means finding new facts from known facts.

→ It helps AI to think & answer questions

Used

- To solve problems
- To answer questions
- To make decisions
- To think

Types of Inference

(a). Forward chaining

→ Starts from known facts

→ Applies rules to generate new facts.

→ Repeats until the goal is reached.

⇒ Uses rules to find new facts.

⇒ Goes forward step by step.

ex: Human (Ram)

Rule: Human(x) → Mortal (x)

Result: Mortal (Ram)

6. Backward Chaining

→ Starts from the goal.
→ works backwards
→ moves backwards step by step.
→ Used in expert systems, AI reasoning

ex:
- Goal – Mortal (Ram)?
- Rule: $\forall x$ Human $(x) \rightarrow$ Mortal (x)

→ check Is Ram a Human? – Yes
⇒ So, Mortal (Ram) → True.

Techniques

- Unification
- Resolution
- Modus Ponens [If $A \rightarrow B$ & A is True then B is true]

* Unification → matching 2 FOL stmts.

→ It is the Process of matching two logical expressions
  - by finding common values for variables.

→ It is used in : inference rules
  - resolution.

Example :

- Expression 1 : Loves (Ram, X)
- Expression 2 : Loves (Ram, Pizza)

⇒ Unifier : X = Pizza

→ These two can be unified using substitution.

Expression 1	Expression 2	Result
P(x)	P(John)	x = John
Q(a, y)	Q(a, Ravi)	y = Ravi
~~Q(Ravi)~~ P(X, X) ~~P(Ravi, Sita)~~	P (Ram, Sita)	Not unifiable (x used differently)

Uses

- in resolution
- in backward chaining.

* Lifting → using resolution in FOL

→ Lifting is the process of applying inference rules to FOL

– instead of Propositional logic.

ex: Parent (x, y) ∨ Loves (x, y)

∼ Parent (Ram, Sita)

(i) $x =$ Ram, $y =$ Sita

(ii). Parent (Ram, Sita) ∨ Loves (Ram, Sita)

∼ Parent (Ram, Sita)

Result: Loves (Ram, Sita)

Propositional Logic	First-order Logic
1). Uses full sentence.	1). Uses Variables & Predicates.
2). Less expressive	2). More expressive
3). Easier	3). Not easier
4). Less Powerful	4). More Powerful
5). No internal structure.	5). It has internal ~~to~~ structure.
6). No quantifiers used	6). Use quantifiers
7). Uses resolution.	7). Uses resolution.
8). ex: $A \rightarrow B$	8). ex: $\forall x\,(Human(x) \rightarrow Mortal(x))$
9). Used in simple Problems	9). Used in NLP, Expert System, AI agent
10). Used in Basic reasoning	10). Used in ~~complex knowledge representation~~. deep reasoning.