Module: 4.1

Knowledge and Reasoning

Motivation:

Motivation of this module is to provide the students with the knowledge:

- What is knowledge base?
- How logical agents represent knowledge base?
- What is knowledge representation language?
- What is logic & knowledge about propositional logic?

Syllabus:

Lecture no	Content	Duration (Hr)	Self-Study (Hrs)
1	Knowledge based Agents The Wumpus World	1	1
2	The Propositional logic First Order Logic: Syntax and Semantic	1	

Learning Objective:

Learner should know about the representation of knowledge and the reasoning processes that bring knowledge to life and are central to the entire field of artificial intelligence. This provides an overview of all the fundamental concepts of logical representation and reasoning. After studying this chapter, students should know about:

1. What are knowledge base agents & what is wumpus world?
2. How Logic & Propositional Logic help in knowledge reasoning?

Theoretical Background:

Knowledge representation (KR) and reasoning' is an area of artificial intelligence whose fundamental goal is to represent knowledge in a manner that facilitates inferencing (i.e. drawing conclusions) from knowledge. It analyzes how to formally think - how to use a symbol system to represent a domain of discourse (that which can be talked about), along with functions that allow inference (formalized reasoning) about the objects. Generally speaking, some kind of logic is used both to supply formal semantics of how reasoning functions apply to symbols in the domain of discourse, as well as to how to supply operators such as quantifiers, modal operators, etc. that, along with an interpretation theory, give meaning to the sentences in the logic.

Predicate logic is the generic term for symbolic formal systems like first-order logic, second-order logic, many-sorted logic or infinitary logic. This formal system is distinguished from other systems in that its formulae contain variables which can be quantified. Two common quantifiers are the existential ∃ ("there exists") and universal ∀ ("for all") quantifiers. The variables could be elements in the universe under discussion, or perhaps relations or functions over that universe. For instance, an existential quantifier over a function symbol would be interpreted as modifier "there is a function".

Frames were proposed by Marvin Minsky in his 1974 article "A Framework for Representing Knowledge." A frame is an artificial intelligence data structure used to divide knowledge into substructures by representing "stereotyped situations." Frames are connected together to form a complete idea.

Knowledge is a collection of facts, information, and/or skills acquired through experience or education or (more generally) the theoretical or practical understanding of a subject. It can be implicit (as with practical skill or expertise) or explicit (as with the theoretical understanding of a subject); and it can be more or less formal or systematic.

Belief is the psychological state in which an individual holds a proposition or premise to be true.

A **hypothesis** (from Greek plural **hypotheses**) is a proposed explanation for a phenomenon. The term derives from the Greek– *hypotithenai* meaning "to put under" or "to suppose". For a hypothesis to be put forward as a **scientific hypothesis**, the scientific method requires that one can test it.

The term **data** refers to qualitative or quantitative attributes of a variable or set of variables. Data (plural of "**datum**") are typically the results of measurements and can be the basis of graphs, images, or observations of a set of variables

Procedural knowledge, also known as **imperative knowledge**, is the knowledge exercised in the performance of some task. See below for the specific meaning of this term in

cognitive psychology and **intellectual property** law. Procedural knowledge is different from other kinds of knowledge, such as declarative knowledge, in that it can be directly applied to a task. For instance, the procedural knowledge one uses to solve problems differs from the declarative knowledge one possesses about problem solving. In some legal systems, such procedural knowledge has been considered the intellectual property of a company, and can be transferred when that company is purchased.

Declarative knowledge is factual knowledge. For example knowing that "A cathode ray tube is used to project a picture in most televisions" is declarative knowledge. Propositional knowledge or declarative knowledge is knowledge or the possession of information that is either true or false. Declarative knowledge is assertion-oriented. It describes objects and events by specifying the properties which characterize them; it does not pay attention to the actions needed to obtain a result, but only on its properties.

Key Definitions:

Knowledge based agent: Agent that reasons logically.

Syntax: describes the possible configurations that can constitute sentences.

Semantics: determines the facts in the world to which the sentences refer.

Course Content:

Lecture : 1

Knowledge Based Agent

The central component of a knowledge based agent is its **knowledge base.** Informally, a knowledge base is a set of representations of facts about the world. Each individual representation is called a **sentence.** The sentences are expressed in a language called a **knowledge representation language.** There must be a way to add new sentences to the knowledge base, and a way to query what is known. Determining what follows from what the KB has been the job of the **inference** mechanism, the other main component of a knowledge-based agent.

function *KB-AGENT(percept)* **returns** an *action*

static: *KB,* a knowledge base

t, a counter, initially 0, indicating time

TELL(KB, MAKE-PERCEPT-SENTENCE(percept, *t))*

action — ASK(KB, MAKE-ACTION-QUERY(t))

TELL(KB, MAKE-ACTION-SENTENCE(action, *t))*

t←*t*+ 1

return *action*

The details of the representation language are hidden inside two functions that implement the interface between the agent program "shell" and the core representation and reasoning system. MAKE-PERCEPT-SENTENCE takes a percept and a time and returns a sentence representing the fact that the agent perceived the percept at the given time, and MAKE-ACTION-QUERY takes a time as input and returns a sentence that is suitable for asking what action should be performed at that time. The details of the inference mechanism are hidden inside TELL and ASK.

We can describe a knowledge base agent at 3 levels:

• **The knowledge level or epistemological level** is the most abstract; we can describe the agent by saying what it knows. Then most of the time we can work at the knowledge level and not worry about lower levels.

• **The logical level** is the level at which the knowledge is encoded into sentences.

• **The implementation level** is the level that runs on the agent architecture. It is the level at which there are physical representations of the sentences at the logical level. The choice of implementation is very important to the efficient performance of the agent, but it is irrelevant to the logical level and the knowledge level.

Knowledge Representation (KR) has long been considered one of the principal elements of Artificial Intelligence, and a critical part of all problem solving. The subfields of KR range from the purely philosophical aspects of epistemology to the more practical problems of handling huge amounts of data. This diversity is unified by the central problem of encoding human knowledge - in all its various forms - in such a way that the knowledge can be used. This goal is perhaps best summarized in the Knowledge Representation Hypothesis:

Any mechanically embodied intelligent process will be comprised of structural ingredients that a) we as external observers naturally take to represent a propositional account of the knowledge that the overall process exhibits, and b) independent of such external semantically attribution, play a formal but causal and essential role in engendering the behavior that manifests that knowledge. A successful representation of some knowledge must, then, be in a form that is understandable by humans, and must cause the system using the knowledge to behave as if it knows it. The "structural ingredients" that accomplish these goals are typically found in the languages for KR, both implemented and theoretical, that have been developed over the years.

The following properties should be possessed by a knowledge representation system.

Representational Adequacy

The ability to represent the required knowledge;

Inferential Adequacy

The ability to manipulate the knowledge represented to produce new knowledge corresponding to that inferred from the original;

Inferential Efficiency

The ability to direct the inferential mechanisms into the most productive directions by storing appropriate guides;

Inquisitional Efficiency

the ability to acquire new knowledge using automatic methods wherever possible rather than reliance on human intervention.

Let's check the take away from this lecture

Exercise

1. The work in AI is that intelligent behavior can be achieved through the manipulation of symbol structures representing bits of ______________
   a. Fact
   b. Knowledge
   c. Logic
   d. Rules

Learning from this lecture: Learners will be able to understand knowledge base agents along with knowledge base representation techniques.

Lecture : 2

First order logic

Propositional logic assumes the world contains facts, Whereas First-order logic (like natural language) assumes the world contains:

Objects: people, houses, numbers, colors, baseball games, wars, …
Relations: brother of, bigger than, inside, part of, has color, occurred after, owns…
Properties: red, round, bogus, prime, multistoried...
Functions: father of, best friend, one more than, plus, …

Example:

• **"One plus two equals three"**
Objects: one, two, three, one plus two
Relation: equals
Function: plus. (One plus two is a name for the object that is obtained by applying the function plus to the objects one and two. Three is another name for this object.)

• **"Squares neighboring the wumpus are smelly."**
Objects: wumpus, square
Property: smelly
Relation: neighboring.

• **"Evil King John ruled England in 1200."**
Objects: John, England, 1200
Relation: ruled
Properties: evil, king.

Syntax and semantic

Constants	KingJohn, 2, NUS,...
Predicates	Brother, GreaterThan, Round...
Functions	Sqrt, LeftLegOf, FatherOf, Cosin...
Variables	x, y, a, b,...
Connectives	$\neg, \Rightarrow, \wedge, \vee, \Leftrightarrow$
Equality	=
Quantifiers	$\forall, \exists$

Atomic sentence = predicate ($term_1$,...,$term_n$) or $term_1$ = $term_2$
Term = function ($term_1$,...,$term_n$) or constant or variable
Term with no variables is called ground term
E.g. Brother(KingJohn,RichardTheLionheart)
E.g. > (Length(LeftLegOf(Richard)), Length(LeftLegOf(KingJohn)))
E.g. GreaterThan (Length (LeftLegOf (John)), (Length (LeftLegOf (Eric))))

Complex sentences are made from atomic sentences using connectives
$\neg S$, $S_1 \wedge S_2$, $S_1 \vee S_2$, $S_1 \Rightarrow S_2$, $S_1 \Leftrightarrow S_2$,
E.g. *Sibling(KingJohn,Richard)* $\Rightarrow$ *Sibling(Richard,KingJohn)*

Propositional calculus or **logic** (also called **sentential calculus** or **sentential logic**) is a formal system in which formulas of a formal language may be interpreted as representing propositions. A system of inference rules and axioms allows certain formulas to be derived, called theorems; which may be interpreted as true propositions. The series of formulas which is constructed within such a system is called a derivation and the last formula of the series is a theorem, whose derivation may be interpreted as a proof of the truth of the proposition represented by the theorem.

Predicate logic is the generic term for symbolic formal systems like first-order logic, second-order logic, many-sorted logic or infinitely logic. This formal system is distinguished from other systems in that its formulae contain variables which can be quantified. Two common quantifiers are the existential ∃ ("there exists") and universal ∀ ("for all") quantifiers. The variables could be elements in the universe under discussion, or perhaps relations or functions over that universe. For instance, an existential quantifier over a function symbol would be interpreted as modifier "there is a function".

UNIVERSAL QUANTIFICATION

∀<variables> <sentence>

Everyone at NUS is smart:

$\forall x\ At(x,NUS) \Rightarrow Smart(x)$

$\forall x$ P is true in a model m iff P is true with x being each possible object in the model

Roughly speaking, equivalent to the conjunction of instantiations of P

Example:

$At(KingJohn,NUS) \Rightarrow Smart(KingJohn) \wedge At(Richard,NUS) \Rightarrow Smart(Richard) \wedge At(NUS,NUS) \Rightarrow Smart(NUS) \wedge \ldots$

Example: “All elephants are gray”

$(\forall x)(elephant(x) \Rightarrow color(x, GRAY))$

EXISTENTIAL QUANTIFICATION

∃<variables> <sentence>

Someone at NUS is smart:

$\exists x\ At(x,NUS) \wedge Smart(x)$

$\exists x$ P is true in a model m iff P is true with x being some possible object in the model

Roughly speaking, equivalent to the disjunction of instantiations of P

Example:

$At(KingJohn,NUS) \wedge Smart(KingJohn) \vee At(Richard,NUS) \wedge Smart(Richard) \vee At(NUS,NUS) \wedge Smart(NUS) \vee \ldots$

Example: “Someone wrote Computer Chess”

$(\exists x\ write(x, COMPUTER\text{-}CHESS))$

A Few Assumptions : All doors are closed at the initial state. Doors must be opened prior to entering a room (obviously) and they must be closed as Shakey just after it enters the room or leaves the room. Your programs will show lots of "open door" and "close door" actions.

Shakey has poor eyesight. Specifically, he has to turn on the light just after entering a room. As Shakey plans to leave a room, after opening the door, Shakey must turn off the light.

Shakey only has one robotic arm that can only do one thing at a time. He can open a door, turn on a light, pickup or drop a box.
You do not have to keep track of what direction Shakey is facing. The important part of this project is the "action plan".

Let's check the take away from this lecture

Exercise

2. A _____________ almost by definition has a well defined syntax and semantics and is concerned with truth preserving inference.
    a. Fact
    b. Knowledge
    c. logic
    d. Rules
3. Truths about the real world and what we represent
    a. Facts
    b. Knowledge
    c. Logic
    d. Rules
4. It is the ability to acquire new knowledge using automatic methods wherever possible rather than on human intervention.
    a. Representational adequacy
    b. Inferential adequacy
    c. Inferential efficiency
    d. Acquisitional efficiency
5. The basis of these perspective is the knowledge representation hypothesis by:
    a. Biran c. Smith
    b. John McCarthy
    c. Herbert
    d. None
6. ___________________ Logic is simple language that is useful for showing key ideas and definitions.
    a. Knowledge
    b. Rules
    c. Propositional
    d. All of the above.

7. The legitimate expressions of the predicate calculus are called as___________________
    a. Well formed formulas
    b. Predicate logic
    c. Logic
    d. None.
8. It is used to represent a relation in a domain.
    a. Predicate symbols
    b. Constant symbols
    c. Variable symbols
    d. Function symbols
9. Denoted by Ǝ is known as ______________________________
    a. Universal Quantifiers
    b. Existential Quantifiers
    c. Both
    d. None.
10. A left hand built by connecting two formulas with _________is called as implication.
    a. Σ
    b. Ʊ
    c. →

d. All of the above.

Learning from this lecture: Learners will be able to understand prepositional Logic and First order logic.

Conclusion

This chapter was introduction to knowledge base agents, Prepositional and Predicate logic required for reasoning.

Short Answer Questions:

Q1. For the following logical expression , construct truth table:

i. $(C\surd \neg D)\rightarrow(D\rightarrow C)$
ii. $(P\leftrightarrow Q)\surd R$

Q2. Transform the following into Disjunctive normal form.

i. $\neg (P\rightarrow Q) \rightarrow R$
ii. $(P\leftrightarrow Q)\hat{}R$

Q3. Briefly describe the following knowledge representation schemes along with their merits and demerits.

iii. Predicate logic
iv. Frames

Q4. Differentiate between propositional and predicate logic.

Q5. What is the difference between knowledge, belief, hypotheses and data?

Q6. What is the difference between declarative and procedural knowledge?

Q7. How do we represent knowledge in AI system?

Q8. Describe the properties of knowledge representation systems.

Q 9 Represent each of these sentences in propositional logic.
a. If I take History, I cannot take Economics.
b. I must take either Japanese or Italian but not both.
c. I must take at least two of cs520, cs552, and cs564.

Long Answer Questions:

Q. 11. Use truth tables to show the following sentences are valid, and thus that the equivalences hold:

P ^ (Q ^ R) <=> (P ^ Q) ^ R	Associativity of conjunction
P ∨ (Q ∨ R) <=> (P ∨ Q) ∨ R	Associativity of disjunction
P ^ Q <=> Q ^ P	Commutativity of conjunction
P ∨ Q <=> Q ∨ P	Commutativity of disjunction
P ^ (Q ∨ R) <=> (P ^ Q) ∨ (P ^ R)	Distributivity of ^ over ∨
P ∨ (Q ^ R) <=> (P ∨ Q) ^ (P ∨ R)	Distributivity of ∨ over ^
~(P ^ Q) <=> ~Q ∨ ~P	de Morgan’s Law
~(P ∨ Q) <=> ~Q ^ ~P	de Morgan’s Law
P => Q <=> ~Q => ~P	Contraposition
~ ~P <=> P	Double negation
P => Q <=> ~P ∨ Q	
P <=> Q <=> (P => Q) ^ (Q => P)	
P <=> Q <=> (P ^ Q) ∨ (~Q ^ ~P)	
P ^ ~P <=> False	
P ∨ ~P <=> True	

Q.12. State whether the following sentences are valid, unsatisfiable, or neither.
Verify your decisions using truth tables or equivalence rules.
a. Smoke => Smoke
b. Smoke => Fire
c (Smoke => Fire) => (~Smoke => ~Fire)
d. Smoke ∨ Fire ∨ ~Fire
e. ((Smoke ^ Heat) => Fire) <=> ((Smoke => Fire) ∨ (Heat => Fire))
f. (Smoke => Fire) => ((Smoke ^ Heat) => Fire)
g. Big ∨ Dumb ∨ (Big => Dumb)
h. (Big ^ Dumb) ∨ ~Dumb

Q. 13. Describe the wumpus world according the properties of task environment.

Q. 14. Prove by resolution that Marcus is not alive now

- Marcus was a man
- Marcus was a Pompeian
- Marcus was born in 40 A.D.
- All men are mortal
- All Pompeians died when volcano erupted in 79 A.D.
- No mortal lives longer than 150 years
- It is now 1991
- Alive means not dead
- If someone dies, then he is dead at all later times

Q.15. From “Horse are animals”, it follows that “The head of the Horse is the head of an animal”. Demonstrate that this inference is valid by carrying out the following steps:
(i) Translate the premise and the conclusion into the language of the first order logic. Use three predicates HeadOf(h,x), Horse(x) and Animal(x)
(ii) Negate the conclusion and convert the premise and negated conclusion into conjunctive normal form.
(iii) Use resolution to show that the conclusion follows from the premise.

References:

Books:

	Title	Authors	Publisher	Edition	Year	Chapter No
1	Artificial Intelligence a Modern Approach	Stuart J. Russell and Peter Norvig	McGraw Hill	3rd Edition	2009	
2	A First Course in Artificial Intelligence	Deepak Khemani	McGraw Hill Education (India)	1st Edition	2013	

Online Resources:

- https://nptel.ac.in/courses/106/102/106102220/
- https://www.javatpoint.com/history-of-artificial-intelligence
- http://people.eecs.berkeley.edu/~russell/slides/