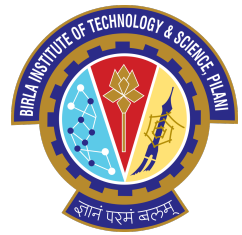
IS-ZC444: ARTIFICIAL INTELLIGENCE

Lecture-12: Inference with Logical Agents + First Order Logic



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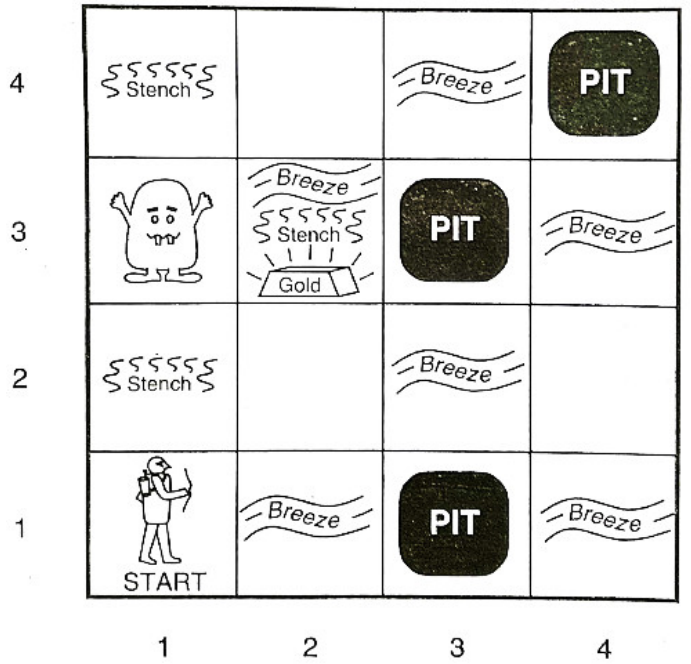
Recall Wumpus World

- **Performance** gold +100, death -100, step -1, arrow -10
- **Environment** smell around wumpus, breeze around pit
- **Actuator** turn left/right, forward, grab, release, shoot
- **Sensor** breeze, glitter, smell, bump, scream



Single Agent, Deterministic, Static, Discrete, !Observable & !Episodic

- $P_{x,y}$ if there is a pit in $[x, y]$
- $W_{x,y}$ if wumpus is in $[x, y]$
- $B_{x,y}$ if breeze is in $[x, y]$
- $S_{x,y}$ if stench is in $[x, y]$

We know R_1: $\neg P_{1,1}$, R_2: $B_{1,1} \Leftrightarrow (P_{1,2} \vee P_{2,1})$,
R_3: $B_{2,1} \Leftrightarrow (P_{1,1} \vee P_{2,2} \vee P_{3,1})$, R_4: $\neg B_{1,1}$, R_5: $B_{2,1}$

Model Checking for Inference

- Seven symbols $P_{1,1}$, $B_{1,1}$, $P_{1,2}$, $P_{2,1}$, $B_{2,1}$, $P_{2,2}$, $P_{3,1}$ have $2^7 = 128$ models. In three of these knowledge base is true.

$B_{1,1}$	$B_{2,1}$	$P_{1,1}$	$P_{1,2}$	$P_{2,1}$	$P_{2,2}$	$P_{3,1}$	R_1	R_2	R_3	R_4	R_5	KB
false	false	false	false	false	false	false	true	true	true	true	false	false
false	false	false	false	false	false	true	true	true	false	true	false	false
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
false	true	false	false	false	false	false	true	true	false	true	true	false
false	true	false	false	false	false	true	true	true	true	true	true	true
false	true	false	false	false	true	false	true	true	true	true	true	true
false	true	false	false	false	true	true	true	true	true	true	true	true
false	true	false	false	true	false	false	true	false	false	true	true	false
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
true	true	true	true	true	true	true	false	true	true	false	true	false

In all those three $\neg P_{1,2}$ is true, hence there is no pit in [1,2].
On the other hand $P_{2,2}$ is true on two and false in one so it is not confirmed whether there is pit in [2,2] or not.

Validity and Satisfiability

- **Validity**: sentence is true in all models (tautologies)

$$A \vee \neg A$$
$$A \vee B \rightarrow A \vee B$$

- **Satisfiability**: sentence is true in some models

$$A \vee \neg B$$
$$A \rightarrow B$$

Determine whether following sentence is valid or satisfiable

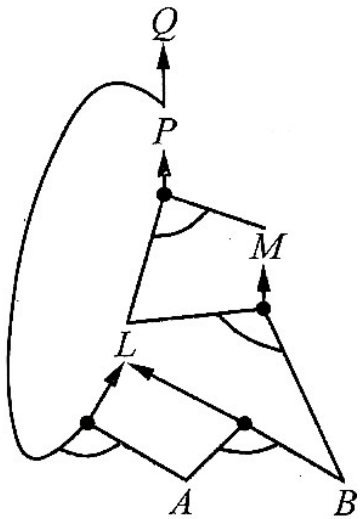
$$((A \wedge B) \rightarrow C) \leftrightarrow (A \rightarrow (B \rightarrow C))$$

Forward Chaining

Determines if a single proposition symbol q is entailed by the knowledge? (data driven reasoning)

- It begins from known facts and adds conclusions of the implication whose all the premises are known
- for $L_{1,1} \wedge breeze \rightarrow B_{1,1}$ if we know $L_{1,1}$ and $breeze$ then $B_{1,1}$ is added in knowledge base [1]

$P \Rightarrow Q$
$L \wedge M \Rightarrow P$
$B \wedge L \Rightarrow M$
$A \wedge P \Rightarrow L$
$A \wedge B \Rightarrow L$
A
B



- Applies Modus Ponens

$$\frac{\phi \quad \phi \rightarrow \psi}{\psi}$$

[1] $L_{1,1}$: location is [1,1]

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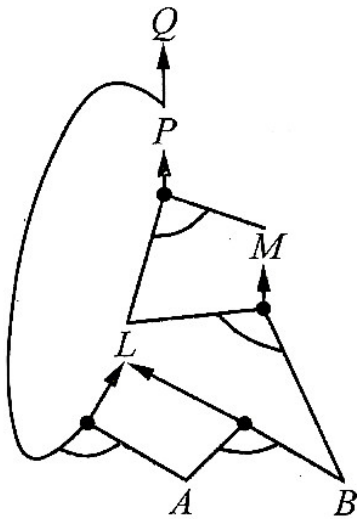

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$$\frac{\phi \quad \phi \rightarrow \psi}{\psi}$$

- An and-or tree gets constructed

[1] $L_{1,1}$: location is [1,1]

Backward Chaining

- Works backward from query
- If query Q is known to be true, then no work is needed.
- Otherwise, find those implications whose conclusion is Q
- If all the premises of one of those implications can be proven true (by backward chaining) then Q is true

$P \Rightarrow Q$

$L \wedge M \Rightarrow P$

$B \wedge L \Rightarrow M$

$A \wedge P \Rightarrow L$

$A \wedge B \Rightarrow L$

A

B

- test(Q) is it true ?
- test(P) is it true ?
- test($L \wedge M$) ?
- ((test($A \wedge B$) or test($A \wedge P$)) and test($B \wedge L$) ? we know A and B so we have L this gives M
- Therefore P and hence Q

First Order Logic (Predicate Logic)

- We have **constants**, **variables**, **predicates** and **functions**
- Here $P(x)$ could means $\forall x$ we have $P(x)$ or $\exists x$ such that $P(x)$
- Variable x has a domain from where it gets values
- $\forall x, \exists y P(x, y)$ is not always same as $\exists y, \forall x P(x, y)$
- When we say $\exists$ a predicate then it is higher order logic

Examples

1. Not every customer have purchased milk and bread

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Examples

1. Not every customer have purchased milk and bread

$$\exists c \;\; Cust(c) \wedge [\neg shop(milk, c) \vee \neg shop(bread, c)]$$

2. Only one customer have purchased guitar

First Order Logic (Predicate Logic)

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Examples

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$$\exists c \;\; Cust(c) \wedge [\neg shop(milk, c) \vee \neg shop(bread, c)]$$

2. Only one customer have purchased guitar

$$\exists x \;\; [Cust(x) \wedge shop(G, x) \wedge \forall y [\neg(x = y) \wedge Cust(y) \Rightarrow \neg shop(G, y)]]$$

3. Only one customer have purchased guitar and pen
4. Highest purchase in forenoon is more than afternoon.

Inference in First Order Logic

- **Universal Elimination** $\forall x \;\; Feels(x, king)$ could be $Feels(Raju, king)$ substitution $\{x/\text{Raju}\}$ is done using some ground term.
- **Existential Elimination** $\exists x \;\; Feels(x, king)$ could be $Feels(man, king)$ if *man* does not appear in knowledge base [2]
- **Existential Introduction** If $Feels(Raju, king)$ then we can say $\exists x \;\; Feels(x, king)$

1. It is crime for Magadh to sell formula to a hostile country
2. Country Bhind, an enemy of Magadh have purchased some formula from Dara
3. Dara is from Magadh
4. Question: Is Dara a criminal?

[2] *man* is a name of person who feels like king

Prolog

- A logic programming language [3]
- Compile as ['a.pl'].
- If :- and , or ; not not
- write('hello'), nl

```
warm_blood(penguin).
warm_blood(human).
produce_milk(penguin).
produce_milk(human).
have_feather(penguin).
have_hair(human).
mammal(X) :-
warm_blood(X),
produce_milk(X),

have_hair(X).
```

- is_even(X) :-
  Y is X//2, X =:= 2*Y.
- write('what is your name/ '), read(X), write('Hi '),write(X).

```
?- mammal(penguin)
no
?- mammal(X).
X = human.
```

Many more things are possible

[3] http://www.swi-prolog.org/

Thank You!

Thank you very much for your attention!

Queries ?

(Reference[4])

[4] 1) Book - *AIMA*, ch-07/08, Russell and Norvig. 2) Book - *Logic in CS*, ch-02, Mitchel Huth and Mark Ryan.