$h(D \to G) = 1$

$A \to B \to C \to F \to D \to G = 29 + 1 + 1$ ✓

$A \to B \to C \to F \to D \to H = 29 + 1 + 4$

$\therefore$ Path : $A \to B \to C \to F \to D \to G = 31$

↑ total cost.

25/1/24/ Thursday.

Propositional Logic (cont):

Whether the combinations of these stmts are:

1. Valid
2. Satisfies
3. Entails into Knowledge Base (KB)

Entailment.

- It means that one thing follows from another.

  $KB \models \alpha$ $\quad\models$ - symbol of entailment

- KB entails sentence α if & only if α is true in all worlds where KB is true.

- eg: the KB containing "The Ravens won" and "The Jays won" entails "The Ravens won or the Jays won".

Validity & Satisfiable:

- Validity is connected to inference via the Deduction Theorem.
- ~~Vad~~ Valid → Tautology.
  Satisfiable → Contigency.
  Unsatisfiable → Contradiction.
- Satisfiability is connected to inference via the following:

  $KB \models \alpha$ ~~if & only if.~~
  α by reduction and absurdum.

Q. Draw truth-table (6 marks)

		a	b	c	d	e
S	T	$\neg(S \vee T)$	$S \not\models T$	$T \vee \neg T$	$\neg(S \leftrightarrow S)$	$\neg S \rightarrow \neg T$
T	T	F	T	T	F	T
T	F	F	F	T	F	T
F	T	F	F	T	F	F
F	F	T	F	T	F	T

$S \leftrightarrow S = (S \rightarrow S) \wedge (S \rightarrow S)$
T ∧ T

a. Identify the valid stmts.
A: $T \vee \neg T$ (c)

b) Identify the invalid / not satisfied stmts?
A: ~~Everything other than~~ α d

c) Identify satisfiable stmts?
A: a, b, e.

d) Does:

$a \models b$	$b \models a$
$a \models c$	$b \models c$
$a \models d$	$b \models d$
$a \models e$	$b \models e$

Whenever a is true then is b true ⇒ $a \models b$.

A: a entails b if & only if, whenever a is true, b is also true. So for every true in a, there should be true in b.
So,

$a \models b$ ⇒ No.
$a \models c$ ⇒ Yes. ★
$a \models d$ ⇒ No.
$a \models e$ ⇒ Yes. ★

$c \models a$ ⇒ No
$c \models b$ ⇒ No
$c \models d$ ⇒ No
$c \models e$ ⇒ No.

$b \models a$ ⇒ No
$b \models c$ ⇒ Yes ★
$b \models d$ ⇒ No
$b \models e$ ⇒ Yes. ★

$e \models a$ ⇒ No
$e \models b$ ⇒ No
$e \models c$ ⇒ Yes ★
$e \models d$ ⇒ No

d is not considered because d is invalid.

e) How many stmts can be entailed into the KB?
A: There are 5 stmts that can be entailed. (Look above).

5 marks.

Q2. A : $a \vee b \vee c$

B : $a \vee b \wedge c$

C : $\neg a \vee (b \vee c)$

D : $\neg a \vee \neg (b \vee c)$

i) find valid stmt

ii) find unsatisfiable stmt

iii) How many stmts can be entailed to KB.

A:

a	b	c	A $a \vee b \vee c$	B $a \vee b \wedge c$	C $\neg a \vee (b \vee c)$	D $\neg a \vee \neg (b \vee c)$
T	T	T	T	T	T	F
T	T	F	T	F	T	F
T	F	T	T	T	T	F
T	F	F	T	F	F	T
F	T	T	T	T	T	T
F	T	F	T	F	T	T
F	F	T	T	F	T	T
F	F	F	F	F	T	T

i) There are no valid stmts

ii) No unsatisfiable stmt.

iii) $A \models B \Rightarrow$ No $\quad B \models A \Rightarrow$ Yes ⋆ $\quad C \models A \Rightarrow$ No

$A \models C \Rightarrow$ No $\quad B \models C \Rightarrow$ Yes ⋆ $\quad C \models B \Rightarrow$ No

$A \models D \Rightarrow$ No $\quad B \models D \Rightarrow$ No $\quad C \models D \Rightarrow$ No

$D \models A \Rightarrow$ No

$D \models B \Rightarrow$ No

$D \models C \Rightarrow$ No

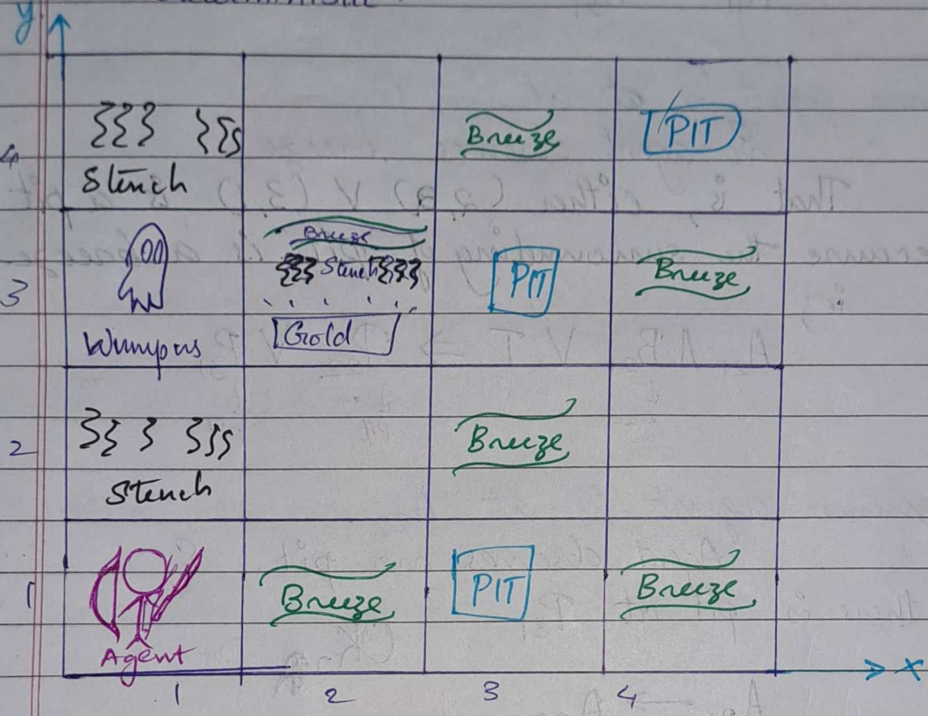
Only 2 stmts can be entailed

31/1/24/ Wednesday.

Wumpus World Problem:

* Use logic package available in python, ↳ for lab. instead of aima

Environment:
- static
- partially observable.
- deterministic.



Propositional atomic stmts:

A_{xy} - Agent is at (x, y) position.
W_{xy} - Wumpus is at (x,y) position.
P_{xy} - Pit is at (x,y) position
B_{xy} - Breeze is at (x,y) position.
S_{xy} - Stench is at (x,y) position
G_{xy} - Gold is at (x,y) position.
V_{xy} - path which the agent has visited

Initial state: A_{11}

first step:

$A_{11} \rightarrow A_{12}$ or $A_{11} \rightarrow A_{21}$ that is: $A_{11} \rightarrow A_{12} \vee A_{21}$

Assume agent is at (2,1).

So agent observes breeze.

That is, either $(2,2) \vee (3,1)$ is a pit (Because the surrounding of pit is a breeze).

ie;

$$A_{21} \wedge \underbrace{B_{21}}_{\text{breeze}} \vee T \Rightarrow \underbrace{P_{22}}_{\text{pit}} \vee \underbrace{P_{31}}_{\text{pit}}$$

Assume agent is at A_{22}.

Agent observes no pit. So there is pit at P_{31}. OK_{22}

$A_{21} \rightarrow A_{22}$

From here it can either go to:

$OK_{22} \rightarrow A_{12} \vee A_{32} \vee A_{23}$

Assume it goes to A_{23}.

$OK_{22} \rightarrow A_{23}$.

Agent observes glittering gold, stench & breeze.

$A_{23} \Rightarrow G_{23}, B_{23}, S_{23}$

$B_{23} \Rightarrow P_{13} \vee P_{33} \vee P_{24}$

$S_{23} \Rightarrow \cancel{W_{13} \vee W_{33} \vee W_{24}}\ W_{13} \vee W_{33} \vee W_{24}$

Pros & Cons of propositional logic:

- Propositional logic is declarative
  - knowledge & inference are separate.
- Allows partial / disjunctive / negated info.
- it is compositional.
- ~~it is~~ meaning in it is context-independent
- has limited expressive power.

First Order Logic:

- Propositional logic assumes that the world contains facts
- first order logic assumes the world contains.
  1. objects - people, houses, numbers etc
  2. relations - red, round, brother of, bigger than etc
  3. functions - father of, bestfriend, one more than, plus, etc
- function (object, relation)

Q. Simon is a man.

A: Simon is a man ← propositional logic.

predicate logic: is_Man (Simon) → generalise is_Man (x)

Q2. Men who are good are chivalrous.

A: ~~G~~A: ~~Men who~~ are good. A: He is a man.

B: ~~Men who~~ are chivalrous.

$G \wedge A \Rightarrow B$ → propositional logic.

Predicate:

$$is\_Man(x, good) \Rightarrow ch(x)$$

Q2. Men who are good are chivalrous.

A: G: ~~Men who~~ are good. A: He is a man.

B: ~~Men who~~ are chivalrous

$G \wedge A \Rightarrow B$ → propositional logic.

Predicate:

is_Man(x, good) $\Rightarrow$ ch(X)

1/2/24 Thursday.

18-25 marks total

→ Convert into first-order predicate logic:

1. Mary loves everyone

A: love( ) ← Take verb out & name it as function

$\forall x$, love(Mary, x)

Quantifiers

Universal $\forall$ Existential $\exists$

2. Everyone loves ~~himself~~ themself.

A: $\forall x$, love(x, x)

3. Everyone loves everyone.

A: $\forall x \forall y$, love(x, y)

4. Mary loves everyone

Rewrite using implication

A: $\forall x$ (Human(x)) $\Rightarrow$ love(Mary, x)

5. Everyone loves everyone except himself.

OR

Everyone loves everyone else.

A: ~~$\forall x \forall y$ love(x, y) $\Rightarrow x \neq y$~~

$\forall x \forall y ((x \neq y) \Leftrightarrow$ love(x, y))

6. Every student smiles. (Use implication)

A: ~~$\forall x$ smile(x)~~

$\forall x$ (Student(x) $\rightarrow$ smile(x))

7. Everyone walks or talks.

A. $\forall x$ (walk(x) $\vee$ talk(x))

8. Every student who walks, talks.

A: $\forall x$ (Student(x) $\wedge$ Walk(x) $\rightarrow$ talk(x))

OR

$\forall x$ ((Student(x) $\rightarrow$ Walk(x)) $\rightarrow$ talk(x))

B Part Question Set

1. The law says that it is a crime for an American to sell weapons to hostile nations. The country Nono, an enemy of America has some missiles and all of its missiles were sold to it by Colonel West, who is an American.

Represent this context in first order logic. Prove that West is criminal.

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1. ~~A~~ ~~$\forall x ((A(x) \wedge Sell(weapons, hostile)) \to Crime(x))$~~

American (x) ∧
~~Hostile (z)~~ ∧
Sell (x, y, z) ∧
Weapon (y) →
Criminal (x)

~~[illegible]~~ (American (x) ∧ Hostile (z) ∧ Sell (x, y, z) ∧ Weapon (y) ⇒ Criminal (x))

- Own (Nono, ~~Missile M~~, M_1)
- Missile (M_1)
- $\forall x$, Missile (x) ∧ Sell (West, x, Nono)
- $\forall x$, Missile (x) ∧ Own (Nono, x) ⇒ Sell (West, x, Nono)
- American (West)
- Missile (x) ⇒ Weapon (y)
- Enemy (x, America) ⇒ Hostile (x)
- Enemy (Nono, America)

All these above statements are going to be fed into the knowledge base.

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6/2/24 Tuesday.

- Resolution
  - ↳ proof by contradiction → We assume that if a stmt is ~~true~~ we assume that its negation is also true.
- Proof by induction

Clausal forms statements:

→ Disjunctive
→ Conjunctive

For applying resolution, we needs stmts in conjunctive normal forms

Paragraph → {Implication, Existential, Universal, Negation, ...} → (CNF) Conjunctive Normal Form → Proof by Resolution

{Implication, Existential, Universal, Negation} ↓ first order logic ↳ 3-4 marks

Conjunctive Normal Form ↳ 6 marks

Proof by Resolution ↳ 3-4 marks

Conversion into CNF:

A sentence expressed as a conjunction of disjunctions of literals is called CNF.

Step 1: Elimination of implication

For single implication:

eg: $A \rightarrow B$ — elimination of implication reduces the stmt to

$\neg(A \vee B)$

In double implication

$A \leftrightarrow B$ — convert to single implication & then convert.

Step 2: Elimination ~~&~~ of existential quantifier

independent: To eliminate an independent existential quantifier, we replace the variable by a constant called Skolem constant (process called Skolemization)

eg: $\exists x$, President(x)

If there is another stmt in KB, George President.

Then, President(George)

dependent: To eliminate the dependent existential quantifier, we replace variable by a Skolem function ~~that~~ accepts the value of x & returns the corresponding value of y.

eg: $\forall x \exists y$, is-Father(x, y)

$\hookrightarrow$ $\forall x$, is-Father$(x, \underline{S(x)})$ ← Skolem function

~~Elim.~~

Step 3: Elimination of Universal Quantifier

To eliminate the universal quantifier, drop the prefix in the prenex normal form.

$\boxed{\forall x}$ is-Father(x, y) ↳ drop this

Step 4: Eliminate the and.

$A \wedge B$ → splits the entire clause into two separate clauses, A, B.

~~$(A \wedge B) \vee C \rightarrow$~~

$(A \vee B) \wedge C$ → splits as $(A \vee B)$, C

$(A \wedge B) \vee C$ → splits as $(A \vee C)$, $(B \vee C)$

To break the stmts into separate clauses, if not possible distribute it with an 'OR'.

Q. Convert the stmts into CNF? (Stmts from previous qn, the paragraph qn).

A:

1. $\forall x((American(x) \wedge Hostile(z) \wedge Sell(x, y, z) \wedge Weapon(y)) \longrightarrow Criminal(x))$

ans: Step 1: Remove implication

~~$\forall x((American$~~

~~$\forall x(\neg(American(x) \wedge Hostile(z) \wedge Sell(x,y,z) \wedge Weapon(y)) \vee Criminal(x)))$~~

$\forall x \neg(American(x) \wedge Hostile(z) \wedge Sell(x, y, z) \wedge Weapon(y)) \vee Criminal(x)$.

Step2. Eliminate existential

No existential present.

Step 3. Eliminate Universal

Bring negation inside.

negation

$(\neg American(x) \lor \neg Hostile(z) \lor \neg Sell(x,y,z) \lor \neg Weapon(y)) \lor Criminal(x)$

2. $Own(Nono, M_1) \land Missile(M_1)$

$Own(Nono, M_1)$ $\qquad$ $Missile(M_1)$.

$Missile(x)$ $\qquad$ $Sell(West, x, Nono)$

$\neg Missile(x) \lor \neg Own(Nono, x) \lor Sell(West; x, Nono)$

$American(West)$

$\neg Missile(x) \lor Weapon(y)$

$\neg Enemy(x, America) \lor Hostile(x)$

$Enemy(Nono, America)$.

Proof done Afterwards.

Will Cont

Q. 1. Ravi likes all kinds of food.
2. Apples and Chicken are food.
3. Anything anyone eats and is not killed is food.
4. Ajay eats peanuts and is ~~sitt~~ still alive.
5. Rita eats everything that Ajay eats.

Prove by resolution that Ravi likes peanut.

A: 1. $\forall f \; isFood(f) \rightarrow Like(Ravi, f)$
2. $isFood(Apple) \land isFood(Chicken)$
3. $\forall x \forall y ((Eats(x,y) \land \neg isKilled(x)) \rightarrow isFood(y))$
4. $Eats(Ajay, peanuts) \land \neg isKilled(Ajay)$ Alive.

~~5. Eats (Aj Rita~~

5. $\forall x \; Eats(Ajay, x) \rightarrow Eats(Rita, x)$

Deduction:

$\forall x \; Alive(x) \rightarrow \neg isKilled(x)$

$\forall x \; \neg isKilled(x) \rightarrow Alive(x)$

Now conversion to CNF

1. $\forall f \; \neg(isFood(f)) \lor Like(Ravi, f) \rightarrow \forall f \; \neg isFood(f) \lor Like(Ravi, f)$

$\rightarrow \neg isFood(x) \lor Like(Ravi, x)$

$\cancel{\forall f (\neg isFood(f) \land \neg Like(Ravi, f))}$

$\cancel{\neg isFood(f) \land \neg Like(Ravi, f)}$

$\cancel{\neg isFood(f)}$, $\cancel{\neg Like(Ravi, f)}$

ie; – $\neg isFood(x) \lor Like(Ravi, x)$

2. $isFood(Apple)$ $\qquad$ $isFood(Chicken)$

3. $\forall x \forall y \; \neg(Eats(x,y) \land \neg isKilled(x)) \lor isFood(y)$

$\forall x \forall y \; \neg Eats(x,y) \lor isKilled(x) \lor isFood(y)$

$\neg Eats(x,y) \lor isKilled(x) \lor isFood(y)$

4. Eats(Ajay, peanuts), ~~Alive(Ajay)~~ Alive(Ajay)

~~5. Eat.~~

5. ~~Alive~~ $\neg$Eats(Ajay, x) $\vee$ Eats(Rita, x)

6. $\neg$Alive(x) $\vee$ $\neg$isKilled(x)

7. isKilled(x) $\vee$ Alive(x).

8/8/24 | Thursday

To prove Like(Ravi, peanuts)

most general unifier (mgu)

First negate it.

So → $\neg$Like(Ravi, peanuts)

Now consider first clause.

$\neg$Like(Ravi, Peanuts) $\neg$isFood(x) $\vee$ Like(Ravi, x)

cancels off

x | peanut

$\neg$isFood(peanut)

$\neg$Eats(x,y) $\vee$ isKilled(x) $\vee$ isFood(y) $\neg$isFood(peanut)

y | peanut

$\neg$Eats(x, peanut) $\vee$ isKilled(x) $\vee$ ~~isFood(peanut)~~

~~$\neg$isFood(peanut)~~

↓

$\neg$Eats(x, peanut) $\vee$ isKilled(x)   Eats(Ajay, peanuts)

x | Ajay

isKilled(Ajay)

isKilled(Ajay) $\neg$Alive(x) $\vee$ $\neg$isKilled(x)

x | Ajay

$\neg$Alive(Ajay)

$\neg$Alive(Ajay)   Alive(x)

x | Ajay

{ } → ~~null~~ null set

We landed at a null set which shows that our assumption was wrong (assumption of negation of it).