AI Project 3

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1) (R&N 8.10)

Occupation (p, o) with person p, occupation o
Customer (p1, p2)
Boss (p1, p2)
Doctor, Surgeon, Lawyer, Actor, Emily, Joe

Ans

(a) Occupation (Emily, surgeon) $\vee$ occupation (Emily, lawyer)

(b) occupation (Joe, actor) $\wedge$ $\exists o$ $o \neq$ actor $\wedge$ occupation (Joe, o)

(c) $\forall p$ occupation (p, surgeon) $\Rightarrow$ occupation (p, doctor)

(d) $\neg \exists p$ customer (Joe, p) $\wedge$ occupation (p, lawyer)

(e) $\exists b$ customer (emily, b) $\wedge$ occupation (b, lawyer)

(f) $\exists p$ occupation (p, lawyer) $\wedge$ $\forall q$ customer (q, p) $\Rightarrow$ occupation (q, doctor)

(g) $\forall p$ occupation (p, surgeon) $\Rightarrow$ $\exists q$ occupation (q, lawyer) $\wedge$ customer (p, q)

2) (R&N 8.20)

p. symbols : $<$
fn. symbols : $+$, $*$
cons. symbols : 0, 1

Ans

(a) $\forall x$ even $(x) \Leftrightarrow \exists n \ (x = n + n)$

(b) $\forall x$ prime $(x) \Leftrightarrow \forall n \forall m ((x = n * m) \Rightarrow (n = 1 \vee m = 1))$

(c) $\forall x$ even $(x) \Leftrightarrow \exists n \exists m$ (prime (n) $\wedge$ prime (m) $\wedge$ $(x = m + n)$)

3) (R&N 9.6)

Ans

(a) $\forall x$ (horse $(x) \Rightarrow$ mammal (x))
$\forall x$ (cow $(x) \Rightarrow$ mammal (x))
$\forall x$ (pig $(x) \Rightarrow$ mammal (x))

could also represent in conjunction

(b) $\forall y \forall x$ (horse (y) $\wedge$ offspring $(y, x) \Rightarrow$ horse (x))

(c) horse (bluebeard)

(d) parent (bluebeard, charlie)

(2)

(e) $\forall x \forall y (parent(x, y) \Leftrightarrow offspring(y, x))$ ∴

e1 - $\forall x \forall y (parent(y, x) \Rightarrow offspring(x, y))$

e2 - $\forall x \forall y (offspring(x, y) \Rightarrow parent(y, x))$

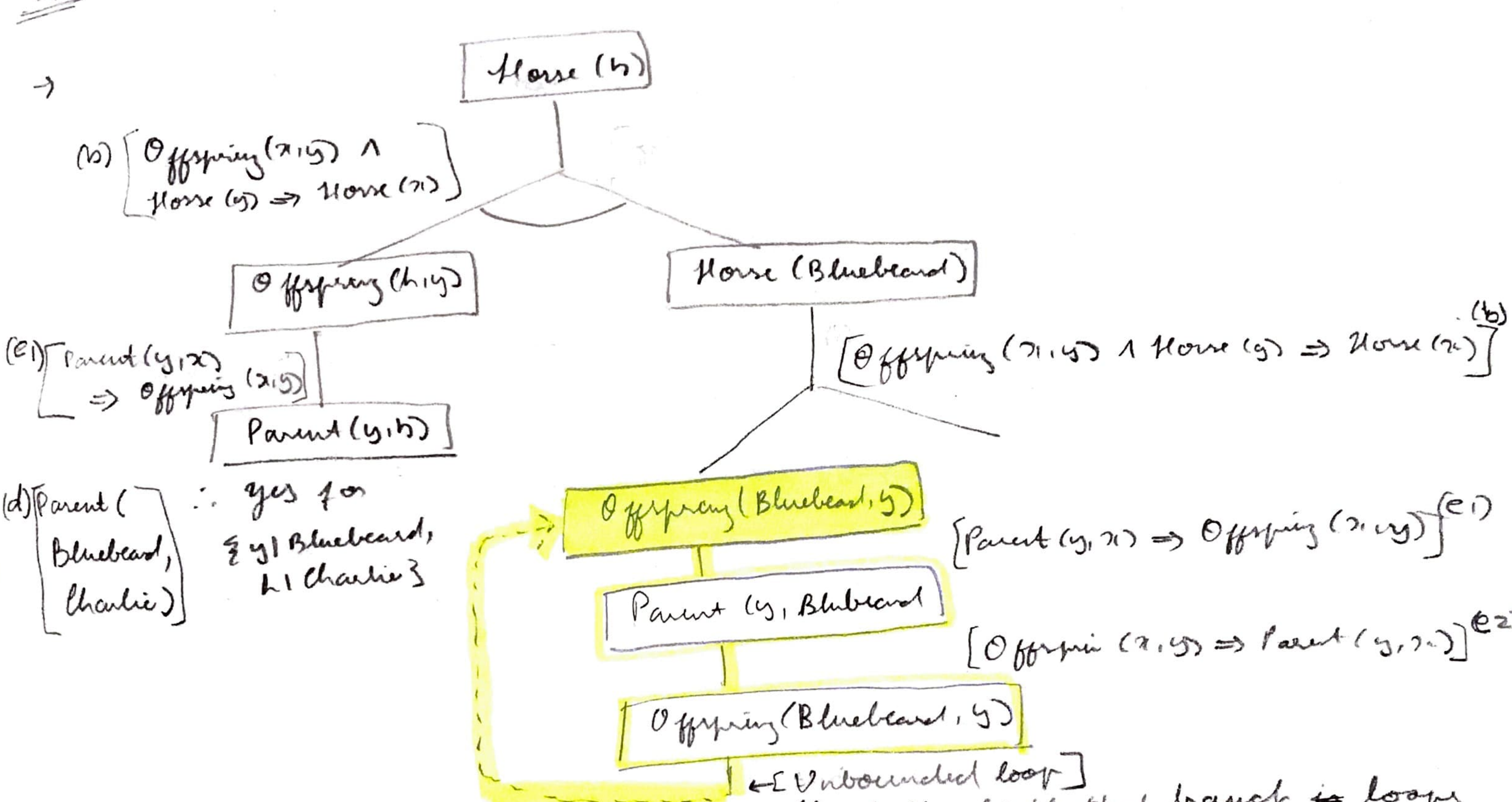
(f) $\forall x (mammal(x) \Rightarrow \exists y (parent(y, x)))$, where $F(x)$ is a skolem function.

$= \forall x (mammal(x) \Rightarrow parent(F(x), x))$

4) (a) Prooftree generated by using a backward chaining algorithm :

Query $\exists h (Horse(h))$

Ans



(b) → In this domain, we can observe that the highlighted branch ~~is~~ loops unboundedly (i.e. infinite loop) ∴ we cannot complete this proof as shown in the tree.

→ The reason for this is rule (b) in combination with all the other clauses ∴ a loop should always exist

(c) 2 solutions — Bluebeard, Charlie for horses should follow

(d) One way to approach this looping is suggested in Smith et. al. (1986). This consists of suspending proving of the looping goal 'and' move on in other directions to the other branches. This will help in finding alternate solutions (if they exist). In our chain above, the highlighted branch should be suspended ∴ this branch fails and ends. Thus Smith's method of suspending enables a way to find the 2 solutions.

5) (a) "Horses are Animals"

"The head of a horse is the head of an animal" } In FOL? using HeadOf(h, x), Horse(x), Animal(x)

3

Ans

→ $\forall x \, (Horse(x) \Rightarrow Animal(x))$

→ $\forall x \, \forall y \, (Headof(x, y) \wedge Horse(y) \Rightarrow \exists z \, (Animal(z) \wedge Headof(x, z)))$

6) → FOL Statements:

(a) $\forall x \ hound(x) \Rightarrow howl(x)$

(b) $\forall x \forall y (has(x,y) \wedge cat(y) \Rightarrow \neg \exists z (has(x,z) \wedge mouse(z)))$

(c) $\forall x (lightsleeper(x) \Rightarrow \neg \exists y (has(x,y) \wedge howl(y)))$

(e) $lightsleeper(Sam) \Rightarrow \neg \exists x (has(Sam, x) \wedge mouse(x))$

(d) $\exists x (has(Sam, x) \wedge (cat(x) \vee hound(x)))$

→ CNF statements (Skolemized)

(a) $\neg hound(x) \vee howl(x)$

(b) $\neg cat(y) \vee \neg has(x,y) \vee \neg mouse(z) \vee \neg has(x,z)$

(c) $\neg lightsleeper(x) \vee \neg has(x,y) \vee \neg howl(y)$

(d1) $has(Sam, F(x))$

(d2) $cat(F(x)) \vee hound(F(x))$

(e1) $lightsleeper(Sam)$

(e2) $has(Sam, G(x))$

(e3) $mouse(G(x))$

→ FOL Resolution

		Substitution
b-e3 i:	$\neg cat(y) \vee \neg has(x,y) \vee \neg has(x, G(x))$	$\{z \mid G(x)\}$
i-e2 j:	$\neg cat(y) \vee \neg has(Sam, y)$	$\{x \mid Sam\}$
j-d2 k:	$hound(F(x)) \vee \neg has(Sam, F(x))$	$\{y \mid F(x)\}$
k-a l:	$howl(F(x)) \vee \neg has(Sam, F(x))$	$\{x \mid F(x)\}$
l-c m:	$\neg lightsleeper(Sam) \vee \neg has(Sam, F(x))$	$\{y \mid F(x), \ x \mid Sam\}$
m-d1 n:	$\neg lightsleeper(Sam)$	None
n-e1 o:	$\square$	None

hence proven

Tree diagram

P.T.O →

(b) $\neg cat(y) \lor \neg has(x,y) \lor \neg mouse(z) \lor \neg has(x,z)$ $\quad$ $mouse(G(x))$ (e3)

$\{z \mid G(x)\}$

$\neg cat(y) \lor \neg has(x,y) \lor \neg has(x, G(x))$ $\quad$ $has(Sam, G(x))$ (e2)

$\{x \mid Sam\}$

$\neg cat(y) \lor \neg has(Sam, y)$ $\quad$ $cat(F(x)) \lor hound(F(x))$ (d2)

$\{y \mid F(x)\}$

$hound(F(x)) \lor \neg has(Sam, F(x))$ $\quad$ $\neg hound(x) \lor howl(x)$ (a)

$\{x \mid F(x)\}$

$howl(F(x)) \lor \neg has(Sam, F(x))$ $\quad$ $\neg lightsleeper(x) \lor \neg has(x,y) \lor \neg howl(y)$ (c)

$\{y \mid F(x),\ x \mid Sam\}$

$\neg lightsleeper(Sam) \lor \neg has(Sam, F(x))$ $\quad$ $has(Sam, F(x))$ (d1)

$\neg lightsleeper(Sam)$ $\quad$ $lightsleeper(Sam)$ (e1)

$\square$

9) (R&N - 10.2) Given action schemas and initial state (from R&N fig 10.1)
Applicable concrete instances of Fly (p, from, to) in the state below?

At (P1, JFK) ∧ At (P2, SFO) ∧ Plane (P1) ∧ Plane (P2) ∧ airport (JFK) ∧ airport (SFO)

Ans

→ Applicable concrete instances :
- Fly (P1, JFK, SFO)
- Fly (P2, SFO, JFK)
- Fly (P1, JFK, JFK)
- Fly (P2, SFO, SFO)

} Should be applicable (I think)

10) (R&N - 10.4)
- PDDL sentences for Shakey's six actions?
- Initial state from fig 10.14?
- Plan for Shakey to get Box2 into Room2?

Ans

→ PDDL sentences :

① Action (Go (x, y, r),
Precond : In (x, r) ∧ In (y, r) ∧ At (Shakey, y) ∧ Position (x) ∧ Position (y) ∧ Room (r),

Effect : ¬ At (Shakey, x) ∧ At (Shakey, y))

② Action (Push (b, x, y, r),
Precond : In (x, r) ∧ In (y, r) ∧ At (b, x) ∧ At (Shakey, x) ∧ Box (b) ∧ Position (x) ∧ Position (y) ∧ Room (r),

Effect : ¬ At (Shakey, x) ∧ At (Shakey, y) ∧ ¬ At (b, x) ∧ At (b, y))

③ Action (ClimbUp (x, b)
Precond : At (Shakey, x) ∧ At (b, x) ∧ ¬ On (Shakey, b) ∧ Position (x) ∧ Box (b),
Effect : On (Shakey, b)) ∧ ¬ On (Shakey, floor)

* Not passing floor value to actions

④ Action (ClimbDown (b, x),
Precond : At (b, x) ∧ On (Shakey, b) ∧ Position (x) ∧ Box (b),
Effect : ¬ On (Shakey, b)) ∧ On (Shakey, floor)

P.T.O →

7

⑤ Action (TurnOn (s, b),
Precond : On(Shakey, b) ∧ At(b, x) ∧ At(s, x) ∧ Position(x) ∧ Switch(s) ∧ Box(b),
Effect : SwitchedOn(s))

⑥ Action (TurnOff(s, b),
Precond : On(Shakey, b) ∧ At(b, x) ∧ At(s, x) ∧ Position(x) ∧ Switch(s) ∧ Box(b)
Effect : SwitchedOff(s) ($\Leftrightarrow \neg$ SwitchedOn(s)))

→ <u>Initial State</u> :

Init (• Room(Room 1) ∧ Room(Room 2) ∧ Room(Room 3) ∧ Room(Room 4) ∧ ..
Room(corridor) ∧ ...
• Position (Door 1) ∧ Position (Door 2) ∧ Position (Door 3) ∧ Position (Door 4) ∧
• In (Door 1, Room 1) ∧ In (Door 2, Room 2) ∧ In (Door 3, Room 3) ∧
In (Door 4, Room 4) ∧ ...
• In (Door 1, Corridor) ∧ In (Door 2, Corridor) ∧ In (Door 3, Corridor) ∧
In (Door 4, Corridor) ∧ ...
• Position (Shakey Init) ∧ In (Shakey Init, Room 3) ∧
At(Shakey, Shakey Init) ∧ ...
• Position (Switch 1) ∧ Position (Switch 2) ∧ Position (Switch 3) ∧
Position (Switch 4) ∧ ...
• In (Switch 1, Room 1) ∧ In (Switch 2, Room 2) ∧ In (Switch 3, Room 3)
In (Switch 4, Room 4) ∧ ...
• Box(Box 1) ∧ Box(Box 2) ∧ Box(Box 3) ∧ Box(Box 4) ∧ ...
• Position (Box 1 Init) ∧ Position (Box 2 Init) ∧ Position (Box 3 Init) ∧
Position (Box 4 Init) ∧ ...
• In (Box 1, Room 1) ∧ In (Box 2, Room 1) ∧ In (Box 3, Room 1) ∧
In (Box 4, Room 1) ∧ ...
• At (Box 1, Box 1 Init) ∧ At (Box 2, Box 2 Init) ∧ At (Box 3, Box 3 Init) ∧
At (Box 4, Box 4 Init) ∧ ... ~~∧ In (Box 3 Init, Room 1)~~ ∧
• ~~In (Box 1 Init, Room 1) ∧ In (Box 2 Init, Room 1)~~
~~In (Box 4 Init, Room 1) ∧ ...~~
• TurnedOn (Switch 1) ∧ TurnedOn (Switch 4) ∧ TurnedOff (Switch 2) ∧
TurnedOff (Switch 3) ∧ ...
• Climbing (Box 1) ∧ Climbing (Box 2) ∧ Climbing (Box 3) ∧ Climbing (Box 4) ∧ ...
• Pushing (Box 1) ∧ Pushing (Box 2) ∧ Pushing (Box) ∧ Pushing (Box 4))

P.T.O → (Thank You for your patience !!.)

→ **Goal** :

Goal (In (Box 2 , Room 2))

→ **Plan** :

Plan (Go (Shakey Init , Door 3 , Room 3) ,
Go (Door 3 , Door 1 , Corridor) ,
Go (Door 1 , Box 2 Init , Room 1) ,
Push (Box 2 , Box 2 Init , Door 1 , Room 1) ,
Push (Box 2 , Door 1 , Door 2 , Corridor) ,
Push (Box 2 , Door 2 , Switch 2 , Room 2))

* ∴ In (Box 2 , Room 2) achieved

5) (a) $\forall x \forall y$ (child (x) $\wedge$ candy (y) $\Rightarrow$ loves (x, y))

(b) $\forall x$ ($\exists y$ (loves (x, y) $\wedge$ candy (y)) $\Rightarrow$ $\neg$ Nutritionfanatic (x))

(c) $\forall x$ ($\exists z$ (eat (x, z) $\wedge$ pumpkin (z)) $\Rightarrow$ Nutritionfanatic (x))

(d) $\forall x \forall z$ (buy (x, z) $\wedge$ pumpkin (z) $\Rightarrow$ carve (x, z) $\vee$ eat (x, z))

(e) $\exists z$ (buy (Stuart, z) $\wedge$ pumpkin (z))

(f) candy (Lifesavers)

(g) child (Stuart) $\Rightarrow$ $\exists z$ (carve (Stuart, z) $\wedge$ pumpkin (z))

* x = person
y = candy
z = pumpkin
in KB
* Stuart, Lifesavers are instances of x, y

Get CNF clauses

(a) $\neg$ child (x) $\vee$ $\neg$ candy (y) $\vee$ loves (x, y)

(b) $\forall x$ ($\neg$ $\exists y$ (loves (x, y) $\wedge$ candy (y)) $\vee$ $\neg$ Nutritionfanatic (x))

= $\forall x$ $\forall y$ ($\neg$ (loves (x, y) $\wedge$ candy (y)) $\vee$ $\neg$ Nutritionfanatic (x))

= $\neg$ loves (x, y) $\vee$ $\neg$ candy (y) $\vee$ $\neg$ Nutritionfanatic (x)

(c) $\forall x$ ($\neg$ $\exists z$ (eat (x, z) $\wedge$ pumpkin (z)) $\Rightarrow$ Nutritionfanatic (x))

= $\forall x \forall z$ ($\neg$ (eat (x, z) $\wedge$ pumpkin (z)) $\vee$ Nutritionfanatic (x))

= $\neg$ eat (x, z) $\vee$ $\neg$ pumpkin (z) $\vee$ Nutritionfanatic (x)

(d) $\neg$ buy (x, z) $\vee$ $\neg$ pumpkin (z) $\vee$ carve (x, z) $\vee$ eat (x, z)

(e) $\underbrace{\text{buy (Stuart, } F(z))}_{(e1)}$ $\wedge$ $\underbrace{\text{pumpkin } (F(z))}_{(e2)}$ (Skolemized !)

(f) candy (lifesavers)

(g) Negated query: $\neg$ (child (Stuart) $\rightarrow$ $\exists z$ (carve (Stuart, z) $\wedge$ pumpkin (z))))

= $\neg$ ($\neg$ child (Stuart) $\vee$ ($\exists z$ (carve (Stuart, z) $\wedge$ pumpkin (z))))

= child (Stuart) $\wedge$ $\neg$ ($\exists z$ (carve (Stuart, z) $\wedge$ pumpkin (z))))

= child (Stuart) $\wedge$ $\forall z$ ($\neg$ carve (Stuart, z) $\vee$ $\neg$ pumpkin (z))

= $\underbrace{\text{child (Stuart)}}_{(g1)}$ $\wedge$ $\underbrace{(\neg \text{ carve (Stuart, } z) \vee \neg \text{ pumpkin } (z))}_{(g2)}$

Predicate - Object Symbols

- child $\rightarrow$ CH
- candy $\rightarrow$ CD
- loves $\rightarrow$ L
- Nutritionfanatic $\rightarrow$ NF
- Pumpkin $\rightarrow$ P
- Eat $\rightarrow$ E
- buy $\rightarrow$ B
- carve $\rightarrow$ CV
- Stuart $\rightarrow$ S
- lifesavers $\rightarrow$ LS

for simpler and easier resolution !

CNF clauses

(a) $\neg CH(x) \vee \neg CD(y) \vee L(x,y)$

(b) $\neg L(x,y) \vee \neg CD(y) \vee \neg NF(x)$

(c) $\neg E(x,z) \vee \neg P(z) \vee NF(x)$

(d) $\neg B(x,z) \vee P(z) \vee CV(x,z) \vee E(x,z)$

(e) $B(S, F(z)) \wedge P(F(z))$ ∴ (e₁) $B(S, F(z))$
(e₂) $P(F(z))$

(f) $CD(LS)$

(g) $CH(S) \wedge (\neg CV(S,z) \vee \neg P(z))$ ∴ (g₁) $CH(S)$
(g₂) $\neg CV(S,z) \vee \neg P(z)$

Resolution — Terms eliminated/substituted

b/c = $\neg L(x,y) \vee \neg CD(y) \vee \neg E(x,z) \vee \neg P(z)$ — (NF elim)

abcd = $\neg CD(y) \vee \neg E(x,z) \vee \neg P(z) \vee \neg CH(x)$ — (L elim)

bcad = $\neg P(z) \vee \neg B(x,z) \vee CV(x,z) \vee \neg CD(y) \vee \neg CH(x)$ — (E elim)

bcadf = $\neg P(z) \vee \neg B(x,z) \vee CV(x,z) \vee \neg CH(x)$ — (CD elim), {y | LS}

bcadfe₁ = $CV(S, F(z)) \vee \neg CH(S) \vee P(F(z))$ — (B elim), {x | S, z | F(z)}

bcadfe₁g₁ = $CV(S, F(z)) \vee P(F(z))$ — (CH elim)

bcadfe₂g₁g₂ = $\Box$ — (all eliminated), {z | F(z), x=S}

∴ Tree diagram

P.T.O →

(11)

7) FOL statement

(b) $\neg loves(x,y) \lor \neg candy(y) \lor \neg Nutritionfanatic(x)$

(c) $\neg eat(x,z) \lor \neg pumkin(z) \lor Nutritionfanatic(x)$

$\neg loves(x,y) \lor \neg candy(y) \lor \neg eats(x,z) \lor \neg pumpkin(z)$

(a) $\neg child(x) \lor \neg candy(y) \lor loves(x,y)$

$\neg candy(y) \lor \neg eats(x,z) \lor \neg pumpkin(z) \lor \neg child(x)$

(d) $\neg buys(x,z) \lor pumpkin(z) \lor carve(x,z) \lor eats(x,z)$

$\neg pumpkin(z) \lor \neg buys(x,z) \lor carve(x,z) \lor \neg candy(y) \lor \neg child(x)$

(f) $candy(lifesavers)$

$\{y \mid lifesavers\}$

$\neg pumpkin(z) \lor \neg buys(x,z) \lor carve(x,z) \lor \neg child(x)$

(e1) $buys(Stuart, F(z))$

$\{x \mid Stuart,\ z \mid F(z)\}$

$carve(Stuart, F(z)) \lor \neg Child(Stuart) \lor pumpkin(F(z))$

(g1) $child(Stuart)$

$carve(Stuart, F(z)) \lor pumpkin(F(z))$

(g2) $\neg carve(Stuart, z) \lor \neg pumpkin(z)$

$\{z \mid F(z)\}$

$\square$

(=)

7) FOL statements

Ans

(a) $\forall x \forall y (warm(x) \Rightarrow drunk(x) \vee (costume(y) \wedge has(x, y) \Rightarrow warm(y)))$

(b) $\forall x\ (costume(x) \wedge warm(x) \Rightarrow furry(x))$

(c) $\forall x\ (AI(student) \wedge student(x) \Rightarrow CS(x))$

(d) $\forall x \exists y (student(x) \wedge AI(x) \Rightarrow has(x, y) \wedge costume(y) \wedge robot(y))$

(e) $\forall x\ (costume(x) \wedge robot(x) \Rightarrow \neg furry(x))$

(f) $\forall x \forall y (CS(x) \wedge student(x) \Rightarrow warm(x)) \Rightarrow (AI(y) \wedge student(y) \Rightarrow drunk(y))$

FOL

(a) $\forall x\ (feelwarm(x) \Rightarrow drunk(x) \vee (\forall y\ has(x, y) \wedge costume(y) \Rightarrow iswarm(y)))$

(b) $\forall y (costume(y) \wedge iswarm(y) \Rightarrow furry(y))$

(c) $\forall x\ (AIS(x) \Rightarrow CSS(x))$

(d) $\forall x\ (AIS(x) \Rightarrow \exists y (has(x, y) \wedge robot(y) \wedge costume(y)))$

(e) $\neg \exists y\ (robot(y) \wedge costume(y) \wedge furry(y))$

(f) $\forall x\ (\forall (CSS(x) \Rightarrow feelswarm(x)) \Rightarrow \forall z (AIS(z) \Rightarrow drunk(z))$

x = person
z = person
y = costume

CNF

(a) $\neg FW(x) \vee D(x) \vee \neg(H(x, y) \wedge C(y)) \vee IW(y)$

$= \neg FW(x) \vee D(x) \vee \neg H(x, y) \vee \neg C(y) \vee IW(y)$

b) $\neg C(y) \vee \neg IW(y) \vee F(y)$

(c) $\neg AIS(x) \vee CSS(x)$

(d) $\neg AIS(x) \vee \exists y\ (H(x, y) \wedge R(y) \wedge C(y))$

$= \neg AIS(x) \vee (H(x, F(x)) \wedge R(F(x)) \wedge C(F(x)))$

$d_1 = \neg AIS(x) \vee H(x, F(x))$

$d_2 = \neg AIS(x) \vee R(F(x))$

$d_3 = \neg AIS(x) \vee C(F(x))$

(e) $\forall y\ \neg(R(y) \wedge C(y) \wedge F(y)) = \neg R(y) \vee \neg C(y) \vee \neg F(y)$

(f) $\neg(\neg CSS(x) \vee FW(x)) \vee AIS(z) \Rightarrow D(z)$

$\neg(CSS(x) \wedge \neg FW(x) \vee AIS(z)) \vee D(z)$

$= (\neg CSS \vee FW(x) \vee D(z)) \wedge (\neg AIS(z) \vee D(z))$

$= (\neg CSS \vee FW(x) \vee D(z)$

$= \neg CSS \vee FW(x) \vee D(z)$

$= \neg AIS(z) \vee D(z)$

Negated query: $\neg((CSS(x) \wedge \neg FW(x) \vee AIS(z)) \vee D(z)$

$\neg(\neg((CSS(x) \wedge \neg FW(x)) \vee AIS(z)) \wedge \neg D(z)$

$= ((CSS(x) \wedge \neg FW(x)) \vee AIS(z))$

$(f1) = \neg D(z)$

$* (CSS(x) \wedge \neg FW(x)) \vee AIS(z)$

$(f2) = CSS(x) \vee AIS(z)$

$(f3) = \neg FW(x) \vee AIS(z)$

FW	feelswarm
IW	iswarm
C	costume
H	has
D	drunk
AIS	AI student
CSS	CS student
R	robot
F	furry

(a) $\neg FW(x) \lor D(x) \lor \neg H(x,y) \lor \neg C(y) \lor IW(y)$

(b) $\neg C(y) \lor \neg IW(y) \lor F(y)$

(c) $\neg AIS(x) \lor CSS(x)$

(d1) $\neg AIS(x) \lor H(x, F(x))$

(d2) $\neg AIS(x) \lor R(F(x))$

(d3) $\neg AIS(x) \lor C(F(x))$

(e) $\neg R(y) \lor \neg C(y) \lor \neg F(y)$

(f1) $\neg D(z)$

(f2) $CSS(x) \lor AIS(z)$

(f3) $FW(x) \lor AIS(z)$

Resolution

Terms eliminated / substituted

P.T.O

$(a|f1) = \neg FW(x) \vee \neg H(x,y) \vee \neg C(y) \vee IW(y)$ (D elim) $\{z|x\}$

$(af1|e) = \neg R(y) \vee \neg C(y) \vee \neg F(y) \vee \neg FW(x) \vee \neg H(x,y) \vee IW(y)$

$(af1e|b) = \neg C(y) \vee \cancel{IW(y)} \vee \neg R(y)\ \neg FW(x) \vee \neg H(x,y)$ (F elim) (IW elim)

$(f1eb|d1) = \neg AIS(x) \vee \neg C(F(x)) \vee \cancel{IW(F(x))} \vee \neg R(F(x)) \vee \neg FW(x)$ (H elim) $\{y|F(x)\}$

$+ d2 = \neg AIS(x) \vee \neg C(F(x)) \vee \cancel{IW(F(x))} \vee \neg FW(x)$ (R elim)

$+ d3 = \neg AIS(x) \vee \cancel{IW(F(x))} \vee \neg FW(x)$ (C elim) $\{x|z\}$

$+ F3 = \square$

Tree diagram

P.T.O →

$\neg feelswarm(x) \vee drunk(x) \vee \neg has(x,y) \vee \neg costume(y) \vee iswarm(y)$ (a) $\neg drunk(z)$ (f1)

$\{z \mid x\}$

$\neg feelswarm(x) \vee \neg has(x,y) \vee \neg costume(y) \vee iswarm(y)$ $\neg robot(y) \vee \neg costume(y) \vee \neg furry(y)$ (e)

$\neg robot(y) \vee \neg costume(y) \vee \neg furry(y) \vee \neg feelswarm(x) \vee \neg has(x,y) \vee iswarm(y)$ $\neg costume(y) \vee \neg iswarm(y) \vee furry(y)$ (b)

$\neg costume(y) \vee \neg robot(y) \vee \neg feelswarm(x) \vee \neg has(x,y)$ $\neg AIS(x) \vee has(x, F(x))$ (d1)

$\{y \mid F(x)\}$

$\neg AIS(x) \vee \neg costume(F(x)) \vee \neg robot(F(x)) \vee \neg feelswarm(x)$ $\neg AIS(x) \vee robot(F(x))$ (d2)

$\neg AIS(x) \vee \neg costume(F(x)) \vee \neg feelswarm(x)$ $\neg AIS(x) \vee costume(F(x))$ (d3)

$\neg AIS(x) \vee \neg Feelswarm(x)$ $feelswarm(x) \vee AIS(z)$ (f3)

$\{x \mid z\}$

$\square$