1. True or False [10%]

(T) $(A \rightarrow B) \rightarrow (\neg B \rightarrow \neg A)$ is valid.

(T) $False \vDash A$ and $(A \wedge \neg A) \vDash (A \vee \neg A)$

(F) $True \vDash \alpha$ is valid.

(T) Ontology of a language refers to those things in the worlds that can be talked about in the language.

(T) In model checking, we divide the universe into subsets of “possible worlds” so that we can check if an entailment holds or not.

(F) In situation calculus, a “situation” refers to a relation in the world.

(T) Successor-state axioms state that some predicate is true after an action if and only if either the action made it true, or it was already true, and the action did not make it false.

(F) An inference procedure i is complete iff whenever $KB \vdash_i \alpha$, it is also true that $KB \vDash \alpha$.

(T) Prolog uses backward chaining.

(F) This sentence is syntactically correct in the first-order logic:

$$\forall_{X,Y} (X = Y) \Leftrightarrow \left(\forall_P P(X) \Leftrightarrow P(Y)\right)$$

2. Propositional Logic [20%]

1. [6%]

a. **[5%]** Construct the truth table for the propositional statement : (p ∧ q) → (p ∨ q)

p	**q**	**(p ∧ q)**	**(p ∨ q)**	**(p ∧ q) → (p ∨ q)**
T	**T**	**T**	**T**	**T**
T	**F**	**F**	**T**	**T**
F	**T**	**F**	**T**	**T**
F	**F**	**F**	**F**	**T**

b. **[1%]** What special name would you give to such a statement?
Tautology or Valid Sentence

2. Using Inference Rules [14%] [2% each]

Consider the following knowledge base that describes how the Mars rover works:

ReceivedWorkInstruction ⇒ Work	**1**
((BatteryIsGood ∧ FlatGround) ∧ (¬Cold)) ⇒ Work	**2**
¬Obstacle ⇒ FlatGround	**3**
Night ⇒ Cold	**4**
Cold ⇒ ¬Hot	**5**
ReceivedRestInstruction ⇒ ¬Work	**6**
¬Dark ∨ Night	**7**

Given the following observations:

BatteryIsGood ∧ ¬Night ∧ Hot ∧ ¬Obstacle ∧ ¬ReceivedWorkInstruction	**8**

Using the various propositional logic inference rules studied in class, show how each of the following conclusions can be inferred: In each case, mention which inference rule is used [1%], and to which sentence(s) above it was applied [1%]. Every sentence can be proven using only sentences with smaller indices (Hint: All of the conclusions can be inferred in atmost 2 steps).

9. ¬Obstacle	**And Elimination on 8**
10. FlatGround	**Modus Ponens on 9,3**
11. ¬Cold	**And Elimination on 8 + Modus Tollens 5**
12. BatteryIsGood ∧ FlatGround ∧ ¬Cold	**And Elimination on 8 + And Introduction 10,11**
13. Work	**Modus Ponens 2,12**
14. ¬Dark	**And Elimination on 8 + Resolution 7**
15. ¬ReceivedRestInstruction	**Modus Tollens 6,13**

3. First Order Logic [20%]

Consider a domain with the following relations and objects.

Color(x, y)	Object x has the color y
On(x, y)	Object x is on top of object y
Besides(x, y)	Object x and object y are beside each other
Expensive(x)	Object x is expensive
Block1, Block2, Block3, Block4	Constants denoting objects
White, Black, Red	Constants denoting colors

Formalize the following sentences for this domain.

1- [3%] Block2 or block3 is white.

$Color(Block2, White) \vee Color(Block3, White)$

2- [4%] Everything red is on top of something black.

$\forall x\ Color(x,Red) \Rightarrow \exists y\ \ Color(y,Balck) \wedge On(x,y)$

3- [4%] Block3 is not on top of any red object.

$\forall x\ Color(x,Red) \Rightarrow \neg On(Block3,x)$

4- [4%] Block4 has something on top of it, but that thing has nothing on top of it

$\exists x\ On(x,Block4) \wedge \nexists y\ On(y,x)$

5- [5%] Every red thing is besides at least two other things and at least of those is black.

$\forall x\ Color(x,Red) \Rightarrow \exists y\ \exists z\ Besides(x,y) \wedge Besides(x,z) \wedge (y \neq z) \wedge (Color(y,Black) \vee Color(z,Black)$

4. Inference

A. Given the following knowledge base:

1. Marcus was a man.
2. Marcus was a Roman.
3. All men are people.

4. Caesar was a ruler.
5. All Romans were either loyal to Caesar or hated him.
6. Everyone is loyal to someone.
7. People only try to assassinate rulers they are not loyal to.
8. Marcus tried to assassinate Caesar.

Hints: Here we provide CNFs for statement 7 and 8 as the followings:
7. CNF: *¬person(x) V ¬ruler(y) V ¬tryAssassinate(x, y) V ¬loyalto(x, y)*
8. CNF: *tryAssassinate(Marcus, Caesar)*

Please translate the following statements into First Order Logic. You also need to convert it to CNF if it's convertible.

1. Marcus was a man [1%]
   (Use predicate: man)

man(Marcus)

2. Marcus was a Roman [1%]
   (Use predicate: roman)

roman(Marcus)

3. All men are people. [1%]
   (Use predicates: man & person)

FOL: ∀x: man(x) --> person(x) CNF: ~man(x) v person(x)

4. Caesar was a ruler. [1%]
   (Use predicate: ruler)

ruler(Caesar)

5. All Romans were either loyal to Caesar or hated him(or both). [1%]
   (Use predicate: roman,loyalto,hated)

FOL: ∀x: roman(x) --> loyalto(x, Caesar) v hated(x, Caesar) CNF: ~roman(x) v loyalto(x, Caesar) v hated(x, Caesar)

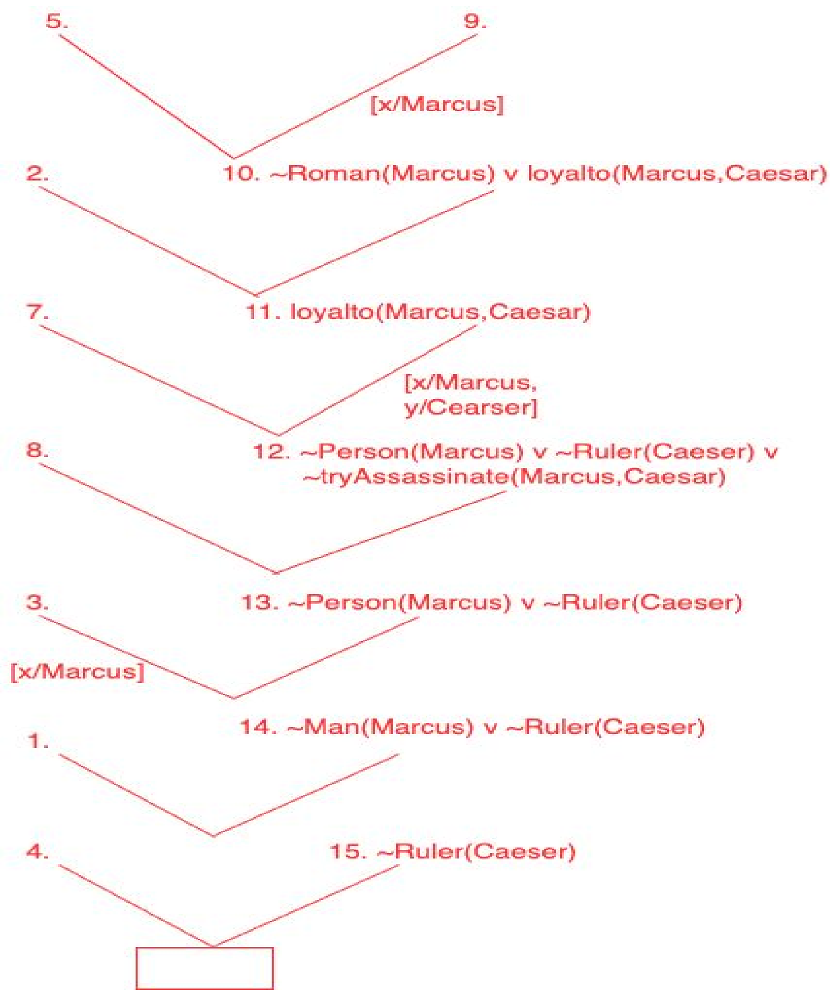
6. Everyone is loyal to someone. [1%]
   (Use predicate: loyalto)

FOL: ∀x ∃y: loyalto(x, y)

CNF: loyalto(z, f(z))   // f is a skolem function and returns a
// person that z is loyal to

B. Prove hated(Marcus, Caesar) using **Resolution**. [14%]

Negating the clause: 9. ~hated(Marcus,Caesar)



[2% for each relevant resolution step, Alternative correct resolution accepted]

5. Planning

Consider the problem of a planning system for picking up astronaut A from Mars. Due to fuel limitations, there are two spacecraft: Spacecraft B can travel between the Earth's surface (ES) and Earth orbit (EO), Earth orbit and Mars orbit (MO), but not Mars orbit and Mars' surface (MS); Spacecraft C can travel only between Mars' surface and Mars orbit, but not further. Initially, Spacecraft B is on Earth's surface, while Spacecraft C and astronaut A are on Mars' surface.

Please use the following literal definitions to answer the next 2 questions:
- at(O, P) means object O is at place P ($O \in \{A, B, C\}$, $P \in \{ES, EO, MS, MO\}$)
- travelable(S, X, Y) means Spacecraft S can travel from place X to place Y ($S \in \{B, C\}$, $X,Y \in \{ES, EO, MS, MO\}$)

5.1. [8%] Complete the descriptions of the STRIPS action for the system

Action: Spacecraft S travels from X to Y with NO astronaut:

noAstronaut(S, X, Y)

Precondition:
Effects:
    Add literal(s):
    Delete literal(s):

Action: Spacecraft S travels from X to Y with astronaut A:

withAstronaut(S, A, X, Y)

Precondition:
Effects:
    Add literal(s):
    Delete literal(s):

5.2. [7%] NASA plans to launch the spacecraft, pick up the astronaut and return to the Earth surface. Write down the initial condition and the goal of this plan using the given definitions in the previous page. The closed world assumption is used, so whatever is not explicitly stated is assumed to be false.

Initial condition:

Goal:

5.3. [5%] Write down the solution plan for 5.2 part using the actions in 5.1 part. (Assume that when spacecraft B and spacecraft C are at the same place, the astronaut could go from one spacecraft to another without any action.)

Rubric:
5.1. [8%]

[-0.5% for each wrong literal till 0]

Action: noAstronaut(S, X, Y)

[2%] Precondition: at(S, X) [1%], travelable(S, X, Y) [1%]

[2%] Effect:

Add: at(S, Y) [1%]
Delete: at(S, X) [1%]

Action: withAstronaut (S, A, X, Y)

[2%] Precondition: at(S, X) [.5%] , at(A, X) [.5%], travelable(S, X, Y) [1%]

[2%] Effect:

Add: at(S, Y), at(A, Y) [.5% each]
Delete: at(A, X), at(S, X) [.5% each]

5.2. [7%]

[-0.5% for each wrong literal that is contradictory to the correct solution] (If a student should happen to write down all the false statements (e.g., ~at(A, ES), etc.) as well, we still give full marks. However, if the false statements are incomplete, 1% will be deducted for not understanding the closed world assumption)

Initial condition:

[1%] at(B, ES),
[1%] at(C, MS),
[1%] at(A, MS),
[.5%] travelable(B, ES, EO),
[.5%] travelable(B, EO, ES),
[.5%] travelable(B, EO, MO),

[.5%] travelable(B, MO, EO),
[.5%] travelable(C, MS, MO),
[.5%] travelable(C, MO, MS)

Goal: [1%] at(A, ES)
[For the goal, besides at(A, ES) as in the correct answer, at(B, ES) can be accepted as an additional literal with no harm (because the problem did say that the spacecraft returns to the Earth Suface) while at(C, MO) is not necessary. So -0.5% for at(C, MO)] [If the negative points are more than positive points, the score becomes 0]

5.3. [5%]

(1) noAstronaut(B, ES, EO)
(2) noAstronaut(B, EO, MO)
(3) withAstronaut(C, A, MS, MO)
(4) withAstronaut(B, A, MO, EO)
(5) withAstronaut(B, A, EO, ES)
(Note: the topological order should be 12345 or 13245 or 31245.)

[If the solution is described in plain words instead of the actions, -2% because it's more like a result of human-planning instead of the STRIPS planner]
[Deduct a maximum of 0.5% if one or more A are missing from the withAstronaut operations]
[Each correct operation: .5%]
[If the order is right, give full credit (5%)] [Each invalid operation: -0.5%]
[Each redundant operation: -0.5%]
[If only the order is wrong (which is unlikely), give 2.5% for 5C]

6. MCQ

1. In the discussions, we showed the definitions of entailment, please circle all that are true:

a. (F) $KB \models \alpha$ if and only if $KB \rightarrow \alpha$ is satisfiable.
b. (T) $KB \models \alpha$ if and only if $KB \rightarrow \alpha$ is valid.
c. (T) $KB \models \alpha$ if and only if $KB \land \neg\alpha$ is unsatisfiable.
d. (F) $KB \models \alpha$ if and only if $KB \land \neg\alpha$ is satisfiable.
e. (T) $KB \models \alpha$ if and only if $\neg KB \lor \alpha$ is valid.

2. In the discussions, we compared several logical inference methods.

Let $KB \equiv \{A \rightarrow B, \neg A \rightarrow C, B \rightarrow D, C \rightarrow D\}$, please circle all that are true

a. It is possible to prove D from KB using Backward chaining (F)
b. It is impossible to prove D from KB using Forward chaining (T)
c. It is possible to prove D from KB using Resolution (T)
d. It is impossible to prove D from KB at all (F)
e. It does not make sense to prove D from KB (F)

3. In the discussions, we showed the universal and existential quantifiers, circle all that are true

a. $\forall x \exists y P(x,y)$ is the same as $\exists y \forall x P(x,y)$ (F)
b. $\forall x \exists y P\left(x,y\right)$ is the same as $\forall x(\exists y P\left(x,y\right))$ (T)
c. $\forall y \exists x P(x,y)$ is the same as $\exists y \forall x P(x,y)$ (F)
d. $\forall y P(x,y)$ is the same as $\neg \exists y \neg P(x,y)$ (T)
e. $\neg \forall y P(x,y)$ is the same as $\exists y \neg P(x,y)$ (T)

4. In the discussions, we showed the unification, please circle all that are true

a. P(C, D, D) and P(x, y, z) are unifiable (T)
b. H(y, G(A,B)) and H(G(x,x), y) are unifiable (F)
c. Older(Mother(y), y) and Older(Mother(x), Mary) are unifiable (T)
d. Knows(Mother(x), x) and Knows(y, y) are unifiable (F)
e. P(x, y) and Q(x, y) are not unifiable (T)

5. In the discussions, we showed logical entailment and inference, please circle all that are true

a. Entailment can be completely checked in the agent's brain/mind (F)
b. Entailment can be checked by truth tables because truth tables divide all possible worlds into groups (T)
c. Inference is the same as Entailment (F)
d. The best inference procedures should be both sound and complete (T)
e. A conclusion derived from a sound inference procedure is not consistent with entailment (F)