Q1 Score: **10.0** **Total Score: 95.0**

1. [10%] General AI Knowledge

For each of the statements below, fill in the bubble T if the statement is always and unconditionally true, or fill in the bubble F if it is always false, sometimes false, or just does not make sense.

	T	F
1	T	●
2	T	●
3	T	●
4	T	●
5	●	F
6	●	F
7	T	●
8	●	F
9	●	F
10	T	●

1. A good knowledge base will be able to answer any question.
2. A truth table will grow polynomially with the number of variables.
3. Fuzzy logic uses a step called segregation to combine results from several rules.
4. Using particular letters for variables in FOL sentences ensures that the values can only be of a certain type.
5. Successor-state axioms solve the representational frame problem.
6. The completeness theorem states that any sentence entailed by a set of sentences can be proven from that set.
7. Some sentences in propositional logic cannot be converted to CNF.
8. Soundness of an inference algorithm means that the algorithm doesn't reach bogus conclusions.
9. Some sentences in propositional logic cannot be converted to Horn Form.
10. Generalized Modus Ponens will derive a solution for all possible values of the variables in the rule.

Q2 Score: **15.0**

2. [30%] Propositional Logic

2.1 CNF [15%]

Convert the following propositional sentence into CNF.
Your answer must be simplified as much as possible and must exactly match the CNF form. You will lose points for any part of your final converted sentence that is not in CNF. At each step, describe the rule used for simplification.

$$\left[\neg(A \Rightarrow B) \vee [(C \vee D) \Rightarrow E]\right] \Rightarrow (B \wedge C)$$

Ans: implication $\alpha \Rightarrow \beta$ can be transferred to disjunction $\neg\alpha \vee \beta$

① $A \Rightarrow B \Leftrightarrow \neg A \vee B$. $(C \vee D) \Rightarrow E \Leftrightarrow \neg(C \vee D) \vee E$.

$[\neg(\neg A \vee B) \vee [\neg(C \vee D) \vee E]] \Rightarrow (B \wedge C)$

② Same rule as ①

$\neg(\neg(\neg A \vee B) \vee (\neg(C \vee D) \vee E)) \vee (B \wedge C)$

③ Demorgan. $\neg(\alpha \vee \beta) = \neg\alpha \wedge \neg\beta$ double negation $\neg\neg\alpha = \alpha$.

$\neg((A \wedge \neg B) \vee (\neg C \wedge \neg D) \vee E) \vee (B \wedge C)$

④ Demorgan Law.

$(\neg(A \wedge \neg B) \wedge \neg(\neg C \wedge \neg D) \wedge \neg E) \vee (B \wedge C)$

⑤ Demorgan.

$[(\neg A \vee B) \wedge (C \vee D) \wedge \neg E] \vee (B \wedge C)$

⑥ $(\alpha \wedge \beta) \vee \gamma \equiv (\alpha \vee \gamma) \wedge (\beta \vee \gamma)$. distribution

Final CNF is:

$(\neg A \vee B) \wedge (B \vee C \vee D) \wedge (\neg E \vee B) \wedge (\neg A \vee B \vee C) \wedge (C \vee D) \wedge (\neg E \vee C)$.

2.2. [15%] Language and Representation.

You are given three boxes.
Exactly one of them contains Gold,
the other two are empty.

Let $\mathbf{B_i}$ represent {Box *i* contains Gold} and $\neg\mathbf{B_i}$ represent {Box *i* is empty}. Answer the following.

1. **[3%]** Represent the statement "Exactly One box contains Gold" using propositional logic in DNF using $\mathbf{B_1}$, $\mathbf{B_2}$, $\mathbf{B_3}$ as proposition symbols. ***(F1)***

Ans: $(B_1 \land \neg B_2 \land \neg B_3) \lor (\neg B_1 \land B_2 \land \neg B_3) \lor (\neg B_1 \land \neg B_2 \land B_3)$

2. **[6%]** Each box has a label as follows:
   a. **Box 1: This box is empty ($\neg\mathbf{B_1}$)**
   b. **Box 2: This box is empty ($\neg\mathbf{B_2}$)**
   c. **Box 3: The Gold is in Box 2 ($\mathbf{B_2}$)**

   Exactly one of the above statements is true (other two are false). Represent this fact using propositional logic. ***(F2)***

Ans: $(a \land \neg b \land \neg c) \lor (\neg a \land b \land \neg c) \lor (\neg a \land \neg b \land c)$

$\Downarrow$. → Final answer is: $(B_1 \land \neg B_2) \lor (B_1 \land B_2)$

$(\neg B_1 \land B_2 \land \neg B_2) \lor (B_1 \land \neg B_2 \land \neg B_2) \lor (B_1 \land B_2 \land B_2)$

$\Downarrow$

B_1

3. **[6%]** Use a truth table to enumerate and find values for ***(F1)*** and ***(F2)*** statements above and ***find the box that contains Gold.***

B1	B2	B3	F1	F2
F	F	F	F.	F.
F	F	T	T.	F
F	T	F	T	F
F	T	T	F	F
T	F	F	T	T
T	F	T	F	T
T	T	F	F	T
T	T	T	F.	T.

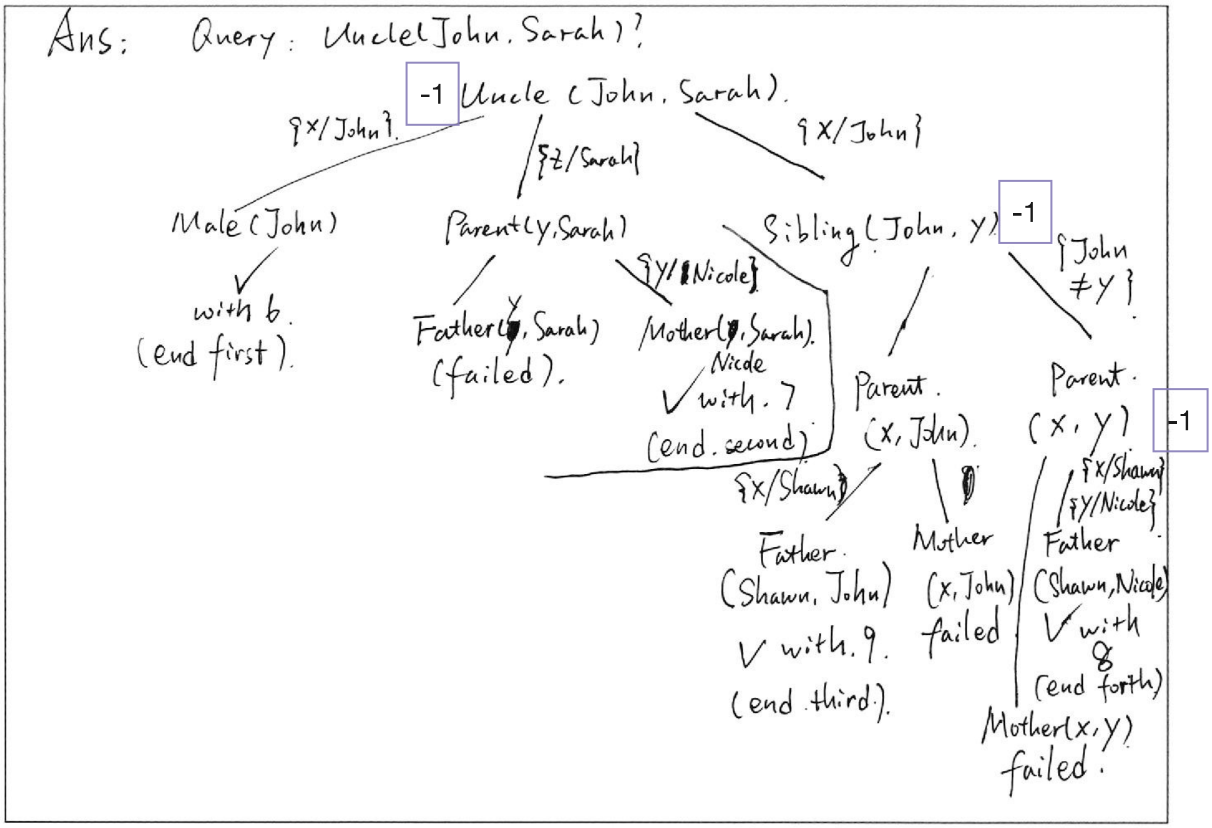
3. [35%] First Order Logic

3.1. [15%] Backward Chaining

Consider the following sentences that are added to a knowledge base in turn. ***Male***, ***Parent***, ***Father***, ***Mother*** and ***Sibling*** are **predicates**, *John, Nicole, Sarah* and *Shawn* are constants, x, y, z, w, p are variables. Assume all sentences are implicitly universally quantified over all variables unless otherwise stated.

1. ***Male(x) ∧ Parent(y, z) ∧ Sibling(x, y) => Uncle(x, z)***
2. ***Father(x, y) => Parent(x, y)***
3. ***Mother(x, y) => Parent(x, y)***
4. ***∀w,p w≠p (Parent(x, p) ∧ Parent(x, w) => Sibling(p, w))***
6. ***Male(John)***
7. ***Mother(Nicole, Sarah)***
8. ***Father(Shawn, Nicole)***
9. ***Father(Shawn, John)***

Given the KB above, show how ***backward chaining with GMP*** can be used to infer whether ***John*** is an ***Uncle*** of ***Sarah*** (i.e., ***Uncle(John, Sarah)***). Draw a backward-chaining inference graph. Be sure to show (1) a backward-chaining inference graph as studied in class, (2) all the substitutions used in unification at each stage, as relevant. Also mark if particular unification is not possible or fails. You will lose marks for any missing node or substitution. You will get 0 if you use any other method than backward chaining with GMP.



Q5 Score: **5.0**

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3.2 [5%] Logic Sentences

Consider the following predicates:

A(x): x is an Animal

M(x): x is a Mammal

B(x): x is a Bird

MR(x): x is Marine (i.e. lives under water)

AR(x): x is Aerial (i.e. can fly)

Using the above predicates, translate the following English sentences into logic expressions:

1. **[1%]** All Mammals are animals

Ans: $\forall x .$ ~~Mammal~~ $\cdot M(x) \Rightarrow A(x).$

2. **[1%]** Some Birds Cannot Fly

Ans: $\exists x \quad B(x) \wedge \neg AR(x).$

3. **[1%]** Bat is the Only Mammal that can Fly

Ans: $\forall x .$ ~~Mammal~~ $M(x) \wedge AR(x) \Rightarrow x = Bat.$

4. **[2%]** Animals are either Marine or Aerial but not BOTH.

Ans: $\forall x . A(x) \Rightarrow (\neg MR(x) \wedge AR(x)) \vee (MR(x) \wedge \neg AR(x))$

Q6 Score: **15.0**

3.3. [15%] Resolution

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Given the query

$\exists x\, E(x) \vee \neg B(x)$

And the following knowledge base:

$\forall x\, A(x) \Rightarrow (B(x) \wedge \neg C(x))$

$\exists x\, A(x) \wedge D(x)$

$\forall x\, C(x) \vee E(x)$

$\neg(E(x) \vee \neg B(x))$

$\neg E(x) \wedge B(x)$

Convert each statement to CNF (hint: some of the given sentences may become split into several CNF sentences), and use **resolution** and a **proof by contradiction** to prove the query. Please show the complete resolution proof, including all substitutions used (you will lose points for any missing step or substitution).

Ans: ① CNF ~~form~~ statement:

$(\neg A \vee B) \wedge (\neg A \vee \neg C)$

1. ⓐ. $\neg A(x) \vee B(x)$.
2. ⓑ $\neg A(y) \vee \neg C(y)$.
3. ⓒ $A(N) \wedge D(N)$.
4. ⓓ ~~$C(Z)$~~ $C(Z) \vee E(Z)$.

~~ⓔ $E(Z)$~~.

$\neg A$ E

$\neg A$ B

② Proof: Negate the query with Skolemization: $\neg E(M) \wedge B(M)$

resolution		unification	result
1.	3 ~~$\neg E(M) \wedge B(M)$~~	x/N	5. $B(N)$
2.	3.	Y/N.	6. $\neg C(N)$
4	6.	Z/N.	7. $E(N)$
5.	7.		8. $B(N) \wedge E(N)$
7.	8.		9. {Null}.

Contradiction exists.

∴ the query is proved

Q7 Score: **3.0**

4. [15%] Planning

4.1 [3%] STRIPS actions

Consider the slightly different block world problem than the one studied in class, where only one box can be placed onto each location A, B, or C on the table. As in the block world studied in class, boxes can be stacked onto other boxes.

Please describe the **STRIPS actions** required for a robot to rearrange the boxes in the Box world described in Fig. 1. (Hint: You may define an action that is to move the box from one place to another.)

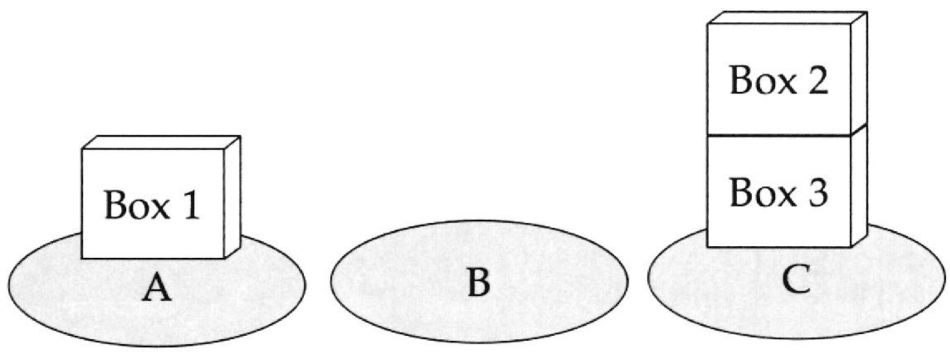


Figure 1: Box world

Ans:

action: Move.(box, place) Precond: Clear(place) Clear(box)

Effect: ~~On~~ At (box, place).

if precond. has On(Box, table). Effect: Clear(table)

action: Move(box, place) Precond: At(box', place)

Effect: At(box, place). On(box, box') Clear(box)

Q8 Score: **4.0**

4.2 [4%] Initial (empty) plan

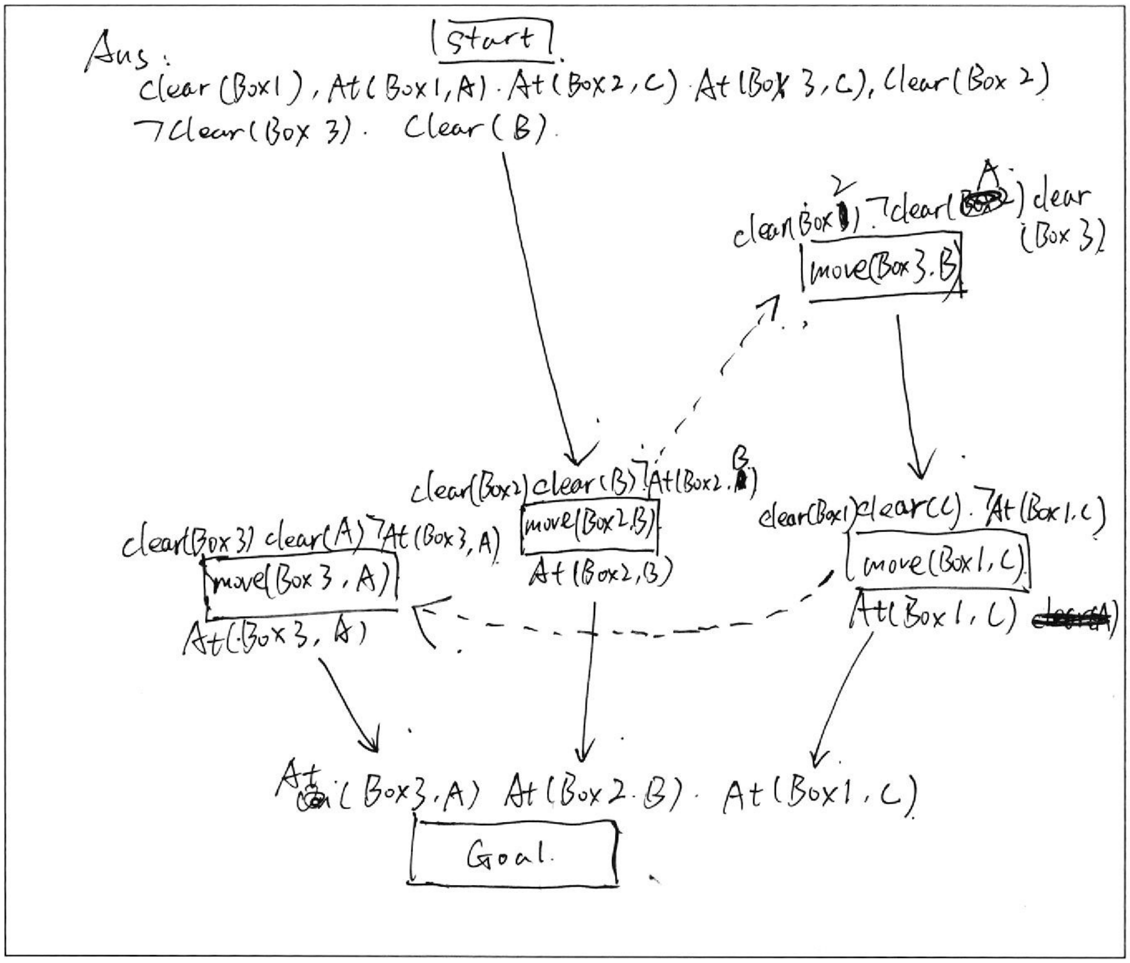
Your plan is to rearrange the boxes from the starting state in figure 1 so that Box 3 is in Place A, Box 2 is in Place B and Box 1 is in Place C.
Write down the initial condition and the goal of this plan using your STRIPS definitions from 4.1.

Ans:
initial condition:
At (Box1, A). At (Box 2, C). At(Box 3, C)
On (Box1, table). On (Box 2. Box3). On(Box3, table)
CLear(B). , Clear (Box1) Clear(Box2), ¬Clear(Box3)
goal: At (Box3. A). At (Box 2. B).
At (Box1, C), Clear(Box1)
Clear(Box 2). Clear (Box 3)
~~On (Box1, table A)~~.

Q9 Score: **8.0**

4.3 [8%] Complete plan

Write down your plan to reach the goal from the initial condition, using the initial condition and goal that you specified in 4.2.



Q10 Score: **8.0**

6. [10%] AI Applications

Circle the letter that corresponds to the best answer for the question:

1. [2pts] In the debate between Neats vs Scruffies, this is home of the Scruffies.
   a. Stanford
   b. CMU
   c. MIT
   d. All of the above
   e. None of the above

2. [2pts] The creators of Prolog sacrifice soundness for efficiency by using:
   a. Inheritance
   b. No Occurs-Check
   c. Frame axioms
   d. All of the above
   e. None of the above

3. [2pts] This uses a type hierarchy/ontology:
   a. Semantic Network
   b. Amazon
   c. Facebook
   d. All of the above choose d finally.
   e. None of the above

4. [2pts] Knowledge sharing is hard because:
   a. Knowledge bases are too small
   b. Knowledge bases have the same query interface
   c. All knowledge bases use the same upper ontology
   d. All of the above
   e. None of the above

5. [2pts] Transitivity reasoning is supported by:
   a. OWL 2
   b. Wordnet
   c. PartOf hierarchy
   d. All of the above
   e. None of the above