1. (a) The question 'Isn't Multi-Agent System all just Social Science?' is an objection to the multi-agent system field. Provide an argument against this objection.

(4 marks)

Answer

- Social science studies human behaviour, norms, and societies through observation and theory.

- Multi-agent systems (MAS) focus on algorithmic design, formal models, and computational mechanisms for artificial agents.

- Example: In game theory, social scientists analyse human strategies, while MAS researchers implement algorithms like Nash equilibrium solvers or auction protocols in code.

- MAS is not "just" social science, it is computational, constructive, and engineering-focused.

1. (b) What is an *optimal agent*? What is a *bounded optimal agent*? Explain the difference between them.

(4 marks)

Answer

- Optimal Agent
  - An optimal agent is one that always selects the action that maximizes its expected performance measure, given its knowledge of the environment.

- Bounded Optimal Agent
  - A bounded optimal agent aims to maximize its performance within the limits of its computational resources.

- Difference
  - An optimal agent assumes unlimited resources and perfect rationality.

  - A bounded optimal agent operates within resource constraints and incomplete knowledge.

1. (c) Clearly list the 5 steps of the Agent Control Loop.

(10 marks)

Answer

<u>Agent Control Loop</u>

1. Agent starts in some initial internal state $i_0$
2. Observes its environment state *e*, and generates a percept *see*(*e*)
3. Internal state of the agent is then updated via *next* function, becoming *next*($i_0$, *see*(*e*))
4. The action selected by the agent is *action*(*next*($i_0$, *see*(*e*)))
5. Goto 2

1. (d) Agent synthesis is a program that takes a task environment, and from this task environment automatically generates an agent that succeeds in this environment. What are the **TWO** properties that an agent synthesis algorithm should have? Clearly explain each of the two properties.

(6 marks)

Answer

- The two properties that an agent synthesis algorithm should have:
  - Soundness
  - Completeness

- Soundness
  - The algorithm must ensure that the agent it produces will succeed in the specified task environment.

  - This property guarantees that the generated agent's actions lead to successful outcomes.

- Completeness
  - The algorithm guarantees to find an agent whenever there exists an agent that will succeed in the task environment given.

  - This generated agent can succeed in the given task environment.

2. Assume that you want to purchase a flat and have two options: Flat A or Flat B. You want to resell the flat in a few years. So, you are interested in whether the flat's value will increase. Depending on the place you choose, there is some probability of increase in the value of the property. You go to work by taking a bus. So, you are also interested in the distance from the bus stop to the flat.

If you purchase Flat A, you will have a probability of 0.5 to find a bus stop that is near to the flat. If you purchase Flat B, you will also have a probability of 0.5 to find a bus stop that is near to the flat. The probability that the value of Flat A will increase in a few years is 0.6, and the probability that the value of Flat B will increase in a few years is 0.4.

The utilities of different cases are given in Table Q2 below.

**Table Q2**

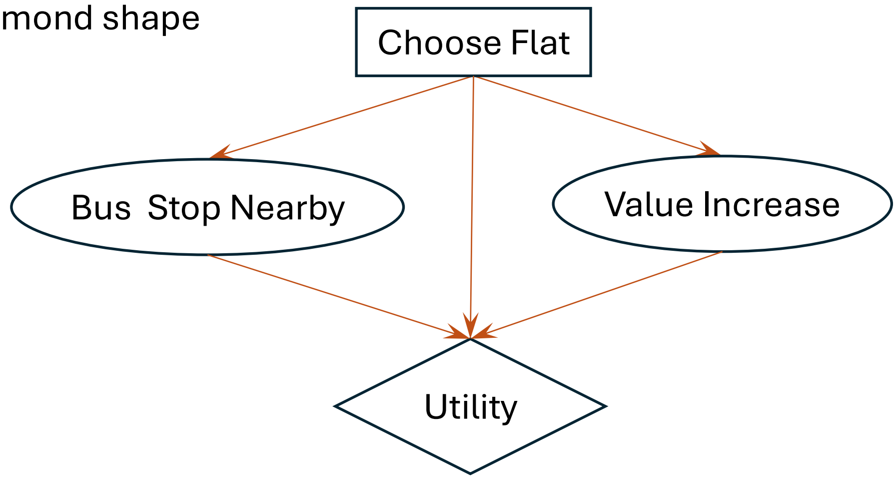
| Which flat to buy | Whether can find a bus stop nearby | Whether the value of the flat will increase | Utility |
|---|---|---|---|
| A | T | T | 0.8 |
| A | T | F | 0.4 |
| A | F | T | 0.6 |
| A | F | F | 0.1 |
| B | T | T | 0.8 |
| B | T | F | 0.3 |
| B | F | T | 0.5 |
| B | F | F | 0.05 |

2. (a) What are the three types of nodes in a decision network for this problem? Draw the decision network.

(10 marks)

Answer

- Decision network nodes
  - Decision nodes : rectangle shape
  - Chance nodes : oval shape
  - Utility nodes : diamond shape



2. (b) What is the expected utility of buying each flat? Which flat should you buy? Show clearly the detailed steps of deriving your answers.

(15 marks)

Answer

| Which flat to buy | Whether can find a bus stop nearby | Whether the value of the flat will increase | Utility |
|---|---|---|---|
| A | T | T | 0.8 |
| A | T | F | 0.4 |
| A | F | T | 0.6 |
| A | F | F | 0.1 |
| B | T | T | 0.8 |
| B | T | F | 0.3 |
| B | F | T | 0.5 |
| B | F | F | 0.05 |

- Flat A probabilities:
  - P( BusStop | A) = 0.5
  - P(¬BusStop | A) = 0.5
  - P( Increase | A) = 0.6
  - P(¬Increase | A) = 0.4

Expected utility of buying Flat A:

- EU(A) = P( BusStop | A) * P( Increase | A) * U(A, BusStop, Increase) +
  P( BusStop | A) * P(¬Increase | A) * U(A, BusStop, ¬Increase) +
  P(¬BusStop | A) * P( Increase | A) * U(A, ¬BusStop, Increase) +
  P(¬BusStop | A) * P(¬Increase | A) * U(A, ¬BusStop, ¬Increase)
  = (0.5 * 0.6 * 0.8) + (0.5 * 0.4 * 0.4) + (0.5 * 0.6 * 0.6) + (0.5 * 0.4 * 0.1)
  = 0.24 + 0.08 + 0.18 + 0.02
  = 0.52

- Flat B probabilities:
  - P( BusStop | B) = 0.5
  - P(¬BusStop | B) = 0.5
  - P( Increase | B) = 0.4
  - P(¬Increase | B) = 0.6

Expected utility of buying Flat B:

- EU(B) = P( BusStop | B) * P( Increase | B) * U(B, BusStop, Increase) +
  P( BusStop | B) * P(¬Increase | B) * U(B, BusStop, ¬Increase) +
  P(¬BusStop | B) * P( Increase | B) * U(B, ¬BusStop, Increase) +
  P(¬BusStop | B) * P(¬Increase | B) * U(B, ¬BusStop, ¬Increase)
  = (0.5 * 0.4 * 0.8) + (0.5 * 0.6 * 0.3) + (0.5 * 0.4 * 0.5) + (0.5 * 0.6 * 0.05)
  = 0.16 + 0.09 + 0.1 + 0.015
  = 0.365

<u>Summary of EU</u>

- EU(A) = 0.52
- EU(A) = 0.365
- Since EU(A) = 0.5 > EU(B) = 0.365, buy flat A

3. (a) Novel coronavirus (COVID-19) is very contagious. Robots might be useful to help combat the spread of the deadly coronavirus, e.g., using robots to deliver medicine, food, disinfect rooms, or even perform surgeries. List and briefly explain a few key ideas in multi-agent systems which can be used to build such a system in which many robots interact with humans including patients, doctors, and nurses.

(5 marks)

Answer

i. Coordination
   - Multi-agent systems enable robots to work together efficiently by coordinating their actions and collaborating on tasks.

ii. Communication
   - Robots must communicate with each other and with human agents (doctors, nurses) to share information about task status, location, or emergencies.

iii. Task Allocation
   - Multi-agent systems can dynamically allocate tasks among robots based on their capabilities and current workload.

iv. Autonomy
   - Each robot in a multi-agent system can operate autonomously, making decisions based on its local environment and goals.

v. Human-Agent Interaction
   - Robots must be able to interpret human commands and behaviours to interact safely.

3. (b) During the COVID-19 crisis, masks are in short supply in many countries including Singapore. Assume that Singapore is starting its own mask production lines to meet the increasing demand. Building a mask production line involves many activities such as getting the equipment, getting raw materials, and hiring workers. Briefly describe how you can use CONTRACT NET to allocate tasks to build a mask production line.

(5 marks)

Answer

- The contract net includes five stages:
  1. Recognition
  2. Announcement
  3. Bidding
  4. Awarding
  5. Expediting

1. Recognition
   - In this stage, an agent recognises it has a problem it wants help with.

2. Announcement
   - In this stage, the agent with the task sends out an announcement of the task which includes a specification of the task to be achieved.

3. Bidding
   - Agents that receive the announcement decide for themselves whether they wish to bid for the task

4. Awarding
   - Agent that sent task announcement must choose between bids & decide who to "award the contract" to.

5. Expediting
   - The successful contractor then expedites the task

3. (c) Vickrey auctions are one-shot second-price sealed-bid auctions. We have seen the advantages of second-price auctions over first-price auctions in class: truth telling is a dominant strategy in a Vickrey auction. Now we introduce a third-price auction in which the winner is the highest bidder, and he pays the third highest bid. Is truth telling still a dominant strategy? Briefly explain your answer.

(5 marks)

Answer

- No, the third-price auction is not a dominant strategy.

- In a third-price auction, the winner pays the third highest bid. This creates an incentive for bidders to strategically misreport their true valuation.

- Bidders can inflate their bid to ensure winning without affecting payment.

- Example:
  - Suppose there are three bidders A, B, C with true valuations of \$10, \$8, and \$6, respectively.
  - If all bidders bid truthfully, A wins the bid and pays \$6.
  - If A overbid significantly, say \$100, A would still win and still pay \$6.
  - In this case, it demonstrates that A bid does not influence the price he pays, so long as he remains the highest bidder.

- Due to bidder's payment is not directly tied to their own bid (but to the third-highest bid), they do not face the same pressure to reveal their true valuation.

3. (d) Consider a coalitional game with agents Ag={1,2} and a characteristic function v defined by v({1})=7, v({2})=13, v({1,2})=25. With reference to this example, explain the meaning of the core of a coalitional game.

(5 marks)

Answer

- Given Ag = {1,2}
  - v({1}) = 7
  - v({2}) = 13
  - v({1, 2}) = 25

- The core of a coalitional game is the set of payoff allocations to agents such that:
  - Efficiency (Group Rationality)
    - $x_1 + x_2 = v(1, 2) = 25$ ------------------ (1)
  - Individual Rationality
    - $x_1 \geq v(1) = 7$ ------------------ (2)
    - $x_2 \geq v(2) = 13$ ------------------ (3)
  - Coalitional Rationality
    - No subset of agents has an incentive to break away, because they cannot do better on their own than the allocation they receive in the grand coalition.

- Finding the core
  - From (1), $x_2 = 25 - x_1$ ----------------- (4)
  - (3) into (4), $13 = 25 - x_1$
    $x_1 = 25 - 13 = 12$
    Allocation $7 \leq x_1 \leq 12$
  - (2) into (4), $x_2 = 25 - 7$
    $x_2 = 18$
    Allocation $13 \leq x_2 \leq 18$
  - Possible distributions that satisfy these conditions are:
    - $x_1 = 7$ and $x_2 = 18$
    - $x_1 = 8$ and $x_2 = 17$
    - $x_1 = 9$ and $x_2 = 16$
    - $x_1 = 10$ and $x_2 = 15$
    - $x_1 = 11$ and $x_2 = 14$
    - $x_1 = 12$ and $x_2 = 13$

<u>Interpretation of the core</u>

- The core guarantees stability
  - No agent or sub-set of agents has incentive to deviate from the coalition.
  - Together, they get the maximum value and split it fairly.

3. (e) Does the Borda count satisfy the Pareto property? Explain your answer.

(5 marks)

Answer

- Yes, the Borda count satisfies the Pareto property.

- A voting system satisfies the Pareto property if, whenever all voters prefer candidate A over candidate B, the final ranking must not rank B above A.

- How Borda works
  - Voters rank all candidates.
  - The candidate with the highest total points wins.

- Example
  ($1^{st}$ place 3 points, $2^{nd}$ place 2 points, $3^{rd}$ place 1 point)
  Voter 1: A > B > C
  Voter 2: A > C > B
  Voter 3: C > A > B
  A gets 8 points, B gets 4 points, C gets 6 points
  Candidate A wins

- The Borda count respects unanimous preferences and thus satisfies the Pareto property.

4. Consider the payoff matrix in Table Q4. The first number in each entry is the payoff received by the row player **A,** while the second number is the payoff received by the column player **B**.

**Table Q4**

| | **B: left** | **B: middle** | **B: right** |
|---|---|---|---|
| **A: up** | **4, 2** | **4, 3** | **5, 2** |
| **A: middle** | **2, 4** | **2, 4** | **3, 5** |
| **A: down** | **4, 1** | **5, 0** | **4, 1** |

4. (a) Identify the dominant strategies (if any) of each player in the payoff matrix. Briefly explain your answer.

(5 marks)

Answer

- Player A (row player):
  - If B plays left, A: up = 4, mid = 2, down = 4 → up or down is best
  - If B plays middle, A: up = 4, mid = 2, down = 5 → down is best
  - If B plays right, A: up = 5, mid = 3, down = 4 → up is best
  - Player A has no dominant strategy

- Player B (column player):
  - If A plays up, B: left = 2, mid = 3, right = 2 → middle is best
  - If A plays middle, B: left = 4, mid = 4, right = 5 → right is best
  - If A plays down, B: left = 1, mid = 0, right = 1 → left or right is best
  - Player B has no dominant strategy

Summary

- Neither player has a dominant strategy.
- This is because no single action yields a better or equal payoff in all situations compared to the other actions.

4. (b) Identify which strategy pairs (if any) in the payoff matrix are in Nash equilibrium. Briefly explain your answer.

(8 marks)

Answer

- To identify Nash equilibrim, we need to find strategy pairs where neither player has an incentive to change their strategy.

| | B: left | B: middle | B: right |
|---|---|---|---|
| **A: up** | **4, 2** | **4, 3** | **5, 2** |
| **A: middle** | **2, 4** | **2, 4** | **3, 5** |
| **A: down** | **4, 1** | **5, 0** | **4, 1** |

1. (A: up, B: left) → (4, 2)
- A against B: left → up = 4, mid = 2, down = 4 → A prefers up or down
- B against A: up → left = 2, mid = 3, right = 2 → B prefers middle
- Not Nash equilibrium

2. (A: up, B: middle) → (4, 3)
- A against B: middle → up = 4, mid = 2, down = 5 → A prefers down
- B against A: up → left = 2, mid = 3, right = 2 → B prefers middle
- Not Nash equilibrium

3. (A: up, B: right) → (5, 2)
- A against B: right → up = 5, mid = 3, down = 4 → A prefers up
- B against A: up → left = 2, mid = 3, right = 2 → B prefers middle
- Not Nash equilibrium

4. (A: middle, B: left) → (2, 4)
- A against B: left → up = 4, mid = 2, down = 4 → A prefers up or down
- B against A: middle → left = 4, mid = 4, right = 5 → B prefers right
- Not Nash equilibrium

5. (A: middle, B: middle) → (2, 4)
- A against B: middle → up = 4, mid = 2, down = 5 → A prefers down
- B against A: middle → left = 4, mid = 4, right = 5 → B prefers right
- Not Nash equilibrium

6. (A: middle, B: right) → (3, 5)
- A against B: right → up = 5, mid = 3, down = 4 → A prefers up
- B against A: middle → left = 4, mid = 4, right = 5 → B prefers right
- Not Nash equilibrium

4. (b) cont

Answer

| | B: left | B: middle | B: right |
|---|---|---|---|
| **A: up** | **4, 2** | **4, 3** | **5, 2** |
| **A: middle** | **2, 4** | **2, 4** | **3, 5** |
| **A: down** | **4, 1** | **5, 0** | **4, 1** |

7. (A: down, B: left) → (4, 1)

- A against B: left → up = 4, mid = 2, down = 4 → A prefers up or down
- B against A: down → left = 1, mid = 0, right = 1 → B prefers left or right
- Nash equilibrium

8. (A: down, B: middle) → (5, 0)

- A against B: middle → up = 4, mid = 2, down = 5 → A prefers down
- B against A: down → left = 1, mid = 0, right = 1 → B prefers left or right
- Not Nash equilibrium

9. (A: down, B: right) → (4, 1)

- A against B: right → up = 5, mid = 3, down = 4 → A prefers up
- B against A: down → left = 1, mid = 0, right = 1 → B prefers left or right
- Not Nash equilibrium

<u>Summary of Nash Equilibrium</u>

- (A: down, B: left) → (4, 1)
- Neither player has an incentive to change their strategy

4. (c) Identify which outcomes in the payoff matrix are Pareto optimal. Briefly explain your answer.

(7 marks)

Answer

- An outcome is said to be Pareto optimal if there is no other outcome that makes one agent better off without making another agent worse off. (win-win)

- If an outcome is Pareto optimal, then at least one agent will be reluctant to move away from it (because this agent will be worse off).

- If an outcome ω is not Pareto optimal, then there is another outcome ω' that makes everyone as happy, if not happier, than ω.

| | **B: left** | **B: middle** | **B: right** |
|---|---|---|---|
| **A: up** | **4, 2** | **4, 3** | **5, 2** |
| **A: middle** | **2, 4** | **2, 4** | **3, 5** |
| **A: down** | **4, 1** | **5, 0** | **4, 1** |

1. (A: up, B: left) → (4, 2)
   - Dominated by (4, 3) & others
   - Not Pareto optimal because can improve to (4, 3), (5, 2)

2. (A: up, B: middle) → (4, 3)
   - No other better domination
   - Pareto optimal

3. (A: up, B: right) → (5, 2)
   - No other better domination
   - Pareto optimal

4. (A: middle, B: left) → (2, 4)
   - Dominated by (3, 5)
   - Not Pareto optimal

5. (A: middle, B: middle) → (2, 4)
   - Dominated by (3, 5)
   - Not Pareto optimal

4. (c) cont

Answer

| | B: left | B: middle | B: right |
|---|---|---|---|
| A: up | 4, 2 | 4, 3 | 5, 2 |
| A: middle | 2, 4 | 2, 4 | 3, 5 |
| A: down | 4, 1 | 5, 0 | 4, 1 |

6. (A: middle, B: right) → (3, 5)
   - No other better domination
   - Pareto optimal

7. (A: down, B: left) → (4, 1)
   - Dominated by (4, 2) & others
   - Not Pareto optimal

8. (A: down, B: middle) → (5, 0)
   - Dominated by (5, 2)
   - Not Pareto optimal

9. (A: down, B: right) → (4, 1)
   - Dominated by (4, 2) & others
   - Not Pareto optimal

Summary of Pareto optimal

- (A: up, B: middle) → (4, 3)
- (A: up, B: right) → (5, 2)
- (A: middle, B: right) → (3, 5)
- No other outcome makes one player better off without making the other worse off

4. (d) Identify which outcomes in these two payoff matrices maximize social welfare. Briefly explain your answer.

(5 marks)

Answer

- Social welfare is measured as the sum of all players' payoffs. The outcome with the highest total payoff maximizes social welfare.

| | B: left | B: middle | B: right |
|---|---|---|---|
| **A: up** | **4, 2** | **4, 3** | **5, 2** |
| **A: middle** | **2, 4** | **2, 4** | **3, 5** |
| **A: down** | **4, 1** | **5, 0** | **4, 1** |

- (A: up, B: left): Total payoff = 4 + 2 = 6
- (A: up, B: middle): Total payoff = 4 + 3 = 7
- (A: up, B: right): Total payoff = 5 + 2 = 7
- (A: middle, B: left): Total payoff = 2 + 4 = 6
- (A: middle, B: middle): Total payoff = 2 + 4 = 6
- (A: middle, B: right): Total payoff = 3 + 5 = 8
- (A: down, B: left): Total payoff = 4 + 1 = 5
- (A: down, B: middle): Total payoff = 5 + 0 = 5
- (A: down, B: right): Total payoff = 4+ 1 = 5

- Maximize social welfare = 8

Summary of maximize social welfare

- (A: middle, B: right) → (3, 5)
- The outcome achieves the highest total payoff maximizes social welfare.