AI6125 Multi-Agent System

Chen Yongquan (G2002341D)
Nanyang Technological University

Assignment 2: Technical Questions

1a. The question 'aren't agents just expert systems by another name?' refers to the relationship between agents and expert systems. Describe what an expert system is. List TWO main differences between agents and expert systems.

The first difference is that agents are capable of independent action on behalf of its user or owner while expert systems require user input to provide a result. For instance, the MYCIN expert system is able to model domain expert decisions in identifying bacterial infections through its inference engine and knowledge base. However, it requires constant user interaction using its user interface to provide corresponding answers. An agent only needs to be told its design objectives and is able to figure out what needs to be done to satisfy them without constant user feedback. Case in point, the Jango e-commerce agent is able to monitor "what's new" lists, special offers and discounts and make shopping recommendations to the user without the user constantly asking

The second difference is that agents are situated in some environment, are aware of it and are capable of autonomous action in the environment in order to meet its delegated objectives. Conversely, expert systems are not aware of the environment and decisions are made using only the inference engine and knowledge base. For instance, the MYCIN system is not aware of the location it is in and the common infections affecting the area. However, the Jango e-commerce agent is aware of the Internet environment it is in and crawl the Internet for new information and make decisions based on any new information from the environment.

1b. Five trends in the history of computing have led the emergence of the field of multiagent systems. One of the trends is intelligence. Explain with an example what intelligence means

Intelligence in the context of multiagent systems refer to the complexity of tasks that we are capable of automating and delegating to computers. For instance, the first computers like the Enigma or Colossus were more or less mathematical calculators used for breaking German Nazi encoded messages. However, computers or agents today are capable of playing Go at professional levels, detecting and classifying objects within visual images represented as data streams, and even learn and adapt to users in the case of personal assistants like Alexa or Siri.

1c. Utility functions can be used as a method for telling agents what to do without telling them how to do it. Give two types of utility functions and discuss the challenges faced when designing such functions.

The two types of utility functions are utility functions designed over states and utility functions designed over runs.

The first type associate utilities with individual states and the task of the agent is to bring about states that maximize utility. However, it is difficult to specify a long-term view when assigning utilities to individual states. For instance, suppose an agent choose to move into a possible state with higher utility over another. It then finds that the possible states after transformation all have extremely low utilities. Conversely, it might have been better for it to choose the other move in the first step, where the possible states after transformation have higher utilities, allowing it to have a larger sum of utilities of states on the run. A possible way to solve this is to discount the utilities for states later on. Another point of consideration is how to assign a value to a run, be it using the maximum, minimum, sum or average of state utilities across the run.

The second type of utility function assigns utility to the runs themselves and inherently takes a long-term view.

Designing utility functions is challenging because we do not think in terms of utilities and it is hard to come up with numbers or values to assign to states or runs. For instance, when making a decision to bring an umbrella in case of rainy weather, we do not usually make our decision based on numerical probabilities in our mind. It is also hard to formulate tasks in terms of utilities.

1d. Two most common types of tasks are achievement tasks and maintenance tasks. Explain what these two types of tasks are.

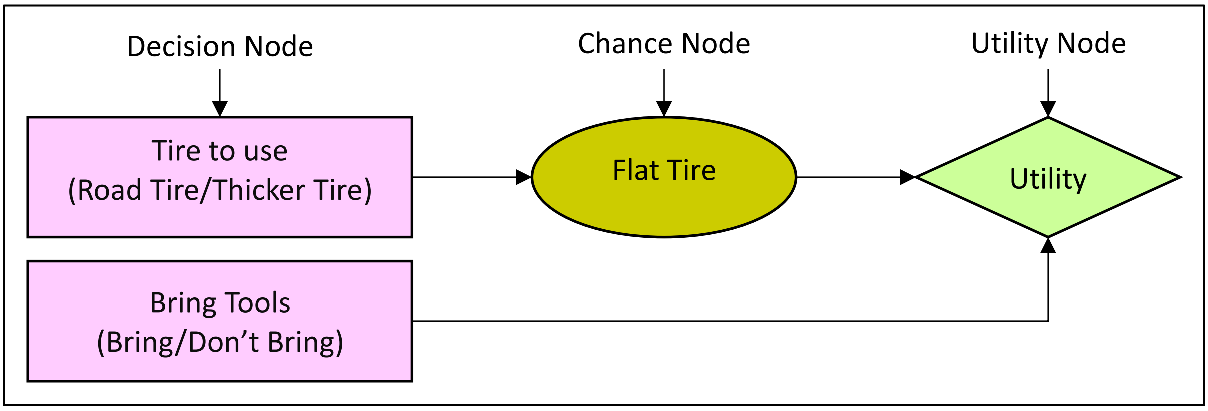
Achievement tasks are those where the agent has to "achieve a state of affairs". Given a set of goal states, the agent succeeds if it brings about at least one of those states.

Maintenance tasks are those where the agent has to "maintain a state of affairs". Given a set of bad states, the agent succeeds if it manages to avoid all the bad states while performing actions.

Continue on next page

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

The three types of nodes are chance nodes, decision nodes and utility nodes.



Tire	Flat Tire	$P(\boldsymbol{Flat\ Tire} = ?\,|\boldsymbol{Tire} = ?)$
Road Tire	Yes	0.4
Road Tire	No	0.6
Thick Tire	Yes	0.1
Thick Tire	No	0.9

Tire	Bring Tools	Flat Tire	Utility
Road Tire	Yes	Yes	50
Road Tire	Yes	No	75
Road Tire	No	Yes	0
Road Tire	No	No	100
Thicker Tire	Yes	Yes	40
Thicker Tire	Yes	No	65
Thicker Tire	No	Yes	0
Thicker Tire	No	No	75

2b. What is the optimal decision? What is the expected utility of the optimal decision? Show clearly the detailed steps of deriving your answers.

$$
\begin{aligned}
& EU(Road\ Tire, Bring\ Tools) \\
&= P(Flat\ Tire|Road\ Tire) \times U(Road\ Tire, Bring\ Tools, Flat\ Tire) + \\
&\quad P(\neg Flat\ Tire|Road\ Tire) \times U(Road\ Tire, Bring\ Tools, \neg Flat\ Tire) \\
&= 0.4 \times 50 + 0.6 \times 75 = 65
\end{aligned}
$$

$$
\begin{aligned}
& EU(Road\ Tire, \neg Bring\ Tools) \\
&= P(Flat\ Tire|Road\ Tire) \times U(Road\ Tire, \neg Bring\ Tools, Flat\ Tire) + \\
&\quad P(\neg Flat\ Tire|Road\ Tire) \times U(Road\ Tire, \neg Bring\ Tools, \neg Flat\ Tire) \\
&= 0.4 \times 0 + 0.6 \times 100 = 60
\end{aligned}
$$

$$
\begin{aligned}
& EU(Thick\ Tire, Bring\ Tools) \\
&= P(Flat\ Tire|Thick\ Tire) \times U(Thick\ Tire, Bring\ Tools, Flat\ Tire) + \\
&\quad P(\neg Flat\ Tire|Thick\ Tire) \times U(Thick\ Tire, Bring\ Tools, \neg Flat\ Tire) \\
&= 0.1 \times 40 + 0.9 \times 65 = 62.5
\end{aligned}
$$

$$
\begin{aligned}
& EU(Thick\ Tire, \neg Bring\ Tools) \\
&= P(Flat\ Tire|Thick\ Tire) \times U(Thick\ Tire, \neg Bring\ Tools, Flat\ Tire) + \\
&\quad P(\neg Flat\ Tire|Thick\ Tire) \times U(Thick\ Tire, \neg Bring\ Tools, \neg Flat\ Tire) \\
&= 0.1 \times 0 + 0.9 \times 75 = 67.5
\end{aligned}
$$

Based on the expected utilities for all 4 combinatorial decisions, the expected utility for using the thick tire and not bringing tools along is the highest with a value of 67.5, thus that is the optimal decision.

Continue on next page

3a. When building a team of fighter jet agents for fighting with another team of fighter jet agents, what are the additional issues we have to consider compared with designing a single fighter jet agent?

In order for a team of fighter jet agents to operate together efficiently as a single unit instead of several separate discrete agents with a 1-vs-all model of the environment, agent collaboration and communication is an additional issue that we have to consider.

To assess how well the team of fighter jet agents are able to collaborate together, we adopt two criteria, mainly coherence and coordination.

Coherence is defined in this context as how well the fighter jet agents are able to behave as a unit along some dimension of evaluation pertaining to the air combat. For instance, the flight/squadron evaluation metric could be the surviving number of jets in the unit at the end, or the total number of targets eliminated as a unit.

Coordination relates to how well are the agents able to avoid "extraneous" activities and synchronize and align their activities. For example, how well the fighter jets are able to keep in tactical formation, whether the agents are able to allocate targets to groups or individual agents or focus on a single objective, and whether the agents are able to call for assistance or assist other agents when under fire.

Building a team of fighter jet agents to fight another team can be viewed as a cooperative distributed problem-solving scenario, for which we can divide into three stages: problem decomposition, sub-problem solution and answer synthesis.

For problem decomposition, the air combat problem is recursively or hierarchically divided into subproblems. For instance, the agents can formulate logical actions at the strategical level that pertains to the entire unit as a whole, e.g. whether to be aggressive or defensive, battlefield management and assets coordination. Moving a level down, the agents can deliberate tactical options such as which formation to fly in. In this way, the air combat scenario is divided into smaller and smaller problems that can be managed at that level, until the decisions made at the individual agent level such as dogfighting maneuvers to perform.

Problem decomposition and deliberation have additional issues we have to consider such as whether the entire decision-making process is centralized, which agents have knowledge of the task structure, or which agents are going to be responsible for solving the sub-problems. For instance, under the Skyborg program, an F-35 fighter jet could control a squadron of companion drones. In such a scenario, most of the strategical and tactical deliberation can be centralized in the F-35 jet. Meanwhile, a squadron of fighter jets organized into individual tactical flight groupings could centralize strategical deliberation in the commanding jet while tactical level deliberation is offloaded onto leader jets for each tactical grouping.

Sub-problem solution is concerned with solving the sub-problems derived from problem decomposition. At this stage, agents typically share some information and may also synchronize their actions. For instance, when exploring the battlefield, fighter agents may divide the task among multiple agents or groups of agents and spread out. While doing so, fighter jet agents may share their map and spotted objects of interest to other agents and also synchronize their exploration routes, so they do not repeat already explored areas or collide with other fighter jets while exploring.

Solution synthesis is concerned with integrating sub-problems solutions to form an overall solution for the combat scenario. Integration of solutions can be done in a hierarchical level too. For instance, against an opposing team with spotters and wingmen, a sub-problem could be eliminating the spotters and wingmen first before targeting the leader of the team. As such, the final objective can only be commenced after the various sub-problems delegated to our sub-groups of jets are completed and communicated to the leader of or every agent on our team. The overall solution is then the complete elimination of the opposing forces with the final key objective being the subjugation of their leader, that has to be preceded by the smaller objectives.

Given the three stages, we can see two main issues that we also have to consider which is task sharing and result sharing. Task sharing is how the exploration task and combat targets are allocated to fighter jet agents while result sharing is what information is shared among the agents and to whom the information is shared to. Sharing every single information across the communication channel could overload the channel with mundane information or hog network resources while sharing too little information could impact the efficacy of the multi-agent system. Also, the flow of information can be considered too, like whether agents submit their information to a centralized controller which then organizes and disseminates them back to all other agents or broadcast them on a common channel.

Next, when designing a single fighter jet agent to fight against another single fighter jet agent, the environment is essentially a multi-agent environment where we have the option to consider the other fighter jet as a conflicting self-interested agent, where its strategies and actions may not be entirely independent of our own agent.

This is as opposed to considering the other fighter jet as an environmental object which our agent interacts with, and we only need to consider the problem as a single agent scenario and agent's choices can be purely based on decision theory. Whereas, if we consider the other fighter jet as an opposing intelligent agent, we have to factor in game theory into the decision-making logic of our own agent.

Thus, when building a team of fighter jet agents to fight against another team of fighter jet agents, such considerations still have to be mulled upon when designing the agents' logic. Such issues may include deception, baiting or jukes by the opposing team, or our own team trying to deceive and bait the opposing team. As such, in game theory, we have to consider whether we or the team have perfect or imperfect information, whether the fighter jets on both teams are of the same make and strategies that apply to them are symmetric or asymmetric.

In actual aerial conflict scenarios, agents also have to take into account what kind of situation they are in and if they are zero-sum or non-zero sum. For instance, given 3 different cases: accidental aerial incursions where jets only have to be escorted out, actual aerial combat, and aerial standoffs where international players are only trying to put military pressure on one another; these situations all have different surrounding context and may or may not be zero-sum games. As such, the optimal action to take may differ when considering the international and economical perspectives and also impact to the agent itself for each of these situations.

3b. Briefly describe the five stages included in the CONTRACT NET protocol.

The contract net protocol consists of five stages: recognition, announcement, bidding, awarding and expediting. In the recognition stage, an agent recognizes it has a problem it wants help with. This assumes that the agent has a goal and it either realizes it cannot achievement the goal in isolation as the task is beyond its capabilities, or it prefer to not achieve the goal in isolation as working with other agents may give a better quality solution or satisfy a time-limit requirement etc.

In the announcement stage, the agent with the task sends out an announcement of the task which includes a specification of the task to be achieved. The specification includes a description of the task, any constraints and other meta-task information such as when the bids must be submitted by.

In the bidding stage, agents that receive the announcement decide for themselves whether they wish to bid for the task. When deciding whether to bid for a task, agents must evaluate whether they are capable of assisting in the task or if their participation could hinder the task. They must also consider whether they are able to meet the constraints defined in the task specification. After these deliberations, should an agent choose to bid for the task, it will then submit a tender.

In the awarding and expediting stages, the agent that sent the task announcement must choose between bids & decide who to "award the contract" to. The result of this process is communicated to agents that submitted a bid. The successful contractor then expedites the task. The successful contractor may also request for further assistance themself and sub-contract their contracted task or sub-tasks derived from it to other agents, which would then involve another contract net.

3c. Anyone who wishes to register a new vehicle in Singapore must first obtain a Certificate of Entitlement (COE). COEs are bid through the COE Open Bidding System. The number of successful bidders is limited by the COEs available for each particular COE category. Each successful bidder pays the price of the highest unsuccessful bid. Assume that each bidder wants only one COE. Is the biding mechanism truthful? Explain why.

The COE open bidding system uses an open bid uniform price auction mechanism which makes truthful bidding the dominant strategy i.e. the system is incentive compatible.

This is because if one should bid their truthful valuation and should he win, he always pays less than their bid price as the final price he pays is the highest unsuccessful bid plus $1. In the worst-case scenario, should he be the last highest bidder meeting the COE quota for the month, he pays the next highest bid which is still lower than their bid price.

However, if he bid higher than his own valuation of the COE to bolster his winning chances, he risks paying more than what he thinks is a reasonable valuation based on their own financial situation and the demand and supply of the COE. If many people think like him and bid higher than their actual valuation, he may end up being one of the bag holders when the number of people doing so number more than the COE quota for that month, and the price becomes artificially inflated. Likewise, if the majority of bidders values the COE higher than his valuation, he may also end up paying more than what his own financial situation can afford, even though the price he pays is the market valuation based around demand and supply.

Finally, should he bid lower than his valuation, he reduces his chance of winning the bid as COE quota is limited. There is also no extra savings as the final price he pays is unaffected by his lower bid versus his truthful bid.

And since the open bidding system reveals the current COE price to everyone and also the pool of bidders is rarely less than the COE quota for the month, the chance of collusion to push down the price under the COE system is very low. Any bidding activity by detractors from a colluding coalition or external parties competing with the coalition can be identified if the current COE price rises above the colluded price.

Continue on next page

4a. Identify which strategy pairs (if any) in these two payoff matrices are in dominant strategy equilibrium. Briefly explain your answer.

Payoff matrix A:

	$\boldsymbol{j}$ **defect**	$\boldsymbol{j}$ **cooperate**
$\boldsymbol{i}$ **defect**	$(7,7)$	$(6,7)$
$\boldsymbol{i}$ **cooperate**	$(7,7)$	$(7,8)$

Payoff matrix B:

	$\boldsymbol{j}$ **defect**	$\boldsymbol{j}$ **cooperate**
$\boldsymbol{i}$ **defect**	$(2,3)$	$(3,3)$
$\boldsymbol{i}$ **cooperate**	$(1,5)$	$(4,2)$

For matrix A, cooperating is a weakly dominant strategy for $\boldsymbol{i}$ as cooperating gives at least as good as or a better payoff than defecting, with a payoff of 7 irregardless of $\boldsymbol{j}$'s strategy. Meanwhile defecting gives a payoff of at most 7 if $\boldsymbol{j}$ defects and a lower payoff of 6 if $\boldsymbol{j}$ cooperates.

Cooperating is also a weakly dominant strategy for $\boldsymbol{j}$ as cooperating gives at least as good as or a better payoff than defecting, with a lowest payoff of 7 if $\boldsymbol{i}$ defects and a highest payoff of 8 if $\boldsymbol{i}$ cooperates. Meanwhile defecting gives a payoff of 7 regardless of $\boldsymbol{i}$'s strategy.

For matrix B, defecting is a weakly dominant strategy for $\boldsymbol{j}$ as defecting gives at least as good as or a better payoff than cooperating, with a lowest payoff of 3 if $\boldsymbol{i}$ defects and a highest payoff of 5 if $\boldsymbol{i}$ cooperates. Meanwhile cooperating gives a payoff of at most 3 if $\boldsymbol{i}$ defects and a lower payoff of 2 if $\boldsymbol{i}$ cooperates.

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

In matrix A, both $\boldsymbol{i}$ and $\boldsymbol{j}$ defecting is a Nash equilibrium.
The payoff for both is (7,7).
If $\boldsymbol{i}$ defects, $\boldsymbol{j}$ can do no better than defecting as the payoff remains the same at 7 even if it cooperates.
If $\boldsymbol{j}$ defects, $\boldsymbol{i}$ can do no better than defecting as the payoff drops to 6 if it cooperates.

Both $\boldsymbol{i}$ and $\boldsymbol{j}$ cooperating is also a Nash equilibrium.
The payoff for both is (7,8).
If $\boldsymbol{i}$ cooperates, $\boldsymbol{j}$ can do no better than cooperating as the payoff drops to 7 if it defects.
If $\boldsymbol{j}$ cooperates, $\boldsymbol{i}$ can do no better than cooperating as the payoff remains the same at 7 even if it defects.

There are no strategy pairs that are in Nash equilibrium in matrix B.

4c. Identify which outcomes in these two payoff matrices are Pareto optimal. Briefly explain your answer.

For matrix A, both $\boldsymbol{i}$ and $\boldsymbol{j}$ cooperating together is Pareto optimal.
The payoff for both is (7,8), giving the highest payoff for both out of all outcomes.
There is no other outcomes that can improve the payoff of $\boldsymbol{i}$ or $\boldsymbol{j}$, and this outcome Pareto dominates all other possible outcomes.

$\boldsymbol{j}$ at least would be reluctant to move away from this outcome as all other outcomes gives it a lower payoff of 7.

For matrix B, $\boldsymbol{i}$ defecting and $\boldsymbol{j}$ cooperating is Pareto optimal.
The payoff for both is $(3,3)$, giving the highest total payoff possible of 6.
If $\boldsymbol{j}$ defects, the total payoff is reduced to 5 and $\boldsymbol{i}$ is worse off with a payoff of 2.
There is no other outcomes that can increase the payoffs of either without the other being worse off: if $\boldsymbol{j}$ defects, it reduces the payoff for $\boldsymbol{i}$, while if $\boldsymbol{i}$ cooperates, it gets a higher payoff of 4 at the expense of $\boldsymbol{j}$.

$\boldsymbol{i}$ cooperating and $\boldsymbol{j}$ defecting is also Pareto optimal with a payoff of $(1,5)$.
This outcome gives the highest payoff for $\boldsymbol{j}$ so $\boldsymbol{j}$ would be reluctant to move away even though $\boldsymbol{i}$'s payoff increases if it does, which would then reduce its own payoff.

Both $\boldsymbol{i}$ and $\boldsymbol{j}$ cooperating are is also Pareto optimal with a payoff of $(4,2)$.
This outcome gives the highest payoff for $\boldsymbol{i}$ so $\boldsymbol{i}$ would be reluctant to move away even though $\boldsymbol{j}$'s payoff increase if it does, which would then reduce its own payoff.

Both $\boldsymbol{i}$ and j defecting, $(2,3)$, is Pareto dominated by $\boldsymbol{i}$ defecting and $\boldsymbol{j}$ cooperating $(3,3)$, so it is **<u>NOT</u>** Pareto optimal.

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

For matrix A, both $\boldsymbol{i}$ and $\boldsymbol{j}$ cooperating together maximizes social welfare as the total payoff is 15, which is the highest total payoff out of all outcomes.

For matrix B, both $\boldsymbol{i}$ and $\boldsymbol{j}$ cooperating, $\boldsymbol{i}$ cooperating and $\boldsymbol{j}$ defecting, and $\boldsymbol{i}$ defecting and $\boldsymbol{j}$ cooperating, all maximizes social welfare as they all give a total payoff of 6, which is the highest possible total payoff out of all outcomes.