**Extensive Auction Games**
**CS404 Agent-based Systems Coursework**

*Introduction*

This project presents the construction of Extensive Auction Games for obtaining paintings by four famous artists: Da Vinci, Rembrandt, Van Gogh and Picasso. In particular, the main goal of the assignment is to create a bidding bot that is able to participate in the auctions and try to overcome other agents there based on certain winning conditions.

At the beginning, an auctioneer creates a room of bots, with number of bots between 2 and 10. Initially, all bots have the same amount of money to spend and are provided with the sequence of paintings to be sold during the game. The auctions could be held in two ways with different objectives and initial circumstances. The goal for the Value Game is to achieve the highest total painting value among all bots in the room after 200 rounds. Also, at each round, the winner pays not the highest bid, but the second highest. In the Collection Game the winner is the one who first manages to collect a minimal target collection of paintings. In this game, the minimal condition is obtaining 3 paintings of any artist, 2 of another artist and 1 of another artist. Here, as opposed to the Value Game, the winner of round pays the highest price for the painting. Since the games require different tactics, for each type of game a corresponding strategy is created, and the description and implementation are provided in this paper. The language used for the implementation code of Extensive Auction Games is Python3.

*Value Game*

*Assumptions*

The strategy for Value Game is based on some assumptions. They are as following:

Assumption 1: Increasing bids at the end of the game may be beneficial. As the game goes on, players will spend their money and their bids would decrease. Thus, since in this type of game the winner pays the second highest bid, it may not only be easier to win at the later rounds but also to spend less money compared to the initial rounds.

Assumption 2: Since the value of each Da Vinci painting is more than the sum of values of every other artist and the value of each Rembrandt painting is also more than the sum of values of Van Gogh and Picasso, the rounds with these items should be handled in a different way, bidding more money on them.

Assumption 3: If none of the bots in the room have money, bidding an amount of 1 is the best strategy.

Assumption 4: If there are only two bots in the room, to win the game it is enough to achieve a value one greater than the total value of the game divided by 2. However, if there are more than two players, the winning value may be equal to the total value of the game divided by the number of players and multiplied by some (special) coefficient greater than 1.

*Strategy*

Initially, the special cases are observed. Firstly, if it is the last round, the whole budget could be bid since after the end of the game the budget left is not considered. Secondly, the budgets of all bots in the room are checked. If all of them have no money left, the bot just bids 1 (Assumption 3). Thirdly, if the current round is before the 30th, the bod bids 10 as it does not want to spend a lot of money at the beginning of game (Assumption 1).

The second part involves calculating the bid. Firstly, the winning value is predicted (Assumption 4). The special coefficient mentioned in Assumption 4 for the game with more than two players is assumed to be equal to the sum of 1 and the number of current round divided by the total amount of rounds. Thus, as game goes on, the special coefficient would increase (Assumption 1). Once the winning value is calculated, it is compared with the sum of the achieved value and the overall value of paintings not presented yet. Here, the bot tries to figure out whether it has to bid more than it is planned or not. If the winning value is greater, the bot bids the planned amount of money multiplied by the special coefficient.

The third part is to handle Da Vinci and Rembrandt paintings as they are special ones. For these cases, at each round with Da Vinci's or Rembrandt's painting the bot tries to predict how much money it is worth to bid. For this, the proportion of the budget to the overall value of paintings not presented yet is multiplied by the value of the current painting. At the end, the received value is compared with the one calculated at the previous part and the maximal of them is finally bid (Assumption 2).

*Collection Game*

*Assumptions*

As for the Value Game, during design and following testing with different conditions, some important assumptions have been made:

Assumption 1: Sometimes it is possible to win a painting even if you do not need it and bid 0 for it. Thus, considering exact numbers (3,2,1) is not enough. It plays a large role in deciding whether the current item is essential or not. Also, this assumption helps to properly answer the questions about how many paintings and what kind of paintings are required.

Assumption 2: Since the budget left at the end of the game is not considered, the bid for an essential painting should be as large as possible.

Assumption 3: The bid of each round should not be greater than the bot's budget divided by the required amount of paintings at the current round. This may help to escape the case when the whole budget is spent without gaining the minimal bundle.

Assumption 4: If there is no benefit in buying the current painting, the bid should be 0. In this case, it is better to save money for the essential paintings.

Assumption 5: Other agents consider special cases of the game as we do. Therefore, no-one bids money for a painting they do not need and bids as much as possible for the essential painting.

Assumption 6: If none of the bots in the room has money, bidding 1 is the best strategy.

It is worth mentioning that all these assumptions are addressed at the strategy.

*Strategy*

At each round, there are two questions: how many paintings and what kind of paintings are required. In order to address them, the first step of the algorithm is to count how many paintings are obtained in the amounts of 3, 2, 1, and 0 so far. However, at this stage Assumption 1 is required, so while counting for an amount of 3, instead of equality (== 3) it is better to have an inequality (>= 3).

The second step consists of considering "special" cases of the auction. "Special" means that it is obvious for the player what to bid and the bid is either 0 or the whole budget. These cases are described as following:

1. Three or more paintings of the current artist are already achieved, so bid 0.
2. The amount of paintings of the current artist is zero and the amount of paintings of any other artist is at least 1, so bid 0. Thus, the aim is to achieve a minimal bundle without paying attention to the current artist(Assumption 4).
3. There are at least two artists whose paintings are obtained in the amount of 3 or greater, but there are not any items of the current artist. It would complete the minimal bundle, so bid the whole budget(Assumption 2).
4. There is at least one artist whose paintings are obtained in the amount of 3 or greater, and at least one artist whose paintings are obtained in the amount of 2, but there are not any items of the current artist. It would complete the minimal bundle, so bid the whole budget(Assumption 2).
5. Correlated to case 4. There is at least one artist whose paintings are obtained in the amount of 3 or greater, and at least one artist whose paintings are obtained in the amount of 2, and there are items of the current artist. Then the current item is not important, so bid 0(Assumption 4).
6. There is at least one artist, whose paintings are obtained in the amount of 3 or greater, no artist whose paintings are obtained in the amount of 2, and at least two artists whose paintings are obtained in the amount of 1 (so the collection now is 3 or greater, 1, 1, x). The paintings of the current artist are achieved in the amount of 1. It would complete the minimal bundle, so bid the whole budget(Assumption 2).

7. Correlated to case 6. There is at least one artist, whose paintings are obtained in the amount of 3 or greater, no artist whose paintings are obtained in the amount of 2, and at least two artists whose paintings are obtained in the amount of 1 (so the collection now is 3 or greater, 1, 1, x). There are not any items of the current artist, so it is not important, and we bid 0(Assumption 4).
8. There are not any artists whose paintings are obtained in the amount of 3 or greater, at least two artists whose paintings are obtained in the amount of 2, and either at least one artist whose paintings are obtained in the amount of 1 (so the collection is 2, 2, 1, x) or the amount of artists whose paintings are obtained in the amount of 2 is strictly more than 2 (so the collection is 2, 2, 2, x). The paintings of the current artist are achieved in the amount of 2. It would complete the minimal bundle, so bid the whole budget(Assumption 2).
9. Correlated to case 8. There are not any artists, whose paintings are obtained in the amount of 3 or greater, at least two artists whose paintings are obtained in the amount of 2, and either at least one artists whose paintings are obtained in the amount of 1 (so the collection is 2, 2, 1, x) or the amount of artists whose paintings are obtained in the amount of 2 is strictly more than 2 (so the collection is 2, 2, 2, x). The paintings of the current artist is not achieved in the amount of 2. It is not important, so bid 0(Assumption 4).
The special cases are observed, and if the current situation is one of them, the bid is obvious and does not require the next steps.
The third step is to calculate the required amount of paintings, as required in Assumptions 1 and 3.
The fourth step is to predict the bid of each other bot and find the maximum value of them(the predicted maximum bid). For each bot all special cases are checked (Assumptions 2,4,5). If bot is not in a special situation, it is assumed that it would bid the bot's budget divided by its required amount of paintings at the current round. However, if all bots have no money, the predicted maximum bid is assumed to be 1 (Assumption 6).
The last step is to compare the predicted maximum bid and the bot's budget divided by the required amount of paintings at the current round and bid the minimum of them (Assumption 3).

*Evaluation and Conclusion*
The two strategies are described in detail in this document. Both designed strategies perform well in a variety of conditions, such as several types of bots and different numbers of bots in the room. As testing shows, the bot typically wins more than 40 out of 50 games for the Collection Game and more than 45 out of 50 games for the Value Game. These results may not be that reliable since the other bots in the room are not well designed. However, the results have been analysed and some conclusions have been made. For the Collection Game, in losing scenarios, the bot usually aims to achieve a painting that does not appear a lot, thus wasting time and allowing other bots to collect the minimal bundle. It is caused by the lack of consideration of the painting order. For the Value Game, in some cases, the losing method usually involves spending all the budget on Da Vinci's or Rembrandt's paintings, and being without sufficient budget at the final rounds of the game, allowing competitors to get paintings for a cheap price.

*Future work*
Due to lack of time, some things are not considered in this work. However, they may improve performance.
For the Collection Game, the main improvement could be achieved by taking into account the paintings order. For example, it may be helpful when creating the boundary at Assumption 3. While dividing the bot's budget by the required amount of paintings, attention could be paid to the occurrences of the paintings. Furthermore, special cases require considering the sequence and occurrences as well. It would help to avoid situations where the bot has to get the essential painting and bids the whole budget for it, but there are no more paintings of that artist.
For the Value Game, creating different strategies for different amounts of bots in the room might improve the performance since it has a direct impact on the special coefficient. The amount of money bid at the beginning of

the game could be observed more carefully as well as the number of first rounds to be skipped. Taking into consideration the values of each artist (not only Da Vinci and Rembrandt) may also be helpful.