Multi-agent Systems Report 1
Group 1

Ralph Dreijer, 6068855
Haico Wong, 6046983
Tiago dos Santos Silva Peixoto Carriço, 2311143
Madhav Girish Nair, 1692954
Alexo Castro Yáñez, 2934213

March 1, 2024

1 Preparation: Analyse Negotiation Domain

1.a

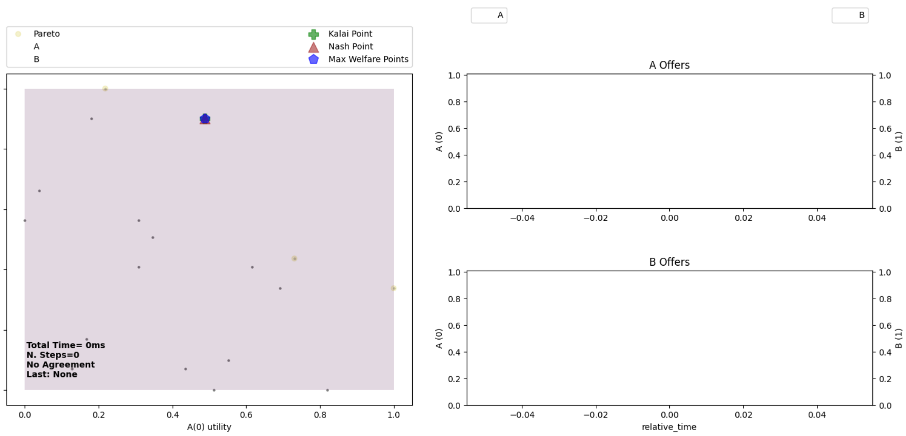

Figure 1: Pareto efficient frontier

1.b

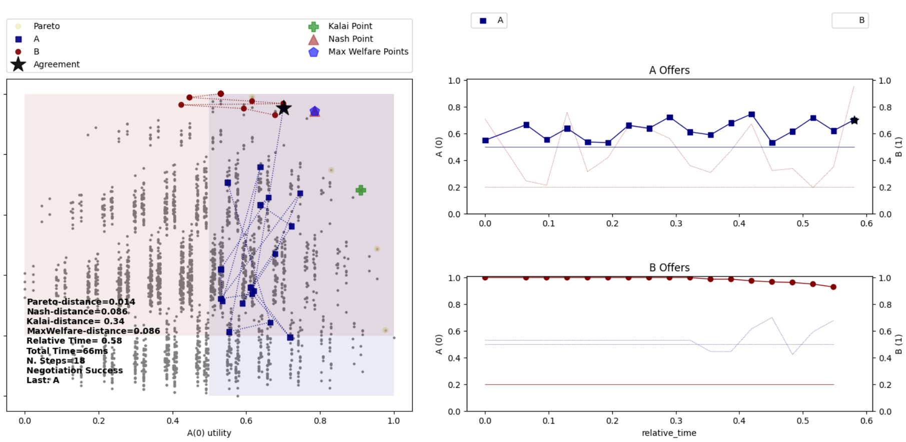

Figure 2: Party Negotiation

By lowering the reservation value from 0.5 to 0.2, `AwesomeNegotiator` showed a greater willingness to lower the utility it got from its bids. Furthermore, the variance of values went up as the reservation value went down. `Boulware` also showed greater willingness to make bids that better suit its opponent, when the reservation value is lower (0.2 instead of 0.5). In contrast with `AwesomeNegotiator` however, it barely concedes on utility it gets from its own bids.

In the final negotiation, as shown in Figure 2, the reservation value for agent A is 0.5 and for agent B it is 0.2.

2 Design a Negotiation Strategy

2.a

The following three metrics can be used to measure the performance of the agent after a negotiation has ended:

- **Pareto distance:** Since utilities of both agents are public, they can exactly compute bids in the Pareto frontier. Optimal agents would only in principle accept bids in the Pareto frontier. So the smaller the Pareto distance, the better the score. The inverse of the Pareto distance can also be used to indicate a higher score for smaller distance, which could be more intuitive as a score.
- **Utility:** In the end, we mostly care about consistently scoring a high utility throughout all the negotiations, as this would give us a high average utility score, and this is what is going to decide who will win the competition.
- **Normalized advantage:** Since the reservation value is randomly determined, it should be considered when calculating the performance, by considering how well the agent performs for a specific reservation value. The numerator for the Equation 1 below is also referred to as the advantage.

$$\text{Normalized advantage} = \frac{\text{obtained utility} - \text{reservation value}}{\text{maximum utility} - \text{reservation value}} \tag{1}$$

This essentially indicates of all the possible utility that the agent could have obtained, how much did it obtain.

2.b

We think that as the common deadline and both utilities are public, the negotiation might become a fight of patience between agents because the bid space does not need to be explored by the agents in order to get knowledge, and each agent can assume that its opponent will stay until the established end, as there are no discounts meaning no benefit of ending a negotiation early without an agreement.

Whoever agent makes the last bid can be computed when starting the negotiation using information such as who starts the negotiation and the parity of the total number of time steps until the deadline. We claim that the agent that makes the last bid has an advantage position in the negotiation, as it can force the opponent to a take-or-leave situation in the last bid(s), if that point is reached, because no one accepted an offer. We therefore propose two different strategies depending on whether we do the last bid or we do not, for both bidding and accepting.

1. We have the last bid: Stubborn strategy to try to force opponent into take-or-leave situation. We don't want, roughly, to accept bids neither propose bids with high utility for opponent. We rely on opponent's reservation value prediction and offer it some bid with high utility for us and utility for them higher than their reservation value.
2. They have the last bid: We need to increase the bidding range and the acceptance to be able to find an agreement before getting too close to the deadline that the opponent can take advantage of doing last bid.

Bidding strategy

As utilities are public, the Pareto frontier is completely known by both agents, so we expect agreements to be really close to it. Therefore, at start of the negotiation, we will make a set of offerable bids that are (close to) Pareto optimal and form a fairly uniform distribution in terms of our agents and opponent's utility, as that allows us to threshold precisely when looking for bids to offer. With the aim of giving as little information as possible to the opponent about our reservation value, we will travel trough the offerable bids starting with the ones with highest utility for us towards our reservation value. We also think that it might be useful to offer some misinformation bids that we do not expect the opponent to accept to try to confuse it about our reservation. More specifically, we will have two variations of bidding strategies based on whether we have the last bid or not.

Opponent has last bid: In this scenario, for the first half of the negotiation, we will implement a (fake) stubborn strategy. The offers made from our part will be recycling the bids above the estimated reservation value of the opponent as well as the Nash point, along the Pareto efficient front. During this half, all bids offered by the opponent are stored and ordered in descending order of our utility. However, since we are at a disadvantage, given that we do not have the final bid, in the latter half of the negotiation, we will implement a strategy that proposes the stored bids from the first half in order. Since these are bids proposed by the opponent, a rational agent is likely to accept one from the list. Going in decreasing utility also increases our changes that the opponent accepts an offer. We are however trying to find a strategy that uses the concession curve to model the bids as it might model a more natural approach to conceding with more advantage to us rather than obliging fully to opponents bids. Further research is being done on this strategy.

We have last bid: The bidding strategy will be stubborn for most of the time, proposing offerable bids that have an utility for our agent higher than the one given by the Nash equilibrium and the reservation values of both agents. Last bids are crucial. When we get to the last (absolute/relative) amount of bids, the bidding strategy could change a bit in our favor, proposing bids with really high utility for us and opponent's utility above their reservation value. At this point the utility for ourselves in the bids might increase with respect to previous offers. As we want to close an agreement before the end, in the very final last steps we will offer bids that are higher in utility for opponent than its predicted reservation value with a certain increasing margin, so for a certain opponent utility that we want to offer we compute the best bid for us and offer it.

Opponent model

For the opponent model, our plan is to divide the entire possible utility space of $[0, 1]$ in a predetermined number of intervals. For each interval, we plan to fit a curve using a possible reservation value and the opponent's current bids. These fitted curves will be compared with the opponent's bids and the curve that most closely matches those bids will be assumed to be the most correct one, allowing us to predict a possible reservation value: the value that was used to fit this curve. Further research is required to decide the algorithm used to fit these curves, since there must be careful consideration regarding the trade-off between, for example, the computational complexity of Bayesian modelling and the simplicity of linear regression. This strategy follows Yu, Ren and Zhang [2], with the additional simplicity that the deadline of the negotiation is known, and, as such, the intervals for the predicted reservation value are of one dimension, instead of the original 2-dimensional space that also considers possible different deadlines.

Acceptance strategy

In both the following strategies, we will also fake our reservation value. The faking will be done by setting a minimum utility value higher than our reservation value, below which no offers will be accepted. This will potentially give us a slight edge by making the opponent offer better bids that what they could have offered. This faking is eliminated in the second half of the negotiation, if no negotiation has been reached.

Opponent has last bid: In this scenario, we are at a disadvantage, making it more advisable for us to have a concession strategy that accepts before the deadline. Hence, we will have a strategy that follows the Conceder strategy of the `IAMhaggler` agent [3]. The concession rate is dictated by the polynomial function defined in Equation 2:

$$U_p(t) = U_0 - (U_{min} - U_0)\frac{t}{t_{max}}^{1/\beta} \tag{2}$$

U_0 here is the initial utility and U_{min} is the estimate of the reservation value, t_{max} is the negotiation deadline, t is the current time step, and the β parameter alters the rate of concession. There are three partition values to the β parameter: $\beta < 1$ (tough), β=1 (linear, no alteration) and $\beta > 1$ (lenient). Any bids with utility equal to or above the proposed utility from Equation 2 will be accepted. The idea is also to split the negotiation into phases (2 or 3) where the rate of concession goes from lenient to tough, so our agent is more desperate to concede closer to the deadline, or to have a continuously decreasing rate of concession.

We have last bid: In this scenario, the idea is that we do not mind the bids getting to the deadline, in fact it might be preferable in some situations. Therefore, we will implement a stubborn strategy, one where we take control of the bids. This means that we will only accept bids above or equal to the Nash equilibrium point. However, this depends on the estimate of the opponents reservation value considering the chance that the reservation estimate is above the Nash point. Therefore, there will be a higher priority given to the reservation estimate compared to the Nash point. Therefore, the bid will only be accepted if the utility that we gain is higher than our concession rate at that given time (minimum utility that would be accepted at that phase) and the Nash point. This is a very greedy strategy which works in theory but more alterations can and will be made once the strategy is implemented and tested. If the deadline is reached, then an offer will be made based on the bidding strategy mentioned above, where the bid gets us the highest possible utility with the opponent getting any utility above their estimated reservation value.

References

[1] J.R. De Ruiter A.S.Y. Dirkzwager M.J.C. Hendrikx. "TheNegotiator: A Dynamic Strategy for Bilateral Negotiations with Time-Based Discounts". In: *Complex Automated Negotiations: Theories, Models, and software Competitions* (2013), pp. 217–221.

[2] Minjie Zhang Chao Yu Fenghui Ren. "An Adaptive Bilateral Negotiation Model Based on Bayesian Learning". In: *Complex Automated Negotiations: Theories, Models, and software Competitions* (2012), pp. 75–93.

[3] Colin R Williams et al. "Iamhaggler: A negotiation agent for complex environments". In: *New Trends in Agent-based Complex Automated Negotiations* (2012), pp. 151–158.