Accepting Optimally in Automated Negotiation with Incomplete Information*

Extended Abstract

Tim Baarslag Koen Hindriks

Interactive Intelligence Group, Delft University of Technology,
Mekelweg 4, Delft, The Netherlands
{T.Baarslag, K.V.Hindriks}@tudelft.nl

1 Introduction

Suppose two parties A and B are conducting a negotiation, and B has just proposed an offer to A. A is now faced with a decision: she must decide whether to continue, or to accept the offer that is currently on the table. On the one hand, accepting the offer and ending the negotiation means running the risk of missing out on a better deal in the future. On the other hand, carrying on with the negotiation involves a risk as well, as this gives up the possibility of accepting one of the previous offers [1]. How then, should A decide whether to end or to continue the negotiation?

Of course, A's decision making process will depend on the current offer, as well as the offers that A can expect to receive from B in the future. However, in most realistic cases, agents have only incomplete information about each other, and therefore, the proposals that A will receive are necessarily uncertain. Moreover, predicting B's future offers is only part of the solution: even when A can predict B's moves reasonably well, A still has to decide how to put this information to good use. In other words, even when a probability distribution over the opponent's actions is known, it is not straightforward to translate this into effective negotiation behavior.

The main contribution of our work is that we address both of A's problems: first, at every stage of the negotiation, we provide a technique to estimate the bidding behavior of various opponent classes by modeling A's dilemma as a stochastic decision problem. For particular opponent classes we are able to provide precise models, and to formulate exact mathematical solutions to our problem. For the second step, using the ranges found earlier, we borrow techniques from optimal stopping theory to find generic, optimal rules for when to accept against a variety of opponents in a bilateral negotiation setting with incomplete information. The solutions proposed are optimal in the sense that there can be no better strategy in terms of utility.

2 Optimal Stopping in Negotiation

We can frame the problem of accepting a bid as an optimal stopping problem, in which an agent is faced with the dilemma of choosing when to take a particular action, in order to maximize an expected reward. In such problems, observations are taken sequentially, and at each stage, one either chooses to stop to collect, or to continue and take the next observation.

*The full version of this paper appears in [2].

The model of bid reception is as follows: at each of a total of N rounds, we receive a bid, which has an associated utility, or value, drawn from a random variable over the unit interval. At this point, we must decide whether to accept the bid, or not. Once we accept, the deal is settled and the negotiation ends. If we continue, then there is no possibility of recalling passed-up offers; i.e., previous offers are unavailable unless they are presented to us again. Hence, at each round, we must decide to either continue or to stop participating in the negotiation, and we wish to act so as to maximize the expected net gain. Once an offer is turned down, and we decide to wait for another bid, the total number of remaining observations decreases by one.

At every stage, the current situation may be described by a *state* (j, x), which is characterized by two parameters: the number of remaining observations $j \in \mathbb{N}$, and the latest received offer $x \in [0, 1]$.

3 Results and Discussion

Let the utility distribution with j rounds remaining be given by a random variable X_j, with associated distribution function F_j. We can think of X_j as the possible utilities we receive when the opponent makes bids, and $F_j(u)$ represents the probability of receiving a bid with utility less than or equal to u. The expected payoff is then given by

$$V(j, x) = \max(x, E(V(j-1, X_{j-1}))),$$

where we abbreviate the second term $E(V(j-1, X_{j-1}))$ as v_j. This represents the expected value of rejecting the offer at (j, x), and going on for (at least) one more period. Thus, using the substitution, we get

$$v_j = E(\max(X_{j-1}, E(V(j-2, X_{j-2}))),$$

which leads to the following recurrence relation:

$$\begin{cases} v_0 = 0, \\ v_j = E(\max(X_{j-1}, v_{j-1})). \end{cases}$$

We can prove that we can rewrite the recurrence relation describing v_j as follows:

$$v_j = v_{j-1} + \int_{v_{j-1}}^{\infty} (1 - F_{j-1}(t))\, \mathrm{d}t.$$

Thus, if we know the distribution F_j for every j, we can compute the values v_j using the above recurrence relation. Then, deciding whether to accept an offer x is simple: if $x \geq v_j$ we accept, otherwise we reject the offer.

Of course, in a general setting we do not know the opponent's behavior, and in that case we require a method to determine the distributions X_j for every remaining round j. In that case, the solutions are only as good as the estimation of the opponent's behavior. We can show however, that our techniques are robust, in the sense that they also perform well when equipped with state of the art opponent strategy prediction techniques. This demonstrates that our optimal stopping mechanism is a valuable element of a negotiating agent's strategy, whether in a complete or incomplete information setting.

References

[1] Tim Baarslag, Koen Hindriks, and Catholijn Jonker. Effective acceptance conditions in real-time automated negotiation. *Decision Support Systems*, 2013.

[2] Tim Baarslag and Koen V. Hindriks. Accepting optimally in automated negotiation with incomplete information. In *Proceedings of the 2013 International Conference on Autonomous Agents and Multi-agent Systems*, AAMAS '13, pages 715–722, Richland, SC, 2013. International Foundation for Autonomous Agents and Multiagent Systems.