

Snake: An Opponent Modeling Agent with Concealing Bidding Strategy

1. Introduction

Snake is a negotiation agent developed for ANL 2026. The agent combines opponent modeling, entropy-based issue weight estimation, Pareto frontier approximation, and a concealing bidding strategy. Its primary objective is to maintain high utility throughout most of the negotiation while estimating the opponent's preferences and selecting offers that balance both parties' interests.

The submitted version adopts a strong Boulware concession strategy and relies on estimated opponent utilities to guide offer generation and acceptance decisions.

2. Opponent Modeling

2.1 Sliding Window Preference Learning

Snake models the opponent using a sliding window containing the most recent 20 offers. Older observations are discarded to allow the model to adapt to recent negotiation behavior.

For each issue, the agent records the frequency of observed values within the window and uses this information to estimate the opponent's preferences.

2.2 Entropy-Based Issue Weight Estimation

The importance of each issue is estimated using information entropy.

The intuition is that values on important issues tend to remain stable throughout the negotiation, resulting in lower entropy. Conversely, issues that frequently change are considered less important.

For each issue i , an inverse entropy score is computed and normalized to obtain estimated issue weights. To avoid abrupt changes, the weights are updated using an Exponential Moving Average (EMA).

This approach allows the agent to dynamically identify which issues appear most important to the opponent.

2.3 Frequency-Based Utility Estimation

For each issue value, the agent calculates a normalized frequency score:

$$score(v) = \frac{freq(v)}{\max(freq)}$$

The estimated opponent utility is obtained as the weighted sum of these normalized frequencies using the entropy-derived issue weights.

2.4 Recent Preference Model

In addition to overall frequencies, Snake evaluates how often each value appears in the most recent offers.

This component captures short-term preference trends that may emerge during negotiation.

2.5 Transition-Based Model

Snake also records values that remain unchanged between consecutive offers.

The assumption is that values repeatedly preserved by the opponent are likely to be important. These observations provide an additional estimate of issue-value desirability.

2.6 Combined Opponent Utility

The final opponent utility estimate is computed as a weighted combination of three models:

$$U_{opp} = 0.4 \cdot U_{freq} + 0.4 \cdot U_{recent} + 0.2 \cdot U_{transition}$$

This combined model is used throughout the negotiation for offer evaluation and Pareto frontier construction.

3. Concession Strategy

Snake employs a strong Boulware concession strategy.

The target utility at negotiation time t is defined as

$$u(t) = u_{max} - (u_{max} - u_{res})t^{60}$$

where u_{max} is the maximum achievable utility and u_{res} is the reservation value.

The exponent $e = 60$ causes the agent to maintain near-optimal utility for most of the negotiation and concede only near the deadline.

4. Offer Generation

4.1 Candidate Selection

The agent first identifies all outcomes whose utility exceeds the current target utility.

Initially, the search space consists of all rational outcomes. Once sufficient observations are collected, the agent may replace this search space with an estimated Pareto frontier.

4.2 Concealing Strategy

A distinctive feature of Snake is its concealing bidding strategy.

The agent tracks how many times each offer has been proposed and preferentially selects offers that have been used less frequently.

The motivation is to reduce the amount of preference information revealed to the opponent and to avoid repeatedly exposing highly preferred outcomes.

Among acceptable offers, the agent first selects those with the minimum visit count and then evaluates them using additional criteria.

4.3 Exploration Using UCB

During the early stage of negotiation ($t < 0.4$), Snake incorporates an Upper Confidence Bound (UCB) exploration bonus:

$$UCB = \sqrt{\frac{\log N}{n}}$$

where N is the total number of generated offers and n is the number of times a specific offer has been proposed.

This encourages exploration of alternative offers and helps gather information about the opponent's behavior.

4.4 Nash-Product-Based Selection

Candidate offers are ranked using an estimated Nash product:

$$NP = (U_{self})^\alpha (U_{opp})^{1-\alpha}$$

where U_{self} is the agent's utility and U_{opp} is the estimated opponent utility.

The parameter α changes over time:

- 0.65 for early negotiation
- 0.60 for middle negotiation
- 0.55 for late negotiation

As the deadline approaches, greater emphasis is placed on the opponent's estimated utility to increase agreement likelihood.

5. Pareto Frontier Approximation

Every 20 observed opponent offers, Snake constructs an estimated Pareto frontier.

Each rational outcome is evaluated using:

- The agent's true utility
- The estimated opponent utility

The outcomes are sorted according to the agent's utility, and non-dominated candidates are retained.

The resulting frontier serves as a reduced search space for future offer generation, allowing the agent to focus on outcomes that appear beneficial to both parties.

6. Endgame Strategy

Near the deadline, Snake prioritizes outcomes that satisfy two conditions:

1. High utility for itself.
2. Sufficiently high estimated utility for the opponent.

The agent also gives additional preference to outcomes that have previously been proposed by the opponent, as such outcomes are more likely to be accepted.

This mechanism attempts to maximize agreement probability while preserving a high utility level.

7. Acceptance Strategy

Snake combines several acceptance criteria.

7.1 AC_{next}

The primary acceptance mechanism is based on the AC_{next} principle.

An offer is accepted when its utility exceeds the utility of the agent's planned next offer, possibly with a small time-dependent margin.

This prevents unnecessary rejections of favorable offers.

7.2 Target Utility Acceptance

An offer is also accepted if it exceeds the current target utility level.

The acceptance margin gradually decreases as the deadline approaches.

7.3 Deadline Protection

To avoid negotiation failure, any offer above the reservation value is accepted when the negotiation is extremely close to the deadline ($t \geq 0.99$).

8. Discussion

The proposed agent combines several complementary mechanisms:

- Sliding-window opponent modeling
- Entropy-based issue weight estimation
- Multi-model opponent utility prediction

- Pareto frontier approximation
- Nash-product-based offer selection
- Concealing bidding through inverse-frequency selection

The strongest characteristic of the submitted version is its emphasis on maintaining high utility while limiting preference revelation. The agent postpones concession until very late in the negotiation and relies heavily on opponent modeling to identify mutually beneficial outcomes.

However, the effectiveness of the approach depends on the quality of the estimated opponent utility function. Inaccurate preference estimation may reduce the quality of the approximated Pareto frontier and the resulting offer choices.

9. Conclusion

Snake is an ANL 2026 negotiation agent that combines entropy-based opponent modeling, Pareto frontier approximation, Nash-product optimization, and a concealing bidding strategy. The agent employs a strong Boulware concession policy and uses estimated opponent preferences to guide both bidding and acceptance decisions. By integrating multiple sources of preference information while reducing preference exposure, Snake aims to achieve high individual utility without sacrificing agreement quality.