Automated Negotiation

A Tutorial

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Outline

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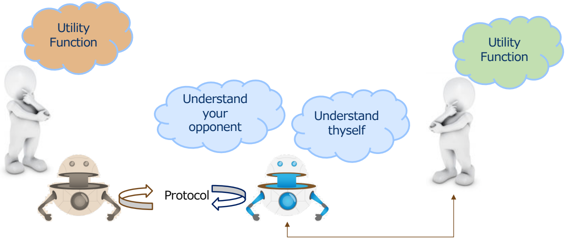

- A method to achieve agreement among self-interested actors.
- Negotiation is important $\rightarrow$ win-win agreements.
- Automatic Negotiation $\rightarrow$ $$$
  - smart contracts, resource allocation, SCM, etc

Definition

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Negotiation

$$\Upsilon \equiv \left(A, T, N, \Omega, M, \left\{\tilde{P}_a, P^n_{ab}\ \forall 1 \leq a, b \leq A,\ 0 \leq n \leq N\right\}\right)$$

$A \in \mathbf{I}^+ - \{1\}$: Number of agents/actors.

$T \in \mathbf{R} \bigcup \infty$: The allowed time of the negotiation.

$N \in \mathbf{I} \bigcup \infty$: The allowed number of rounds of the negotiation.

$\Omega \equiv \{\omega_j\} \bigcup \phi$: Possible outcomes including ϕ signifying disagreement.

M The negotiation *mechanism* (protocol) defining rules of encounter for agents.

$\tilde{P}_a$: Preferences of **actor** a.

P^n_{ab}: Information available to **agent** a about preferences of **actor** b at the beginning of round n.

Known Preferences Assumption

$$P^n_{aa} = \tilde{P}_a$$

Preference Representations

Preference Types

Partial Ordering $\succcurlyeq$ Defines preference as a partial ordering over Ω.

Ranking A total ordering over a subset of Ω.

Utility Function $\tilde{u}$ Defines a numeric value for every outcome in Ω.

$$\tilde{u} : \Omega \rightarrow \Re$$

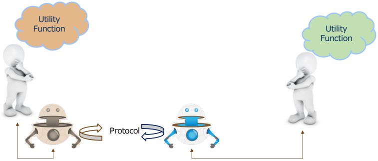
Probabilistic Utility Function u Defines a distribution of values.

$$u : \Omega \times \Re \rightarrow [0, 1]$$

Known Ufun Assumption

$$u_a^t(\omega, x) = u_a^0(\omega, x) = \begin{cases} 1 & \tilde{u}(\omega) = x \\ 0 & otherwise \end{cases}$$

Components of the Negotiation Problem



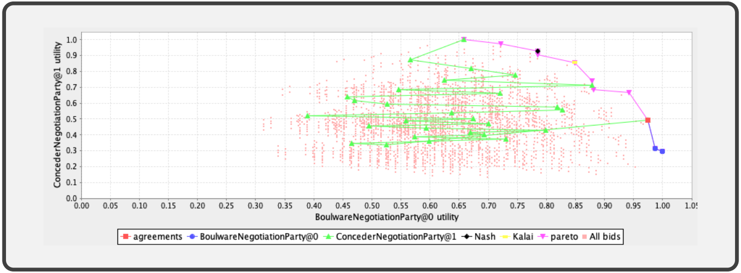
Negotiation Protocol Defines how negotiation is to be conducted [Mechanism Design Problem].

- Alternating Offers Protocol
- Single Text Protocol
- ...

Negotiation Strategy Defines how an agent behaves during the negotiation [Effective Negotiation Problem].

- Time-based strategies: Boulware, conceder, ...
- Tit-for-tat variations
- ...

Important Concepts



Pareto Frontier Outcomes that cannot be improved for one actor without making another worse off.

Welfare Total utility received by all actors.

Surplus utility Utility above disagreement utility.

Nash Equilibrium Strategies that are best responses to each other.

Sub-game Perfect Equilibrium A Nash Equilibrium in every sub-game.

Types of Automated Negotiation Problems

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Negotiator type

1. Agent-Agent negotiation
2. Agent-Human negotiation

Number of negotiators

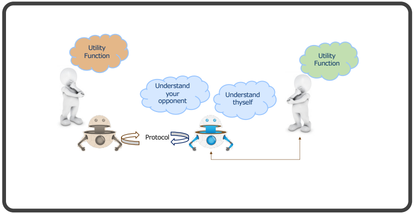
1. Bilateral negotiation
2. Multilateral negotiation

Outcome Space

1. Single Issue: $\Omega = \{\omega_0, \omega_1, ...\}$
2. Multiple Issues: $\Omega = \prod_{i=1}^{n_i} I_i$

Protocol Type

1. Mediated
2. Unmediated



Platforms [Used in this tutorial]

Genius

a Java-based negotiation platform to develop general negotiating agents and create negotiation scenarios. The platform can simulate negotiation sessions and tournaments and provides analytical tools to evaluate the agents' performance.[a]

[a] Lin et al., "Genius: An Integrated Environment for Supporting the Design of Generic Automated Negotiators".

NegMAS

a Python-based negotiation platform for developing autonomous negotiation agents embedded in simulation environments.[a]

[a] Mohammad, Greenwald, and Nakadai, "NegMAS: A platform for situated negotiations".

Outline

Unmediated Protocols

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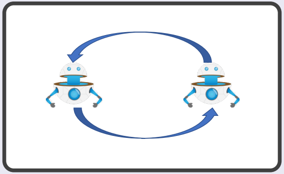
Main Features

- No central coordinator.
- Agents negotiate by exchanging *messages*.
- All proposals come from negotiators.



Examples

Nash Bargaining Game Single iteration, single issue, bilateral protocol with complete information.

Rubinstein Bargaining Protocol Infinite horizon, single issue, bilateral protocol with complete information[a].

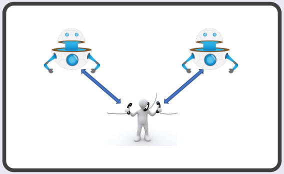
Stacked Alternating Offers Protocol Finite horizon, multi-issue, multilateral protocol with partial information[b].

[a] Rubinstein, "Perfect equilibrium in a bargaining model".
[b] Aydoğan et al., "Alternating offers protocols for multilateral negotiation".

Mediated Protocols

Main Features

- Has A central *mediator*.
- Agents negotiate by exchanging *messages* with the *mediator*.
- Proposals can come from the mediator or the negotiators.



Examples

Single Text Protocol The mediator proposes a single hypothetical agreements, gets feedback about it and modifies it based on this feedback.

Outline

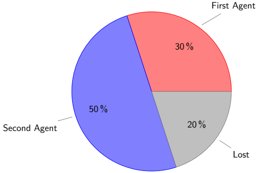
Nash Bargaining Game: Description

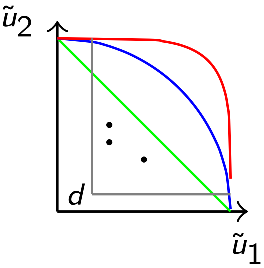
A single-step full-information bilateral negotiation with $\Omega = [0,1]^2$ and two utility functions $(\tilde{u}_1, \tilde{u}_2)$ such that:

- A (usually convex) feasible set of agreements F. A common example is to define F as all the outcomes for which the total utility received by negotiators is less than or equal to one:

$$F = \{(\omega_1, \omega_2) | \tilde{u}_2(\omega_2) + \tilde{u}_1(\omega_1) \leq 1\}.$$

- A disagreement point $d \equiv \tilde{u}_1(\phi) + \tilde{u}_2(\phi) \in \Re^2$ which is the utility value received by the two players in case of disagreement (reserved values).





Nash Bargaining Game: Solution

- Nash Point (1950): The point at which the product of surplus utility (above reservation value) of negotiators is maximized

$$\arg\max_{\omega_1,\omega_2} \prod_{i=1}^{2} \left(\tilde{u}_i(\omega_i) - \tilde{u}_i(\phi)\right)$$

- Kalai-Smorodinsky Point (1975): The Pareto outcome with equal ratios of achieved surplus utility and maximum feasible surplus utility

$$\arg\max_{\omega_1,\omega_2\in F} (\omega_1 + \omega_2) \text{ s.t. } \left(\frac{\tilde{u}_1(\omega_1) - \tilde{u}_1(\phi)}{\tilde{u}_2(\omega_2) - \tilde{u}_2(\phi)} = \frac{\max_{v\in F}(\tilde{u}_1(v)) - \tilde{u}_1(\phi)}{\max_{v\in F}(\tilde{u}_2(v)) - \tilde{u}_2(\phi)}\right)$$

- Kalai Point (1977): The Pareto outcome maximizing the utility for the unfortunate player. Defining P as the Pareto front

$$\arg\max_{\omega_1,\omega_2\in P} \min_{i\in\{1,2\}} \left(\tilde{u}_i(\omega_i) - \tilde{u}_i(\phi)\right)$$

Rubinstein's Bargaining Protocol: Description

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- Two agents sharing a pie.
- Each agent is under a different time-pressure: $\tilde{u}_i^{t+\Delta}(\omega) < \tilde{u}_i^t(\omega)$.
  Examples of time-pressure:
  - **Exponential** $\tilde{u}_i^{t+\Delta}(\omega) = \delta_i^\Delta u_i^t(\omega)$.
  - **Linear** $\tilde{u}_i^{t+\Delta}(\omega) = u_i^t(\omega) - \Delta c_i$
- Actor's initial utility is the assigned part of the pie: $\tilde{u}_i^0 = \omega_i$.
- Time pressure and utility information are common knowledge.
- No externally imposed time-limit.
- Zero reservation value: $u_i^\tau(\phi) = 0 \; \forall \tau$.

Main Result

There is a unique *sub-game perfect equilibrium* that requires a single negotiation step in most cases.

Rubinstein's Bargaining Protocol: Equilibrium

Exponential Discounting

The negotiation ends in **one step** with the first agent proposing and the second agent accepting *for asymmetric cases*:

$$(\omega_1^*, \omega_2^*) = \left(\frac{1-\delta_2}{1-\delta_1\delta_2}, \frac{\delta_2(1-\delta_1)}{1-\delta_1\delta_2} \right)$$

Linear Discounting

The negotiation ends in **one step** with the first agent proposing and the second agent accepting:

$$(\omega_1^*, \omega_2^*) = \begin{cases} (c_2, 1-c_2) & c_1 > c_2 \\ (x, 1-x)\ \forall x \in [c_1, 1] & c_1 = c_2 \\ (1, 0) & c_1 < c_2 \end{cases}$$

Negotiation With Incomplete Information

Impossibility Result

Define a good mechanism as:

- Incentive compatible.
- No external subsidy.

Assuming rationality, there is *no* good mechanism that can guarantee agreement when it is dominant[a].

[a] Myerson and Satterthwaite, “Efficient mechanisms for bilateral trading”.

Example

- A buyer values a product at v.
- A seller can create the product at cost c.
- $v > c$.
- There is no way to design a good mechanism that results in agreement for all v, c values.

Outline

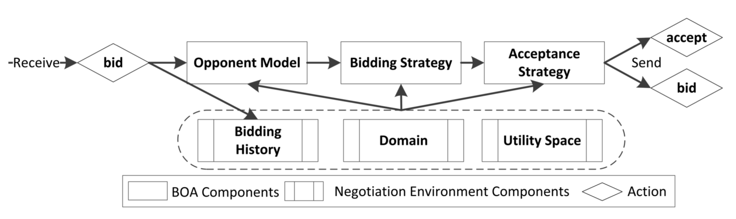
Stacked Alternating Offers Protocol[1]

```python
n_agreed, current = 0, randint(0, n_agents)
offer = agents[current].offer()
```

```python
while True:
    if timedout():
        return 'TIME_OUT'
    current = (current + 1) % n_agents
    response = agents[current].respond(offer)
    if response == 'accept':
        n_agreed += 1
    if n_agreed == n_agents:
        return offer  # agreement
    elif response == 'end_negotiation':
        return 'FAILURE'
    elif response == 'reject':
        offer = agents[current].offer()
```

[1] Aydoğan et al., "Alternating offers protocols for multilateral negotiation".

Negotiator Components[2][3]



OBA Atchitecture

Opponent Model predicts opponent behavior.

Bidding Strategy Generates new bids.

Acceptance Strategy Decides when to accept.

[2] Baarslag et al., "Decoupling Negotiating Agents to Explore the Space of Negotiation Strategies".

[3] Supported by Genius

Bidding Strategy

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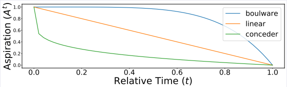
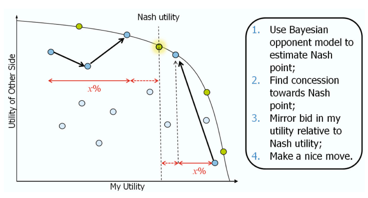
Time-based strategies

Offer an outcome with a utility just above the current *aspiration level* which is monotonically decreasing.



(Nice) Tit-for-Tat (bilateral)

Concede as much as the opponent and do not retaliate.[a]



[a] Baarslag, Hindriks, and Jonker, "A tit for tat negotiation strategy for real-time bilateral negotiations".

Opponent Modeling

What is being modeled?

- Opponent preferences.
- Opponent strategy.
- Acceptance probability.
- Future offers.
- Opponent Type.

When is it modeled?

- Before the negotiation.
- During the negotiation.

Data

- This negotiation vs. past negotiations.
- This opponent vs. this opponent group vs. others.
- Exchanged offers vs. agreements

Opponent Model: Example

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Bayesian Learning

Hypothesis A hypothesis about the opponent's behavior.

Evidence Behavior of the agent (e.g. its offers/rejections).

$$P(H|E) = \frac{P(E|H)P(H)}{P(E)}$$

Example

Hypothesis space: Utility function as a weighted sum of basis functions

$$u(\omega) = \sum_{i=1}^{n} \alpha_i f_i(\omega_i; \sigma_i)$$

Evidence: Rejection and offers (assuming a strategy).

Acceptance Model

Examples

Accept if the utility of the offer $\succ$

- **Previous** my last offer.
- **Current** what I am about to offer.
- **Expected** the best offer I expect to receive (needs an opponent model).
- **Threshold** an offer with the current utility threshold (τ).
  - **Constant** May be a fraction of maximum utility.
  - **Time-based** Monotonically decreasing with time.
  - **Predictive** Predicts the expected/max utility on rejection (e.g. Gaussian Process).

Outline

1. Negotiation
2. Negotiation Protocols
3. Game Theoretic Analysis
4. Strategies for SAOP
5. Challenges
   - Negotiation Under Uncertainty
   - Preference Elicitation
   - Concurrent Negotiation

Outline

Negotiation Under Uncertainty

The challenge

How to negotiate when you have *partial* information about your actor's utility function?

The Game

- ANAC 2019 agent game @ IJCAI introduced the first competition in this domain.
- Input is a ranking of a subset of the outcomes.

Example Solutions

- Regress the utility of all outcomes using a polynomial model.
- Use a GP to create a probabilistic ufun.

Outline

Preference Elicitation

The challenge

How to reduce Uncertainty in user preferences:

- before negotiation (offline preference elicitation).
- while negotiating (online preference elicitation).

The Game

- ANAC 2020 agent game @ IJCAI introduced the first competition in this domain
- Input is a ranking of a subset of outcomes but you can can add an outcome to the ranking at a cost.

Types of questions

Utility Value what is $\tilde{u}(\omega)$?

Utility Constraint Is $\tilde{u}(\omega) \geq x$? Usually implemented as a standard gamble.

Utility Comparison Is $\omega_1 \succ \omega_2$?

Outline

Concurrent Negotiation

Generality

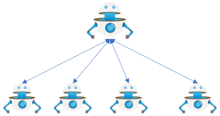
- Specific scenario (buyer-seller).
- General domain

Decommitment

- Symmetric de-commitment.
- Asymmetric de-commitment.
- No de-commitment.

Timing

- Synchronous.
- Any-time.



The SCM league focuses on this challenge.

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