Automated Negotiation

A Tutorial

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Outline

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1. Negotiation
2. Negotiation Protocols

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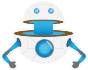

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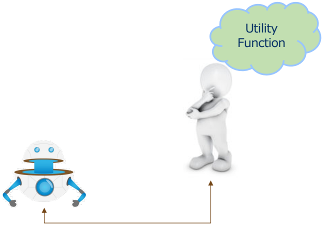
- Negotiation is important → win-win agreements.
- Automatic Negotiation → $$$
  - smart contracts, resource allocation, SCM, etc



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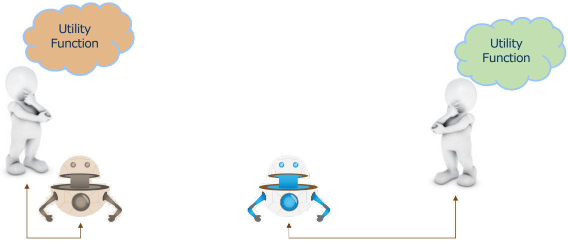

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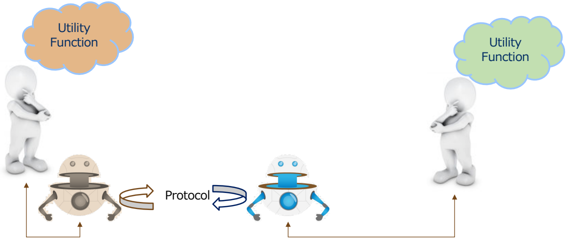

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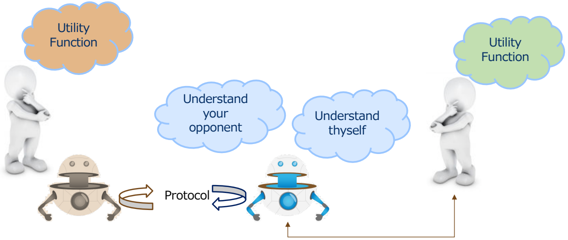

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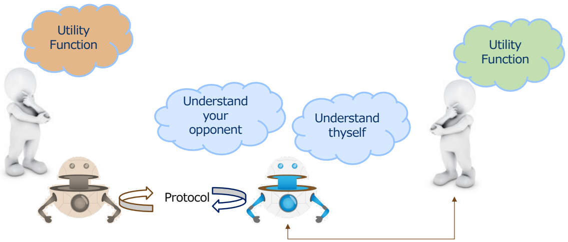

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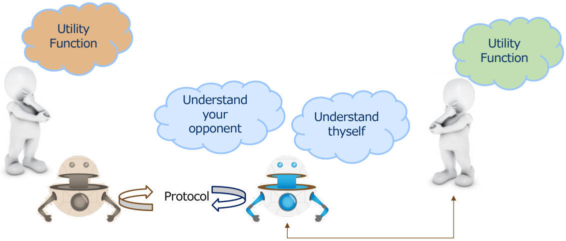

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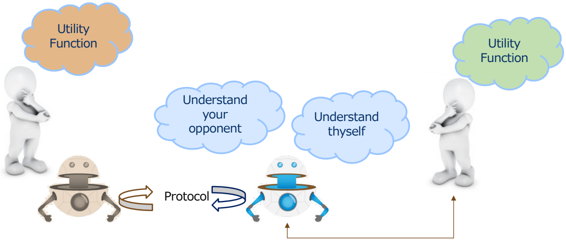

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Known Preferences Assumption

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

Preference Representations

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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.

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

Probabilistic Utility Function u Defines a distribution of values.

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

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

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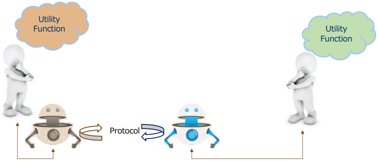


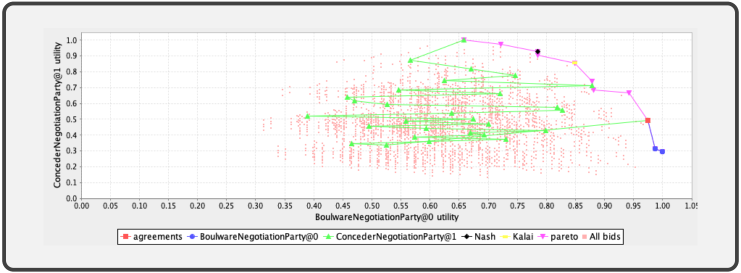
Negotiation Protocol Defines how negotiation is to be conducted [Mechanism Design Problem].

- 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.

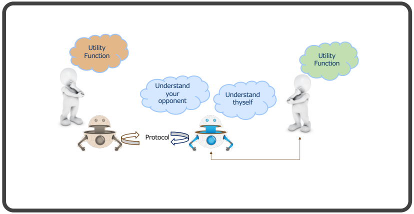
Welfare Total utility received by all actors.

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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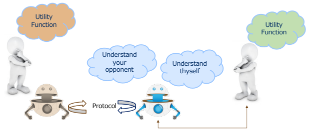
Negotiator type

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



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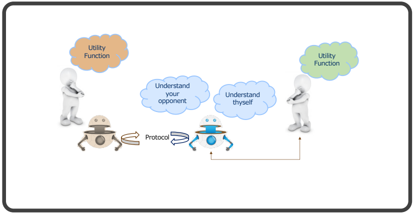

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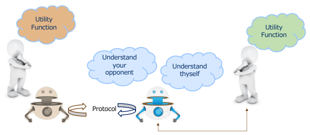
Outcome Space

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



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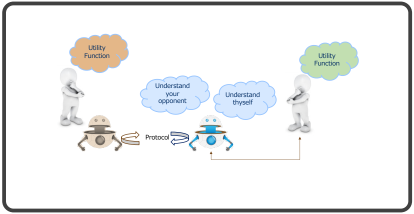
Protocol Type

1. Mediated
2. Unmediated



Platforms [Used in this tutorial]

Genius [Lin et al., 2014]

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.

NegMAS [Mohammad et al., 2019]

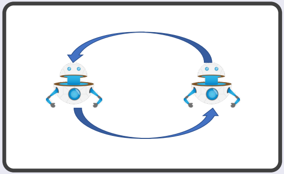
a Python-based negotiation platform for developing autonomous negotiation agents embedded in simulation environments.The main goal of NegMAS is to advance the state of the art in situated simultaneous negotiations.

Outline

Unmediated Protocols

Main Features

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



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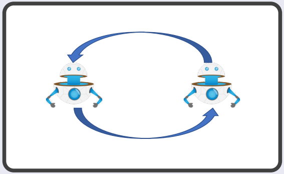


Examples

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

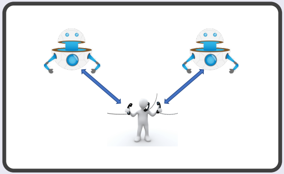
Rubinstein Bargaining Protocol Infinite horizon, single issue, bilateral protocol with complete information [Rubinstein, 1982].

Stacked Alternating Offers Protocol Finite horizon, multi-issue, multilateral protocol with partial information [Aydoğan et al., 2017].

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.



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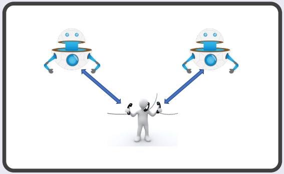

Examples

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

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Nash Bargaining Game: Description

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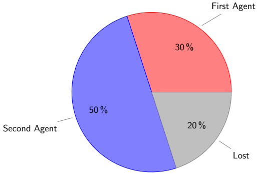

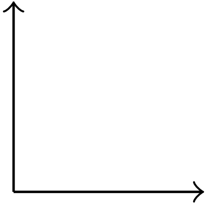

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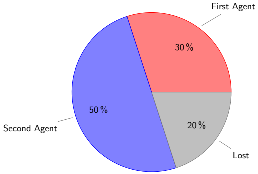

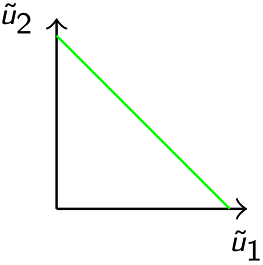

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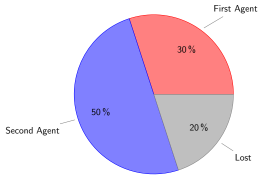

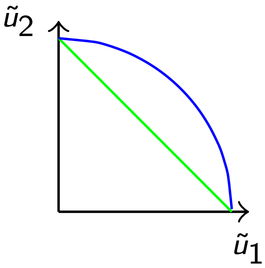

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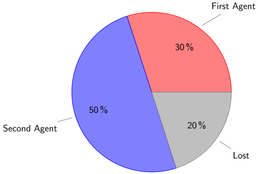

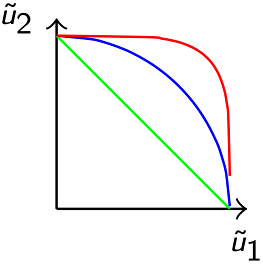

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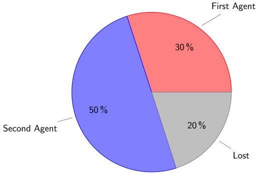

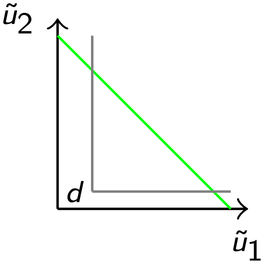

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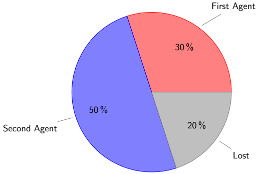

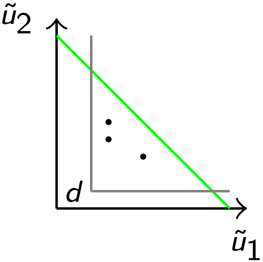

Nash Bargaining Game: Solution

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

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

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

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

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

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

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- Two agents sharing a pie.

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Rubinstein's Bargaining Protocol: Description

- Two agents sharing a pie.
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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*:

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

Rubinstein's Bargaining Protocol: Equilibrium

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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 Full information

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Hick's Paradox

Why do rational parties negotiate when they have full information?

Negotiation With Full information

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Becuase the world exists!! [Fernandez and Glazer, 1989]

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- A union negotiating with management about a wage raise in rounds.
- The union *can* strike.
- Both parties are perfectly rational and fully informed.

Negotiation With Full information

Hick's Paradox

Why do rational parties negotiate when they have full information?

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- A union negotiating with management about a wage raise in rounds.
- The union *can* strike.
- Both parties are perfectly rational and fully informed.

Main Findings:

- Sub-game perfect equilibria exist in which there is some finite striking time followed by agreement.
- That happens in real time even when round length goes to zero.

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 [Myerson and Satterthwaite, 1983].

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

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

Stacked Alternating Offers Protocol

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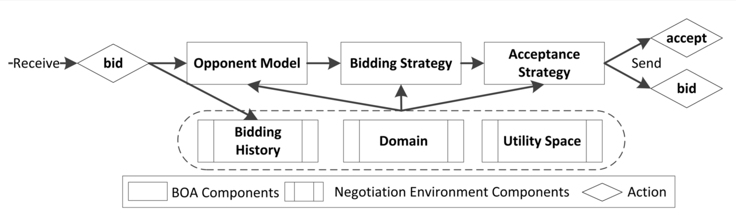
```python
n_agreed, current = 0, randint(0, n_agents)
offer = agents[current].offer()
```

```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  # contract
    elif response == 'end_negotiation':
        return 'FAILURE'
    elif response == 'reject':
        offer = agents[current].offer()
```

Negotiator Components [Baarslag et al., 2014][1]



OBA Atchitecture

Opponent Model predicts opponent behavior.

Bidding Strategy Generates new bids.

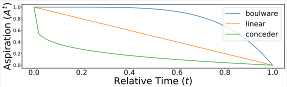
Acceptance Strategy Decides when to accept.

[1] Supported by Genius

Bidding Strategy

Time-based strategies

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



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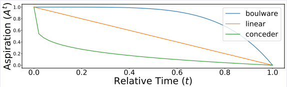
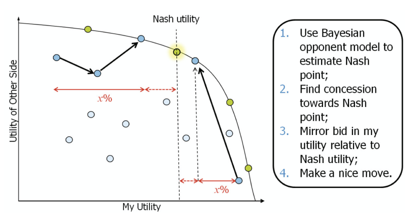


(Nice) Tit-for-Tat (bilateral) [Baarslag et al., 2013]

Concede as much as the opponent and do not retaliate.



Opponent Modeling

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What is being modeled?

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

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Data

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

Acceptance Model

Examples

Accept if the utility of the offer $\succ$

Acceptance Model

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Previous my last offer.

Acceptance Model

Examples

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Previous my last offer.

Current what I am about to offer.

Acceptance Model

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- **Previous** my last offer.
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  - **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).

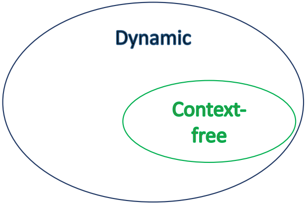
Outline

Outline

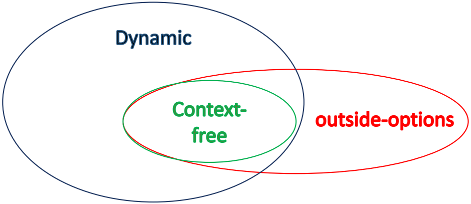
Situated Negotiation

Context-free

Situated Negotiation



Situated Negotiation



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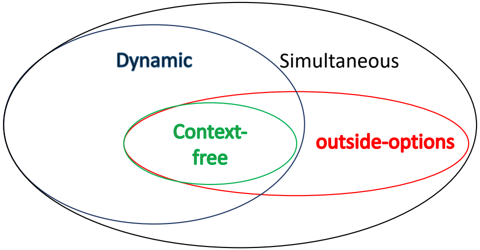

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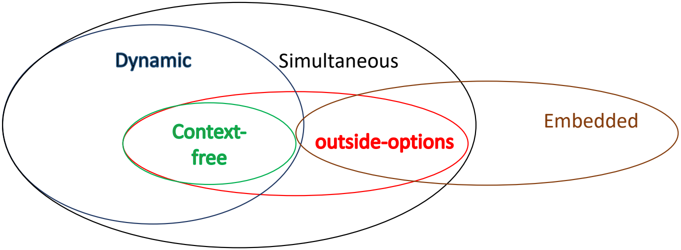

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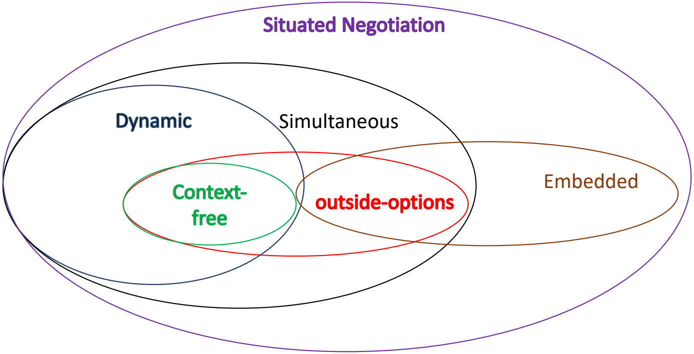

Outline

Negotiation Under Uncertainty

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The challenge

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

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The Game

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

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- 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).

Preference Elicitation

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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 $\omega_1 \succ \omega_2$?

Elicitation Procedures

1. Long history in the decision support and economics research community.
2. Take away message: .

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(ω^*, ω_*, p) : Getting ω^* with probability p otherwise ω_*

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Example query

Do you prefer to get ω for certain over (ω^*, ω_*, p)?

Elicitation Procedures/Strategies

Probability Equivalence

find p so that $\omega = (\omega^*, \omega_*, p)$

Certainty Equivalence

find ω so that $\omega = (\omega^*, \omega_*, p)$

- Both require *normalized* utilities.
- Both require knowledge of $\omega^* \succ \omega \succ \omega_*$.
- Lead to different biases.

Comparison-only Procedures

1. Titration-down: $p_k = 1 - s \times k$
2. Titration-up: $p_k = s \times k$
3. Ping-pong: $p_k = \begin{cases} s \times \lfloor k/2 \rfloor & \text{k is odd} \\ 1 - s \times k/2 & \text{k is even} \end{cases}$

Importance of Elicitation

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Negotiation with Elicitation

$m,\ \Omega,\ R,\ \tilde{U}_i\ \forall 1 \leq i \leq m\ ,\ \hat{U}_i^0\ \forall 1 \leq i \leq m$

m	Number of agents/actors
$\Omega = \{\omega_j\}$	Possible outcomes (assumed countable)
n	Number of outcomes $\lvert\Omega\rvert$
$R(i) \equiv r_i$	Reserved value for agent i
$\tilde{U}_i : \Omega \rightarrow [0,1]$	Utility of outcomes to **actor** i
$\hat{U}_i^0 : \Omega \rightarrow P$	Probability distribution of utility values for **agent** i $\hat{U}_{ij}^0 \equiv \hat{U}_i^0(\omega_j)$
$P : \{[0,1] \rightarrow [0,1]\}$	A probability distribution on the closed interval $[0,1]$

What is Elicitation Doing?

Reduces uncertainty in $\hat{U}$

State of the Art

- Lots of work on preferences/utility elicitation in decision making domain.
- Some work on incremental utility elicitation.
- Few works on incremental utility elicitation during negotiations

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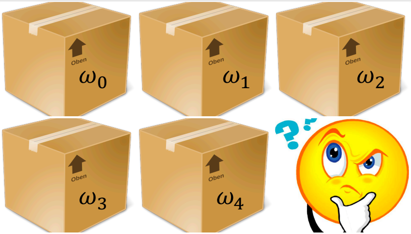
Why Is Negotiation Different

1. The acceptance model changes over time → environment dynamics are not static.
2. Exploration is extremely costly.
3. Usually negotiations are not repeated much.
4. Cannot train on a simulator (in most cases).

Pandora's Problem [Economics]

1. A set of n boxes ($\{\omega_j\}$).
2. Opening a box j gives a reward between 0 and ∞ according to distribution p_j after t_j time-steps, and costs c_j.
3. Future rewards are discounted with a known factor β.



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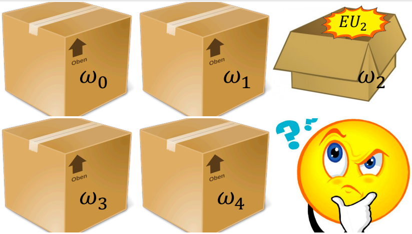

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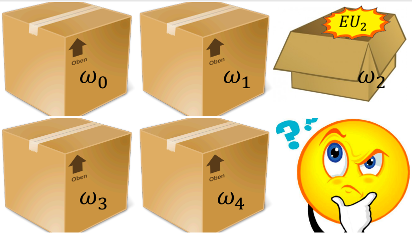

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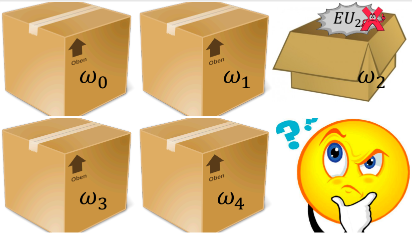

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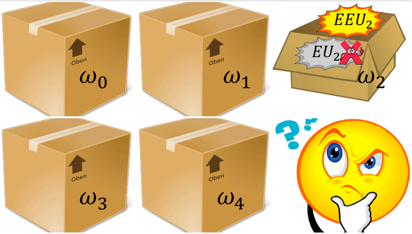

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Solution: Pandora's Rule [Weitzman, 1979]

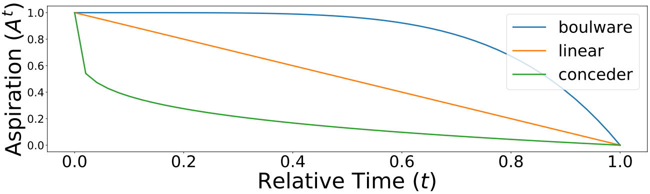
For each box j, find z_j which is the solution to:

$$c_j = \beta_j \int_{z_j}^{\infty} (u - z_j)\, p_j(u)\, du - (1 - \beta_j)\, z_j$$

Open the box with highest (z_i) if it is larger than the best utility.

Optimal Elicitation [Baarslag and Gerding, 2015]

Adapts Pandora's Rule to the negotiation context:



1. $\beta = 1.0$
2. Define aspiration level as: $A^t \equiv r_i + \left(A^0 - r_i\right) \times \left(1 - \frac{t}{N}^{1/e}\right)$
   $e > 1 \rightarrow$ Boulware, $e = 1 \rightarrow$ Linear, $e < 1 \rightarrow$ Conceder
3. $p_j = \Lambda_i^t(\omega_j) \times \mathbb{E}\left(\hat{U}_{ij}^t\right) + \left(1 - \Lambda_i^t(\omega_j)\right) \times A^t(\omega_j)$
4. Assume that there is an open box giving r_i with outcome index 0.
5. End the negotiation once the best box is 0.

Why is OE sub-optimal?

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Main Issue

Assuming that all uncertainty is removed by elicitation.

1. Assuming that $\hat{U}_{ij} \to \delta\left[u = \tilde{U}_i\left(\omega_j\right)\right]$

Why is OE sub-optimal?

Main Issue

Assuming that all uncertainty is removed by elicitation.

1. Assuming that $\hat{U}_{ij} \to \delta\left[u = \tilde{U}_i\left(\omega_j\right)\right]$
2. Consider any practical strategy (e.g. titration-down):
   - After the first question: $\hat{U}_{ij}^t \to \hat{U}_{ij}^{t+1}$
   - z_j was calculated using $\hat{U}_{ij}^t$ and must be recalculated.

Take-away message

Avoid deep-elicitation.

Extensions to Pandora's algorithm

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Closed-form Calculation of z-index[Mohammad and Nakadai, 2018b]

$$z_j = \begin{cases} \frac{a+b}{2}\beta - c_j & z_j \leq a \\ \frac{-\lambda \pm \sqrt{\lambda^2 - 4\zeta}}{2} & a < z_j \leq b \end{cases}$$

λ $-2\left(b + \frac{a-\beta}{\beta}(b-a)\right)$

ζ $b^2 - \frac{2c_j}{\beta}(b-a)$

The balanced expectation operator

$$\mathcal{E}(\hat{U}_{ij}^t) = \frac{t}{N} \times Min\left(\hat{U}_{ij}^t\right) + \left(1 - \frac{t}{N}\right) \times Max\left(\hat{U}_{ij}^t\right)$$

Min/Max a *biased* estimator that exaggerate the lower/upper part of its input. For $U(a, b)$, $Min, Max = a, b$.

Value of Information Algorithm

- Based on [Chajewska et al., 2000] in decision-support context.
- Adapted to the negotiation context.

Main Idea

- Assume an accurate opponent model (acceptance probability)
- Given a set of queries $Q \rightarrow$ find the one with the maximum difference between the expected expected utility before and after asking it[Baarslag and Kaisers, 2017, Mohammad and Nakadai, 2018a].

VOI Based Elicitation

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Policy

$$\pi^t = \left(\omega^t, \omega^{t+1}, \omega^N\right) \text{ where } \omega^x \in \Omega$$
$$K\left(\omega|\pi\right) \equiv \text{index of } \omega \text{ in } \pi$$
$$\pi\left(k\right) = \omega \text{ where } K\left(\omega|\pi\right) = k$$

Optimal Policy

$$\pi^{t*} = \arg\max_\pi EEU^t\left(\pi, \left\{\hat{U}^t_\omega\right\}\right)$$

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Probability of Agreement

$$Pa^t\left(\omega|\pi\right) = \begin{cases} \Lambda^t\left(\omega\right)\prod_{k=1}^{K_\pi(\omega)-1}\left(1-\Lambda^t\left(\pi\left(k\right)\right)\right) & \omega \in \pi \\ 0 & otherwise \end{cases}$$

Optimal Policy

$$\pi^{t*} = \arg\max_\pi EEU^t\left(\pi, \left\{\hat{U}^t_\omega\right\}\right)$$

VOI Based Elicitation

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Policy

$$\pi^t = \left(\omega^t, \omega^{t+1}, \omega^N\right) \text{ where } \omega^x \in \Omega$$
$$K\left(\omega|\pi\right) \equiv \text{index of } \omega \text{ in } \pi$$
$$\pi\left(k\right) = \omega \text{ where } K\left(\omega|\pi\right) = k$$

Probability of Agreement

$$Pa^t\left(\omega|\pi\right) = \begin{cases} \Lambda^t\left(\omega\right)\prod_{k=1}^{K_\pi(\omega)-1}\left(1-\Lambda^t\left(\pi\left(k\right)\right)\right) & \omega \in \pi \\ 0 & otherwise \end{cases}$$

Expected Expected Utility [Boutilier, 2003]

$$EEU^t\left(\pi, \left\{\hat{U}^t_\omega\right\}\right) = \sum_{\omega\in\Omega} Pa\left(\omega|\pi\right)\mathbb{E}\left(\hat{U}^t_\omega\right)$$

Optimal Policy

$$\pi^{t*} = \arg\max_\pi EEU^t\left(\pi, \left\{\hat{U}^t_\omega\right\}\right)$$

VOI Based Elicitation II

Questions and Answers

$$Q \equiv \{q_l\}$$
$$q_l \equiv \left\{\left(Ans_s^l, p_s\right)\right\}$$
$$Ans_s^l \equiv \left\{\hat{U}_\omega^{t+1}\right\}$$
$$\sum_s p_s = 1$$

VOI Based Elicitation II

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Expected value of information

$$EVOI\left(q^l, \left\{\hat{U}_\omega^t\right\}\right) = \mathbb{E}_s\left(\max_\pi EEU\left(\pi, Ans_s^l\right)\right) - \max_\pi EEU\left(\pi, \left\{\hat{U}_\omega^t\right\}\right)$$

VOI Based Elicitation II

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Questions and Answers

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Elicitation

Ask q^* where

$$q^* = \arg\max_q \left(EVOI\left(q^l, \left\{\hat{U}_\omega^t\right\}\right) - c_q\right)$$

c_q Cost of asking question q

VOI main Issues

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Accurate Agreement Model Assumption

- Everything depends on the probability of agreement (Pa)
- Pa depends on the **product** of probabilities in the acceptance model (Λ^t)

$$Pa^t(\omega|\pi) = \begin{cases} \Lambda^t(\omega) \prod_{k=1}^{K_\pi(\omega)-1} (1 - \Lambda^t(\pi(k))) & \omega \in \pi \\ 0 & otherwise \end{cases}$$

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Speed: Complexity $= O(nN|Q||Ans|)$

- Too many *argmax* and $\mathbb{E}$ operations.
- Every policy extends to the end of the negotiation.

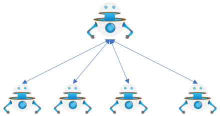
$$q^* = \arg\max_q \left(EVOI\left(q^l, \left\{\hat{U}^t_\omega\right\}\right) - c_q \right)$$

$$EVOI\left(q^l, \left\{\hat{U}^t_\omega\right\}\right) = \mathbb{E}_s\left(\max_\pi EEU\left(\pi, Ans^l_s\right)\right) - \max_\pi EEU\left(\pi, \left\{\hat{U}^t_\omega\right\}\right)$$

$$\pi^{t*} = \arg\max_\pi EEU^t\left(\pi, \left\{\hat{U}^t_\omega\right\}\right)$$

Outline

Concurrent Negotiation



Concurrent Negotiation

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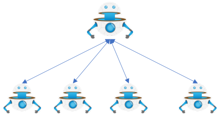
Generality

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



Concurrent Negotiation

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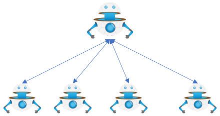
- Symmetric de-commitment.
- Asymmetric de-commitment.
- No de-commitment.



Concurrent Negotiation

Generality

- Specific scenario (buyer-seller).
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Decommitment

- Symmetric de-commitment.
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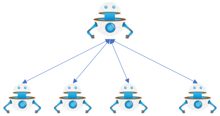
Timing

- Synchronous.
- Any-time.



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- Automated negotiation can enhance societal welfare.
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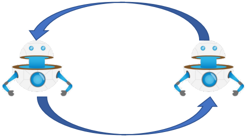

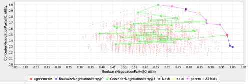

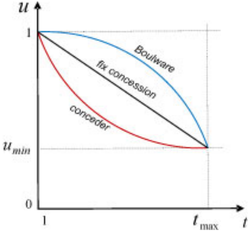

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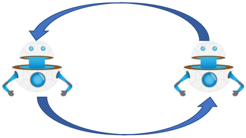

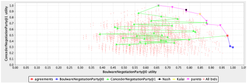

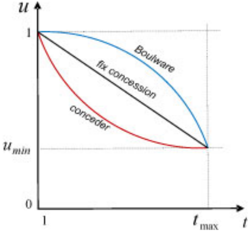

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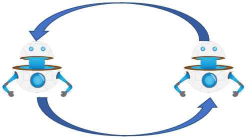

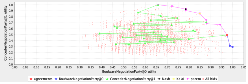

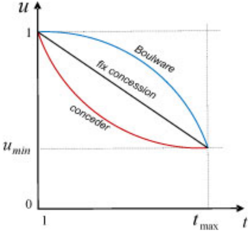

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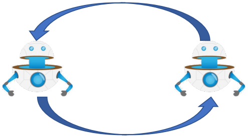

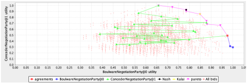

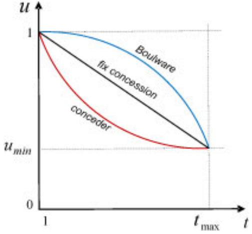

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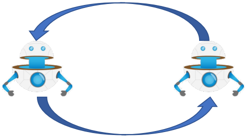

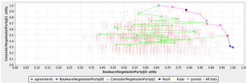

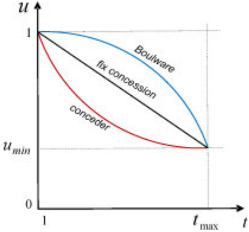

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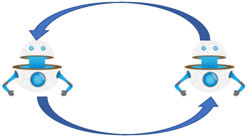

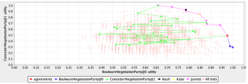

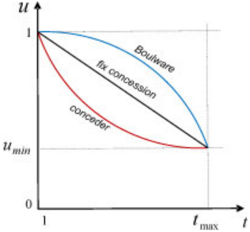

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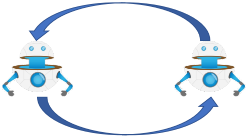

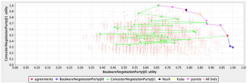

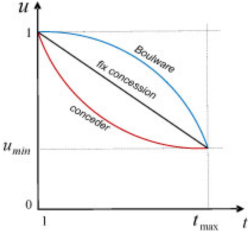

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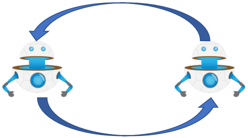

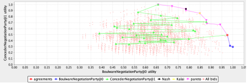

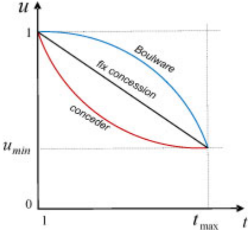

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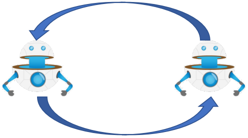

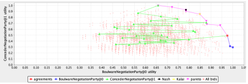

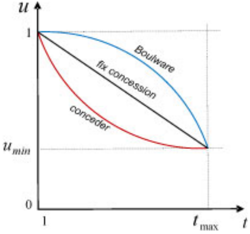

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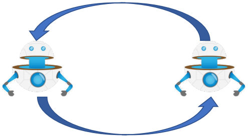

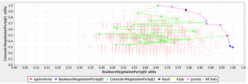

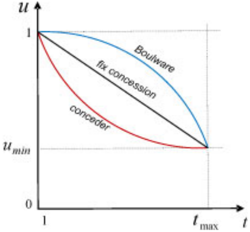

Thank you for listening (y.mohammad@aist.go.jp)

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