Week 3: Negotiation_Agents

1. Domain Background

1.1. Domain Background

1.1.1. Human Versus Automated Nagotiators

Disadvantages of Human-Beings:

1. tend to reach outcomes that are sub-optimal for all parties.
2. bounded rationality
3. slowly discover what they want, also means preferences are **constructive**
4. Human rationalise their intuitions
5. Humans tend to bargain from a position
6. Human tend to be rather lazy and tired
7. humans tend to have emotions during a negotiation

Topic	Human	NSS
Natural language understanding	Good	Bad
Calculating (bids)	Bad	Good
Memory of bids and overview	Bad	Good
Contextual background	Bad	Good
Knowledge level	General	Negotiation specific
Emotion recognition	good & allowed	good & ethically circumspect
Emotional attitude	influenced	unaffected

Table 1: Human versus Negotiation Support System (MSS)

1.2. Domain model

1.2.1. Issues and Bids

A set of **issues X**, and for each issue $x \in X$ a set of **values** (or choices) for each of those issue , that is $V(x)$.

$S \rightarrow$ the space of all possible **bids**

$b_p^r \in S$ → the bid made by negotiator p in round $r \in N$

Relations between bid and issues:

$$b = (v_1, v_2, ..., v_n);$$
$$v_1 \in x_1, ..., v_n \in x_n$$
$$X = X_1 \times X_2 \times ...X_n;$$

1.2.3. Utility/Value function

Utility/ Value function reflects the stakeholder's preferences on a particular outcome, it likes a kind of grade. $U : X \rightarrow [0, 1]$

- with probability/ risks → Utility function
- without probability/risks → Value Function

For per issue, it always called **evaluation function**

For every bid $b \in D$

$$\text{Utility of Agent A: } U_A(b)$$
$$\text{Utility of Agent B: } U_B(b)$$
$$U_A(b) = \sum_j W_{A,j} E_{A,j}(b)$$
$$where \quad W_{A,j} \longrightarrow \text{weight of issue } X_j \text{ and } \sum W_{A,j} = 1$$
$$E_{x,j}(b) \longrightarrow \text{evaluation of value of issue j in bid b (evaluation function)}$$

1.2.4. Preference Profile

$(a, c) <_p (b, d)(a, b \in V(i), \quad c, d \in V(j))$, expresses that the combination (b,d) is preferred over (a,c)

1.2.5. Negotiation Parties

Let P be a set of at least two negotiating parties. Without loss of generality assume that the names of the negotiating parties are $p_1, \cdots, p_k$, where $k = |p|$

1.2.6. Normalization

For **discrete domains**, given issue $j \in I$with range S_j, and a non-normalised evaluation function $v_j : S_j \rightarrow R$, we define the normalized evaluation function $uj : S_j \rightarrow [0, 1]$ by

$$U_j(x) = \frac{v_j(x)}{\max_{y \in S_j} v_j(y)}$$

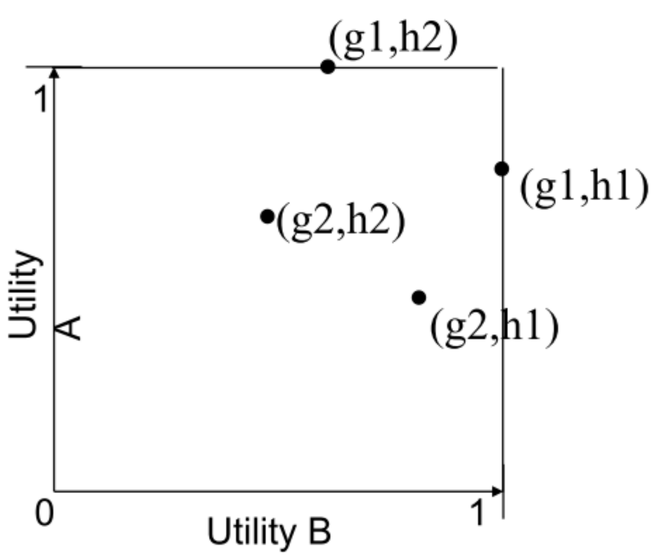
1.2.7. Example of Components in Utility

Utility (2)

- 2 issue example
  G: g1, g2
  H: h1, h2
- Agent A
  $E_{A,1}(g1) = 1$
  $E_{A,1}(g2) = 0.5$
  $E_{A,2}(h1) = 0.3$
  $E_{A,2}(h2) = 1$
  $w_{A,1} = 0.7$
  $w_{A,2} = 0.3$
  $U_A((g1, h1)) = 0.79$
  $U_A((g2, h1)) = 0.44$
  $U_A((g1, h2)) = 1$
  $U_A((g2, h2)) = 0.65$

- 2 issue example
  G: g1, g2
  H: h1, h2
- Agent B
  $E_{B,1}(g1) = 1$
  $E_{B,1}(g2) = 0.6$
  $E_{B,2}(h1) = 1$
  $E_{B,2}(h2) = 0.4$
  $w_{B,1} = 0.4$
  $w_{B,2} = 0.6$
  $U_B((g1, h1)) = 1$
  $U_B((g2, h1)) = 0.84$
  $U_B((g1, h2)) = 0.64$
  $U_B((g2, h2)) = 0.48$

1.2.8. Outcome Space



- Result of a bid:
  - $R : D \rightarrow ([0, 1], [0, 1])$
  - $R(b) = (U_A(b), U_B(b))$
- 2 issue example
  G: g1, g2
  H: h1, h2
- Bid

Bid	UA	UB
(g1,h1)	0.79	1
(g2,h1)	0.44	0.84
(g1,h2)	1	0.64
(g2,h2)	0.65	0.48

2. Negotiation Protocol

A **negotiation protocol** governs the **interaction** between negotiating parties by determining

- how the parties interact/exchange information
- “ **who** can say **what** and **when** they can say it ”

2.1. Negotiation Classification

2.1.1. Bilateral Negotiation & Multiparty Negotiation

2.2. Alternating Offers Protocol

Usually for Bilateral Negotiation, Multiparty Negotiation is suitable too.

1. One of the agents **initiates** negotiation with an offer
2. The agent receiving an offer can
    a. accept that offer
    b. make a counter offer
    c. end negotiation
3. process continues in turn-taking until consensus or termination

2.3. Mediated Single Text Negotiation Protocol

For Multiparty Negotiation

$$generate \ \rightarrow \ vote \ \rightarrow \ label \ \rightarrow \ modify \ \rightarrow \ vote \ \rightarrow \ update \ \rightarrow \ iteration$$

1. **Mediator generates** an offer and asks negotiating agents for their **votes** either to accept or to reject this offer.
2. Agents **votes** according to their acceptance strategy
3. If all negotiating agents vote “accept”, the bid is **labeled as the most recently accepted.(MRA)**
4. Mediator **modifies** the most recently accepted bid by **exchanging one value arbitrary** and asks negotiating agents’ **votes** again.
5. It **updates** the most recently accepted bid if all negotiating agents vote as “accept”
6. continues iteratively until **reaching a predefined number** of bids

2.3.1. Mediated Single Text Negotiation Hill-Climber Agent

Accept a bid if its utility is **higher than the** utility of the **most recently accepted bid(MRA)**

2.3.2. Mediated Single Text Negotiation: Annealer Agent

Calculates the **probability of acceptance** for the current bid

$$\mathrm{P}(\text{ accept }) = \min\left(1, \mathrm{e}^{-\Delta \mathrm{U}/\mathrm{T}}\right)$$
$$T : \text{Virtual temperature gradually declines over time}$$

<u>Higher probablity for acceptance</u>

- The utility difference is **small** & virtual temperature is **high**
- Tendency to accept individually **worse bids earlier** so the agents find win-win bids later

2.4. Other Non-Mediated Alternating Offers Protocol

2.4.1. Monotonic Concession Protocol

enforces the agents to **make a concession** or to stick to their previous offer.

2.4.2. Sequential-Offer Protocol

2.4.3.Unstructured Communication Protocol (UCP)

Any agent may propose an offer **at any time** and offers can be **retracted** at any time. Agents can accept a given offer by **repeating** the same offer. When all agents propose the same offer, this offer is considered an agreement.

3. Negotiation Strategies

The aim for a negotiation strategy is to **optimize your outcome while increasing the probability** that others accept your bids.

- which action the agent will take
- how the agent will generate its offers
- how the agent decide whether the opponent's counter-offer is acceptable

3.1. Bidding Strategies

Two types of negotiation tactics are very common:

1. time dependent tactics
2. behavior-dependent tactics

3.1.1. Random Walker

generates an offer randomly:

1. selects values of issues **randomly**
2. Proposes only those bids whose own utility **greater than** its **reservation utility(RU)**

3.1.2. Time-dependent Concession Strategy

Each agent has a **deadline** and the agent's behavior changes with respect to the time.

An offer which is not acceptable at the beginning, may become acceptable over time (**conceding** while approaching the deadline).

3.1.2.1. Concession Function

A **function** determines how much the agent will concede

1. Remaining negotiation **time**
2. Parameter related to **concession speed (β)**

3.1.2.2. Conceder Tactic

$\beta > 1 \rightarrow$ concedes fast and goes to its reservation value quickly.

3.1.2.3. Boulware Tactic

$\beta < 1 \rightarrow$ hardly concedes until the deadline

3.1.3. Trade-off Strategy

consider own utility + take opponent's utility into account

The importance of the issues may be different for the negotiating agents(e.g. delivery time might be more important for the consumer), so the agent may demand more on some issues while concedes on other issues without changing its overall utility as if possible(e.g. higher price in order to have an earlier delivery)

1. Selects a subset of bids **having the same utility** with its previous offer **(iso-curve)**
    - If not possible, it makes minimal concession such as 0.05
2. Among those bids, choose the bids which **might be more preferred** by its opponent
    - Heuristic: the most **similar one to opponent's last bid**

3.1.4. Behaviour Dependent Strategies

The agent **imitates its opponent's** behaviour.

3.1.4.1. Absolute Tit-For-Tat

E.g. The opponent increases the price by 50 units then the agent will decrease the price by 50 units.

3.1.4.2. Relative (proportionally) Tit-For-Tat

Taking into account the **changes of its opponent's behaviour** in a number of previous steps

3.1.4.3. Averaged Tit-For-Tat

Taking into account the **average changes within a window of size** of its opponent history

3.2. Opponent Modelling Strategies

3.2.1. Why

1. Exploit the opponent

2. Maximize chance of reaching an agreement
    a. Requiring outcome with acceptable utility for opponent, i.e. resolving the conflict of interest.
3. Increase the efficiency of a negotiated agreement
    a. Searching through the outcome space for outcomes that are mutually beneficial
    b. Reaching better/optimal agreements
4. Avoid unfortunate moves
5. which is worse for both agents
6. Make trade-offs and maximize social welfare
7. Reach agreements early
    a. Reducing communication cost

3.2.2. What

1. Learning which issues are important for the opponent
    a. Issue weights
2. Learning opponent's preferences
    a. Evaluation of issue values
    b. Preference ordering of issue values
3. Learning about opponent's strategy
    a. Predicting the utility of its next offer
4. Learning what kind of offers are not acceptable
    a. Reservation value
    b. Constraints

3.2.3. Some Possible Methods

1. Kernel density estimation for estimating the opponent's **issue weights**
    a. **Intuition:** The opponent has a tendency to **concede slowly on important issues.**
    b. **Assumption**: Weighted scoring function & Concession based strategy
2. Bayesian Learning for predicting **evaluation functions and weights**
    a. **Hypothesis for evaluation functions**: uphill, downhill, triangular
    b. **Assumption**: Linear additive functions & Concession based strategy
3. A guessing heuristic for predicting the **opponent's unknown weights**
    a. Some of the weights are revealed by the opponent
    b. Requiring domain knowledge

4. Concept-based Learning (RCEA) for **classifying offers regarding their acceptability**
    a. **Assumption**: Conjunctive & Disjunctive Constraints
    b. **Intuition**: Avoid offering unacceptable offers to opponent

3.2.4. Frequency Analysis Heuristic

Based on **how often the value of an issue changed** and **the frequency of appearance of values** in offers

1. Learning issue weights: importance of issues
    a. Heuristic: value often changed → issue low weight.
2. Learning issue value weights: evaluations of the issue values
    a. Heuristic: A preferred value → appeared more in offers

> Example:

- Assume that we have two issues (X, Y) and opponent 's first offer is [x1,y1].
    - Take the predicted weights 0.5 and 0.5 for X, Y respectively
- Second offer [x1, y2]
    - W1=0.5 +n since opponent didn't change the value of X
    - W2=0.5
    - If n= 0.1 then new weights will be 0.6, 0.5 respectively
        - W1new= 0.55 W2new= 0.45

- Assume negotiation round=45 and our opponent's offer history
    - "Brand" issue in Laptop domain

Issue Values:	**Dell**	**Mac**	**HP**
# of times appeared in offers	20	15	10
Estimated Evaluation	1.0 (20/20)	0.75 (15/20)	0.5 (10/20)

3.3. Acceptance Conditions

Why and when should we accept?

3.3.1. Break off

A **break off** is usually an undesirable outcome

1. In every negotiation with a deadline, one of the negotiating parties has to accept an offer to avoid a break off.
2. it is important to consider under which conditions to accept.

3.3.2. The acceptance Dilemma

1. too early acceptance → suboptimal agreements
2. too late → break off

Total Average Utility = Agreement Percentage × Average Utility of Agreements

3.3.3. Acceptance Conditions

$$AC_{const}(\alpha) \longrightarrow \text{Accpet when the opponent's bid is better than } \alpha$$
$$AC_{next} \longrightarrow \text{Accept when the opponent's bid is better than our upcoming bid}$$
$$AC_{time}(T) \longrightarrow \text{Accept when time} T \in [0,1] \text{has passed}$$

Usually we will use a combined acceptance conditions, for example:

$$AC_{combi}(T,\alpha) \Leftrightarrow AC_{next} \vee (AC_{Time}(T) \wedge AC_{const}(\alpha))$$

splits the negotiation time into two phases: [0,T) and [T,1]

3.4. Several Famous Strategy

Hardheaded Strategy

Hardheaded is a **time based concession strategy** that **plays Silent moves until the deadline approaches**. In that final phase Hardheaded **concedes**

Trade-off Strategy

- The Trade-off strategy predominantly bids over the estimated iso-curves, thus trying to play nice moves(Option C). As the Trade-off strategy l**ooks at the bids made by the opponent.** So, it hardly make unfortunate moves

- However, an agent can be confused by its opponents' unfortunate move.

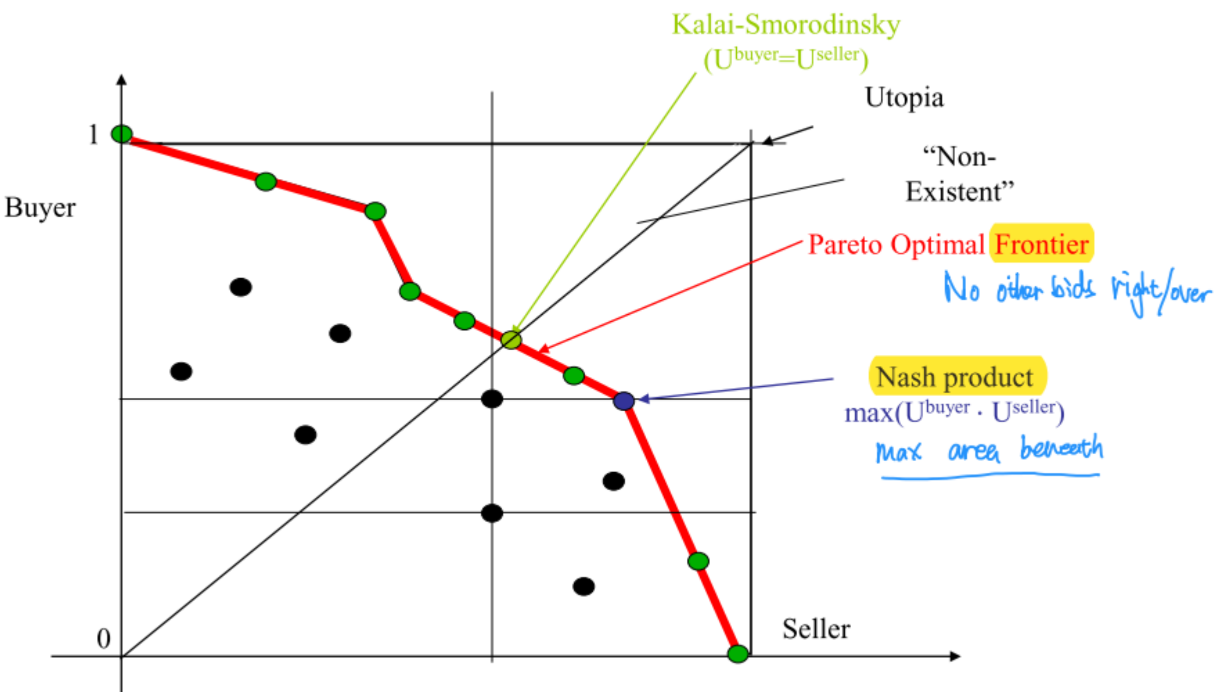
- A agent trade-off strategy will generate almost no selfish moves and very few concession moves (because when comes to the deadline) and most nive moves

Boulware strategy

- Boulwarism is the tactic of making a **"take-it-or-leave-it"** offer in a negotiation, with **no further concessions or discussion.**
- That means agent based on boulware strategy always only do silent moves

4. Analysis of Negotiation Dynamics

4.1. Outcome Analysis



4.1.1. Nash equilibrium, Nash Product(Nash bargaining Solution)

1. **Nash equilibrium** is a concept of game theory where the optimal outcome of a game is one where no player has an incentive to deviate from his chosen strategy after considering an opponent's choice.

   Nash points:

$$\max \quad arg_{a \in S}\left(\prod_{p \in P}(u_p(a) - r_p)\right)$$

2. The bid (or bids) that **maximizes the product** of utilities of the parties, under the assumption that all utility values are positive.

   If that is not the case, you have to transpose the utility space to positive values

   Max area beneath.

4.1.2. Kalai-Smorodinsky-Point (Kalai-Smorodinsky bargaining Solution,)

Tries to maintain the ratio of maximum gains

$$KSP = \min arg_{a \in F}(r_a - r_{eq})$$
$$\text{where F is the Pareto Optimal Frontier}$$
$$\text{where} r_a = \frac{u_1(a)}{u_2(a)}$$

The philosophy behind the Kalai-Smorodinsky bargaining Solution, is that of **fair division**

4.1.3. Kalai point(Egalitarian point, Rawls point)

Maximizes the minimum of the utilities of the parties. To be found at the intersection of POF and EPP.

$$KP = arg \max_{a \in F} arg \min_{p \in P} u_p(a)$$

The philosophy behind this entails that in a cooperative environment, the utility of the individual that is the worst off, is the utility of a group. The group should therefore try to maximize its utility

4.1.4. Strictly Dominated Bid

If there exists another bid that is better for at least one party, while 476 simultaneously not worse for any other party in the negotiation

4.1.5. Pareto Optimal Frontier

$$POF = \{b \in D | \forall b' \in D : b \neq b' \rightarrow (U_A(b') < U_A(b) \vee U_B(b') < U_B(b)\}$$

The Pareto Optimal Frontier is the set of bids, such that there is no other bid that is better for at least one party, without making things worse for the other parties

Process:

Consider all possible offers and for each offer check if it is strictly dominated by any other offer. If that is the case, remove it

4.1.6. Equal Proportion of Potential Line (EPP)

The line from (0,0) to (1,1)

4.1.7. Comparance

1. **Resource monotonicity**

   ensures that when there is a utility gain compared to the base situation, no party should be worse off.

2. **Independence of Irrelevant Alternatives（IIA）**

   states that when a new solution is added to the domain, and this solution is not the agreement, it is irrelevant and should not influence the negotiation outcome.

3. **Scale Invariance**

   states that if party p1 can get a utility gain of c · u1 and player p2 can get a utility gain of c · u2, the solution should remain the same for any positive real number c.

4. Nash bargaining Solution does not adhere to resource monotonicity, adhere to IIA and Scale Invariance.
5. The Kalai-Smorodinsky bargaining Solution adheres to resource monotonicty and Scale Invariance, but drops the Independence of Irrelevant Alternatives (IIA) axiom.
6. Egalitarian social welfare bargaining Solution adheres to both the resource monoticity axiom as well as IIA, but drops the Scale Invariance axiom

4.2. Negotiation Dance & Negotiation Trace

1. **negotiation dance**

   defining it as the set of negotiation traces of negotiation moves made by each of the negotiating parties

2. **negotiation move**

   two subsequent bids made by a negotiating party

3. **negotiation trace**

   the sequence of moves made by negotiating party

4.3. Negotiation Step

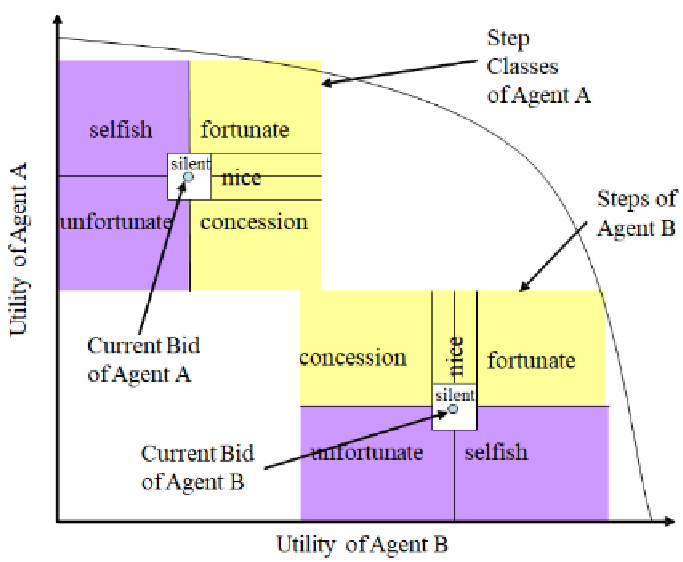


Figure 3: Moves

$U_S(b)$: utility of "Self" for bid b

$U_O(b)$: utility of "Other" for b

$\Delta_a(b, b') = U_a(b') - U_a(b),\ a \in \{S,O\}$

$\Delta_a(s)$: $\Delta_a(b, b')$ for a step $s = b \rightarrow b'$.

A trace t is a series of negotiation steps, i.e., transitions $b \rightarrow b'$ with b, b' offers.

Sensitivity to Opponent Preferences

A rational negotiator would try to make *fortunate, nice, or concession steps*.

$$\text{sensitivity}_a(t) = \frac{\%_{Fortunate}(t_a) + \%_{Nice}(t_a) + \%_{Concession}(t_a)}{\%_{Selfish}(t_a) + \%_{Unfortunate}(t_a) + \%_{Silent}(t_a)}$$

- In case no selfish, unfortunate or silent steps are made we stipulate that $sensitivity_a(t)=\infty$.
- If $sensitivity_a(t)<1$, then an agent is more or less insensitive to opponent preferences;
- If $sensitivity_a(t)>1$, then an agent is more or less sensitive to the opponent's preferences, with complete sensitivity for $sensitivity_a(t)=\infty$.