Negotiation

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Outline of the Course

- Lecture I: Bilateral Negotiation
- Lecture II (tomorrow am): Multilateral Negotiation
- Lecture III (tomorrow pm): Argument-based Negotiation

General References

Negotiation is a huge topic, it has been studied in many fields for many years.

Raiffa. *The art and science of negotiation*. 1982.

These are some general AI/MAS books, notes, with nice chapters on negotiation:

Wooldridge. *An Introduction to Multiagent Systems*. MIT Press-2004.

Vidal. *Fundamentals of Multiagent Systems*. 2007.

And these are two classic books on the subject:

Rosenschein & Zlotkin. *Rules of Encounter: Designing Conventions for Autamted Negotiation among Agents*. 1994.

Kraus. *Strategic Negotiation in Multiagent Environments*. 2001.

Approaches to Negotiation

It is also common to find the following distinction:

- Game-theoretic—use of mathematical tools, as developed in game-theory, to analyze strategical interaction. Provable properties, strong assumptions.
- Heuristic-based—design of good strategies in practice, in specific domains of negotiation. More realistic assumptions, more difficult to guarantee properties.
- Argument-based—allows the exchange of arguments during negotiation.

Outline of the Talk

1. The setting
2. What is a good outcome?
3. Protocols

Bilateral Negotiation: The Setting

We first describe the outcome set $\mathcal{O}$. This set may have different characteristics.
Compare the following scenario:

1. we must decide on the next location for the summer school.

$$o_1 = \langle \text{bali} \rangle$$

2. we must divide a chocolate-vanilla cake
division of a continuous resource.

$$o_1 = \langle 1/3, 2/3 \rangle$$

3. there are 4 candies, we must decide on a complete allocation of resources to children.
allocation of indivisible resources.

$$o_1 = \langle \{c_1, c_4\}, \{c_2, c_3\} \rangle$$

The Setting: The Outcome Set

The outcome set may be very large, even in the discrete case:

- allocations of indivisible resources
  g goods, so $|\mathcal{O}| = |\mathcal{A}|^g$ outcomes
- choice in a multi-issue domain
  p issues, with D_i the domain of the issue i, so $|\mathcal{O}| = \Pi_i |D_i|$

Example: Choosing the next holiday package:

- $D_d = \{\text{1week}, \text{2weeks}\}$
- $D_c = \{\text{bali}, \text{lisboa}, \text{moscow}, \text{dakar}\}$
- $D_h = \{\text{pension}, \text{hotel1}, \text{hotel2}, \text{hotel3}, \text{hotel4}\}$
- $D_t = \{\text{plane}, \text{bike}, \text{car}\}$

This yields $2 \times 4 \times 5 \times 3 = 120$ outcomes.

The Setting: Agents' Preferences

Next we have discuss how agents express their preferences.

A preference structure represents an agent's preference over the set of outcomes $\mathcal{O}$. There are different types of preference structures:

Roughly speaking, preferences can be ordinal or cardinal.

- an ordinal preference structure is a binary relation over the outcomes $\mathcal{O}$, which is reflexive, transitive (and often complete).

$$o_1 \succeq o_2$$

"o_1 *is at least as good as* o_2"

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- a cardinal preference structure is expressed as a valuation function

$$v : \mathcal{O} \mapsto Val$$

where *Val* can be a totally ordered scale of qualitative values ("very good", "good", ...), or some quantitative values.

The Setting: Agents' Preferences

Very often quantitative values are used. But beware of the exact interpretation of this "value".
Following (Luce and Raiffa, 1957), make sure to distinguish:

1. values are in utility terms, no interpersonal comparison of utility are permitted, and no side payments are allowed
2. values are in utility terms, interpersonal comparison is meaningful, and no side payment are allowed
3. values are in monetary terms, utility is linear in money, interpersonal comparisons are meaningful, and monetary side payments are allowed.

From now, we denote by $u_i(o)$ the utility of agent i for the outcome o.

Luce & Raiffa. *Games and Decisions*. 1957.

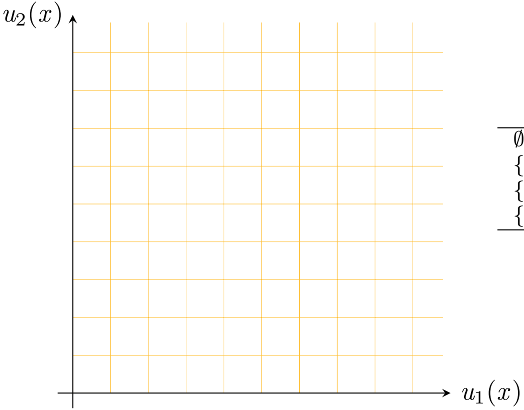
Negotiation Domains: Resource Allocation

In the context where agents seek to agree on an allocation of indivisible resources (or tasks), the following distinction is useful:

- task-oriented domains—the utility function is common to all agents (and commonly sub-additive), and agents are only concerned with the tasks its gets
- state-oriented domains—the utility function is common to all agents, but agents can value the state in general (not only its bundle of resources)
- worth-oriented domains—the utility function may be different for the different agents

Rosenschein & Zlotkin. *Rules of Encounter*. 1994.

Negotiation Domain: Convex Outcome Sets



	u_1	u_2
$\emptyset$	0	0
$\{r_1\}$	1	3
$\{r_2\}$	3	3
$\{r_1, r_2\}$	7	8

What are the outcomes? Can you place them on this figure?

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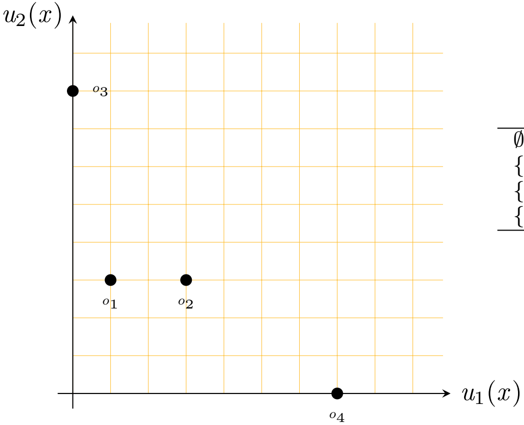

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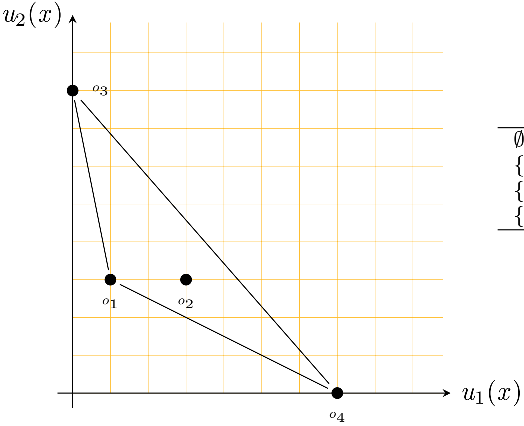

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Randomization between possible outcomes defines a new outcome. For instance, any point on the segment $o_3 - o_4$ is a randomized outcome of the form $\langle p.u_1 + (1-p).u_1, p.u_2 + (1-p).u_2 \rangle$. But then the outcome set becomes a convex region.

Some (important) assumptions and remarks

The following remarks are useful:

1. ordinal preferences do not allow interpersonal comparison
2. ordinal preferences cannot represent intensities, cardinal preferences can
3. ordinal preferences can handle incomparabilities, but cardinal preferences cannot
4. explicit representation of cardinal and ordinal preferences require space complexity of $O(|\mathcal{O}|)$ and $O(|\mathcal{O}|^2)$

In the following, we make some assumptions:

1. preferences of agents are common knowledge among all agents (we come back to this later)
2. agents can provide explicit representation of their preferences (more compact way of representing preferences are possible)

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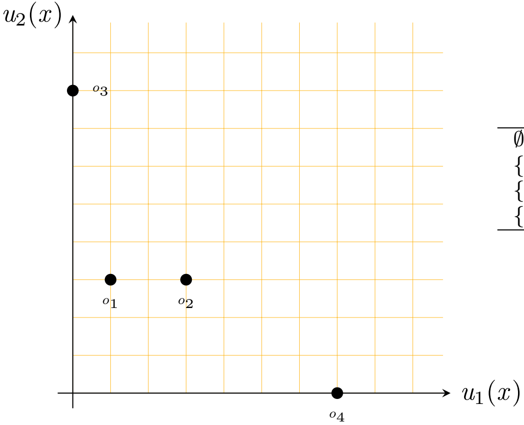
Pareto-optimality

- An outcome o_1 Pareto-dominates another outcome o_2 if o_1 is at least as good as o_2 for all agents, and strictly better for at least one.
- An outcome is Pareto-optimal if no other outcome dominates it.



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$\emptyset$	0	0
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Efficiency

There may be many Pareto-optimal outcomes. Outcomes may also maximize some measure of social welfare:

- utilitarian— maximizes $\sum_i u_i(o)$
- egalitarian— maximizes $\min_i u_i(o)$
- Nash product— maximizes $\Pi_i u_i(o)$

Example:

	u_1	u_2
$\emptyset$	0	0
$\{r_1\}$	1	3
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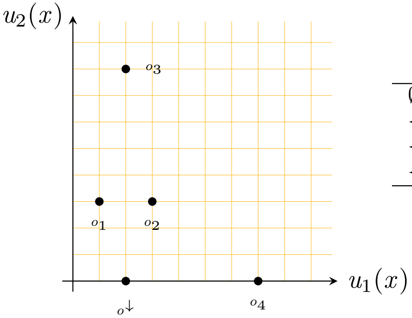
- Which outcome maximizes the utilitarian social welfare, the egalitarian social welfare, and the Nash product?
- Which of these notions imply Pareto-optimality?

Individual Rationality

- We denote by $o^{\downarrow}$ the disagreement (or conflict) point.
  It indicates the utility that each player gets if the negotiation fails.
  This needs not be the same for both agents.
- Individual rationality: agents should be better off engaging in the negotiation, that is, for all i, the outcome of the negotiation o must be such that:

$$u_i(o) \geq u_i(o^{\downarrow})$$



	u_1	u_2
$\emptyset$	2	0
$\{r_1\}$	1	3
$\{r_2\}$	3	3
$\{r_1, r_2\}$	7	8

The Negotiation Set

IR plus Pareto brings the negotiation set (Luce and Raiffa, 1957). However, this set contains many possible solutions. Can we restrict further the set of intuitively "fair" outcomes?

Nash (1950) takes an axiomatic approach, and under some assumptions (in particular that the outcome set is convex), shows that the unique solution to a bargaining problem must be the Nash product, provided we accept some "intuitive" axioms.

Nash Bargaining Solution

A bargaining problem is described as a pair $\langle \mathcal{O}, o^{\downarrow} \rangle$.
We write $o^* = NBS(\langle \mathcal{O}, o^{\downarrow} \rangle)$ for the outcome selected.
Basic axioms:

- Pareto the solution should be on the Pareto-frontier
- IR the outcome should be individually rational

Additional axioms:

- Symmetry
- Linear Invariance
- Independance of Irrelevant Alternatives

We discuss them in more details now.

Nash Bargaining Solution: Symmetry

Intuitively, symmetry says that agents should be treated the same when their initial situation is equivalent. So,

1. if $u_1(o^{\downarrow}) = u_2(o^{\downarrow})$, and
2. if $\forall o \in \mathcal{O}$: $\exists o' \in \mathcal{O}$ such that $u_1(o) = u_2(o')$ and $u_2(o) = u_1(o')$

then the outcome o^* must be such that $u_1(o^*) = u_2(o^*)$

Nash Bargaining Solution: Linear Invariance

Intuitively, linear invariance says two things:

- independance of scale—the outcome does not depend on the scale used by the agent to represent its utility.
  Suppose agent 1 uses a scale [0,10] to represent its utility, while agent 2 uses a scale [0,100]. The fact that agent 1 enjoys utility 9 and agent 2 utility 50 does not mean that agent 2 is more "happy".
- independance of zero—a translation of the scale of utilities does not affect the outcome.
  Suppose agent 1 uses a scale [0,9], while agent 2 uses a scale [1,10]. The scale of agent 2 can be translated to [0,9] without any consequence on the outcome.

Nash Bargaining Solution: IIA

Intuitively, Independence of Irrelevant Alternatives (IIA) says that if the outcome o^* of the negotiation lies in some sub-region of the outcome set, then the negotiation should still select o^* if we restrict the outcome set to this sub-region.

So, removing "irrelevant outcomes" should not affect the result.

More precisely, for any $O \subseteq \mathcal{O}$,
if $NBS(\langle \mathcal{O}, o^{\downarrow} \rangle) = o^* \in O$ then $NBS(\langle O, o^{\downarrow} \rangle) = o^*$.

Discussion on the Axioms

Which axioms do you find controversial?

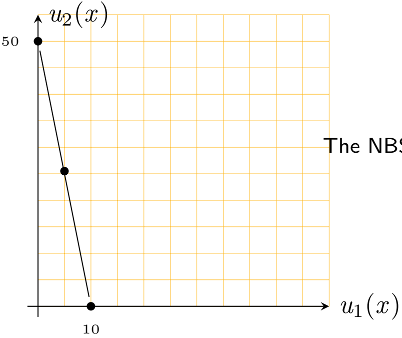
Discussion on the Axioms

Which axioms do you find controversial?

Interestingly, we will see that discussing these axioms sometimes unveils interesting links to argumentation...

Nash Bargaining Solution: Linear Invariance

We follow the exposition of (Luce and Raiffa).
Consider the following bargaining problem.

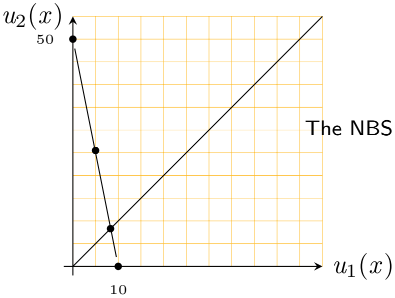


The NBS is $\langle 5, 25 \rangle$

Nash Bargaining Solution: Linear Invariance

Agent 1 can put forward the following argument:
"The solution should be $o^* = \langle 8.33, 8.33 \rangle$" because

1. if you go for $\langle 5, 25 \rangle$, if will simply refuse it (threat) (I will only loose 5, you will lose 25...)
2. the reference point should be $\langle 0, 0 \rangle$, so we should gain the same.



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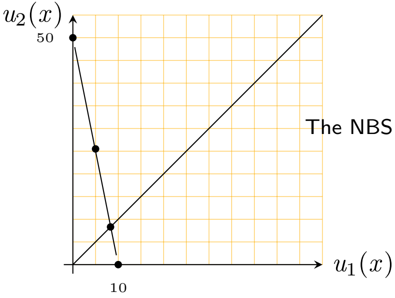
Nash Bargaining Solution: Linear Invariance

Agent 2 can then put forward the following argument:
"No, we must chose $\langle 8.33, 8.33\rangle$", because
If we chose $o^* = \langle 8.33, 8.33\rangle$ instead of $\langle 5, 25\rangle$, I give up more than 16, while you only gain a bit more than 3..."



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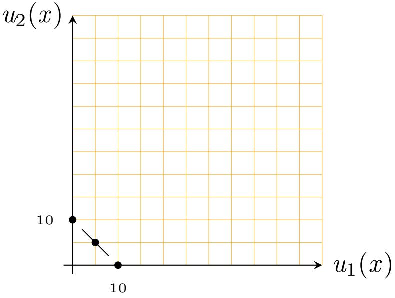
Nash Bargaining Solution: Linear Invariance

Agent 1 may then say:
"Come on. Suppose there is this other game. I prefer to play in our game" because I expect to get more from our game. I am fine to let you have more in our game than in this one, as long as I get something in return...

> *"Such an argument implicitly assumes an interpersonal comparison of utility. Nash feels that such comparisons are not meaningful and that such an argument cannot be made sound" (Luce & Raiffa)*



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Properties of Protocols

A protocol specifies the rules of interaction (who can say what?). For instance, we may allow simultaneous moves, or sequential moves.

A strategy specifies the behavior of the agent (which move to select among all the legal ones?)

We usually require the following properties of protocols+strategies:

- termination—the negotiation will terminate
- guaranteed agreement—the negotiation will end on an agreement (not on the conflict point)
- efficiency—upon termination, the negotiation provides an efficient (eg. Pareto-optimal) outcome
- equilibrium—captures a notion of stability. In particular:
  - symmetric Nash equilibrium: assuming agent 1 uses strategy s, agent 2 cannot be better off using a different strategy than s.
  - subgame perfect equilibrium: in the case of sequential protocol.

Monotonic Concession Protocol

The protocol proceeds in rounds where agents make simultaneous offers. Let o_i^t and o_j^t be the offers made by agent i and agent j, at round t.

In the initial round, agents make the offer they like, then in the following rounds, each agent must either:

- stick to their previous offer, or
- make a concession (an offer which gives the other more utility)

An agreement is found when, for at least an agent, the offer made by the other agent is at least as good as its own current offer. That is:

$$u_i(o_j^t) \geq u_i(o_i^t) \text{ or } u_j(o_i^t) \geq u_j(o_j^t)$$

(Flip a coin if both agents agree).

A disagreement occurs when both agents stick to their current offer.

Monotonic Concession Protocol: Zeuthen strategy

How should agents play this game? Zeuthen proposes the following:

The willingness to risk conflict (denoted Z_i^t), intuitively captures "how bad" would be a conflict for agent i at round t. It is given by the following formula (assuming $(0,0)$ for the conflict):

$$Z_i^t = \begin{cases} 1 & \text{if} \quad u_i(o_i^t) = 0 \\ \frac{u_i(o_i^t) - u_i(o_j^t)}{u_i(o_i^t)} & \text{otherwise} \end{cases}$$

From this, the Zeuthen strategy is specified as follows, for agent i:

- compute your willingness to risk conflict Z_i^t and that of your partner
- the one with the smallest value should concede
- make the minimal concession making Z_j^t become smaller than Z_i^t

Monotonic Concession Protocol: Example

[Too lazy to do a nice picture here]

Monotonic Concession Protocol: Example

round	offer a_1	offer a_2	$u_1(o^t_{a_1}), u_1(o^t_{a_2})$	$u_2(o^t_{a_1}), u_2(o^t_{a_2})$	Z_1	Z_2
1	$\langle\emptyset, \{a,b,c\}\rangle$	$\langle\{a,b,c\},\emptyset\rangle$	9,0	0,9	1	1
2	$\langle\{a\},\{b,c\}\rangle$	$\langle\{a,c\},\{b\}\rangle$	7,4	3,7	$\frac{3}{7}$	$\frac{4}{7}$
3	$\langle\{a,c\},\{b\}\rangle$	$\langle\{a,c\},\{b\}\rangle$	4,4	7,7	stop	stop

Monotonic Concession Protocol: Properties

The properties of the MCP + Zeuthen strategy are as follows:

- termination is guaranteed, as well as agreement upon termination (there is always at least an agent willing to concede)
- because the offers considered are in the Negotiation Set to start with, Pareto-optimality is obvious

Now a stronger result:

- The outcome maximizes the Nash product.

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Explanation: The problem comes from the last step of the protocol. If both agents have the same Z, both are willing to concede, and so one agent can exploit this and deviate to get a better outcome.

Monotonic Concession Protocol

Some final remarks on MCP.

- it is possible to extend the Zeuthen strategy (by allowing a mixed strategy in the last step) to retrieve stability
- a more simple one-step protocol is possible!

The one-step protocol is as follows:

- agents simultaneously make a single offer
- select the one maximizing the product of utilities

What is the best strategy for an agent given this protocol?

Monotonic Concession Protocol

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What is the best strategy for an agent given this protocol?
Given this protocol, the strategy for an agent is to select, among the outcomes maximizing, the one giving him the best utility.

Rosenschein & Zlotkin. *Rules of Encounter*. 1993.

Alternating Offers

We now discuss a sequential protocol.

- an agent starts by making an offer. In the next round, the other agent can either accept or make a counter-offer.
- the protocol integrates a discount factor λ_i to capture the fact that negotiation is time constrained. An offer accepted at round t by agent i brings utility $u_i(o^t) \times (\lambda_i)^t$.

The sequential nature of this protocol allows backward induction solving.

Rubinstein. *Perfect equilibrium in a bargaining model.* Econometrica-1982.

Set $\lambda = 1$ for agents (they are patient).

- suppose the number of rounds is known in advance. But then the last agent to make an offer gets all the "power". What is his best strategy?

Alternating Offers

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  Always refuse the offers of the other, then make an offer $\langle 1-\epsilon, \epsilon \rangle$ *in the last round (this last step is actually an ultimatum game: more on this later)*
- suppose the number of rounds is not known in advance
  Suppose a_1 *uses this strategy: Always propose* $(1-\epsilon, \epsilon)$*, and always refuse the offer of the other. What is* a_2 *best response to this?*

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- suppose the number of rounds is not known in advance
  Suppose a_1 *uses this strategy: Always propose* $(1-\epsilon, \epsilon)$*, and always refuse the offer of the other. What is* a_2 *best response to this? Always refusing yields the conflict outcome. So* a_2 *must accept at some point, no reason to postpone: accept in the first round.*
  Immediate acceptance of any offer is a Nash equilibrium, given that a_2 knows a_1's strategy.

Alternating Offers: Example

Take $\mathcal{O} = \{o_2, o_3, o_6\}$, with $o_2 = \langle 7, 3\rangle$, $o_3 = \langle 5, 4\rangle$, and $o_6 = \langle 4, 7\rangle$.

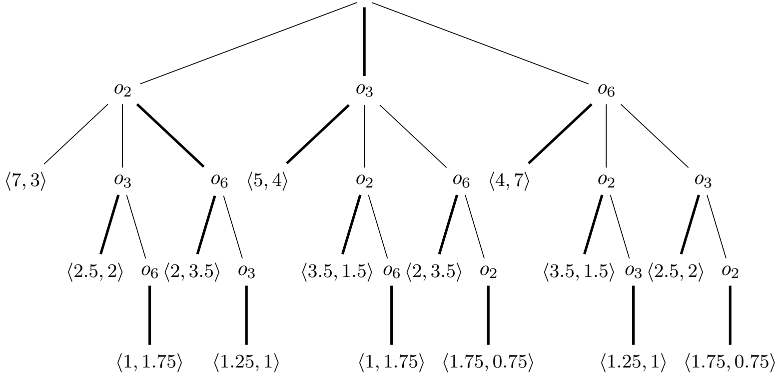

Figure: Backward Induction with the alternating-offer protocol

A Word of Caution (I)

Back to the ultimatum game.

Remember: One agent proposes an offer (say a division of a pie), the offer may either accept or reject. If it accepts the offer is chosen outcome, otherwise the conflict outcome.

What do you a human agent will propose in real life?

A Word of Caution (I)

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What do you a human agent will propose in real life?

- many studies in economics
- usually offers more around a 60/40 division
- importance of social context, reputation, etc.

A Word of Caution (II)

Now consider the following game, known as the centipede game.

There are 100 candies to share, and two agents. The protocol for negotiation is as follows. In each round:

- player i can either take 1 or 2 candies
- if he takes 2 candies, the protocol terminates, and agents keep the candies they have collected so far (the rest is wasted)
- if he takes 1 candy, the protocol continues, by giving the turn to the other agent, and so on.

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Can you analyze this game?

Heuristic-Based Negotiation

Often, agents have not an exact knowledge about the preferences of others. It is possible to conceive general profiles of agents, specifying high-level behavior.

- boulware agents—very slow concession until we get close to the deadline, then exponential increase
- conceder agents—prone to concede in the first rounds of negotiation and get close to reserve price, then slow increase

But how can we make sure that a move is indeed a concession in the first place?

Faratin et al.. *Negotiation decision functions for autonomous agents*. Robotics and Autonomous Systems-1998.

Heuristic-Based Negotiation

Consider a multi-issue domain.
Suppose agents' utilities are given as weighted sums. Agents give difference importance to different criteria.

$$u_i(o) = \sum_c w_i^c u_i^c(o)$$

Note: note necessarily zero-sum, nor negatively correlated utilities.

Faratin et al. distinguish:

- response strategies—concession operate on a single issue
- compensation strategies—concede on a single issue but ask more on other issues (trade-offs), so that the new offer has the same utility for itself, but a higher utility for the other one.

Faratin et al.. *Using similarity criteria to make issue trade-offs in automated negotiations*. AIJ-2002.

But trying to guess/approximate an agent preference structure based on its negotiation behavior is very challenging!

Idea: seek the offer which is the "closest" from the other agent offer in the preceding move. To do this, compute similarity among offers.

Heuristic-Based Negotiation

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Idea: seek the offer which is the "closest" from the other agent offer in the preceding move. To do this, compute similarity among offers.

Example:

$\mathcal{D}_c = \{\text{yellow}, \text{violet}, \text{magenta}, \text{green}\ldots\}$

Choose criteria to assess how similar colors are (eg. warmness, perception,...)

$h_w = \{(\text{yellow}, 0.9), (\text{violet}, 0.1), (\text{magenta}, 0.1), (\text{green}, 0.3), \ldots\}$

$h_p = \{(\text{yellow}, 1), (\text{violet}, 0.5), (\text{magenta}, 0.4), (\text{green}, 0.1), \ldots\}$

By giving to similarity criteria (eg. 0.7 and 0.3) , we can compute eg.

$$sim(\text{magenta}, \text{green}) =$$

$$0.7 \times (1 - |h_w(\text{magenta}) - h_t(\text{green})|) + 0.3 \times (1 - |h_w(\text{magenta}) - h_t(\text{green})|)$$

Heuristic-Based Negotiation

But trying to guess/approximate an agent preference structure based on its negotiation behavior is very challenging!

Idea: seek the offer which is the "closest" from the other agent offer in the preceding move. To do this, compute similarity among offers.

Example:

$\mathcal{D}_c = \{\text{yellow}, \text{violet}, \text{magenta}, \text{green}\ldots\}$

Choose criteria to assess how similar colors are (eg. warmness, perception,...)

$h_w = \{(\text{yellow}, 0.9), (\text{violet}, 0.1), (\text{magenta}, 0.1), (\text{green}, 0.3), \ldots\}$

$h_p = \{(\text{yellow}, 1), (\text{violet}, 0.5), (\text{magenta}, 0.4), (\text{green}, 0.1), \ldots\}$

By giving to similarity criteria (eg. 0.7 and 0.3) , we can compute eg.

$$sim(\text{magenta}, \text{green}) =$$

$$0.7 \times (1 - |h_w(\text{magenta}) - h_t(\text{green})|) + 0.3 \times (1 - |h_w(\text{magenta}) - h_t(\text{green})|)$$

- we can then compute similarity among offers (by summing similarity, taking weights into account)
- finally the agent seeks among all offers giving her the same utility the one which is most similar to the other agent's previous offer.

Testing Strategies: Agent Competitions

In recent years, competitions involving negotiating agents have emerged, allowing to test and compare various strategies on different problems.

- ANAC Competition: Automated Negotiating Agents Competition
- TAC: Trading Agent Competition (auctions, etc.)
- Genius platform (negotiation problems, library of agents' strategies) `http://mmi.tudelft.nl/negotiation/index.php/Genius`
- many papers and even books on analysis of the best strategies

Wellmann, Greenwald, & Stone. *Autonomous Bidding Agents: Strategies and Lessons from the TAC competition*. 2007.

Multilateral Negotiation

Outline of this morning's lecture.

- multilateral negotiation with mediator
- a multilateral protocol for agents with ordinal preferences
- extension of monotonic concession protocol
- contract-based multilateral negotiation
- negotiation on networks

Single Text Mediated Agent

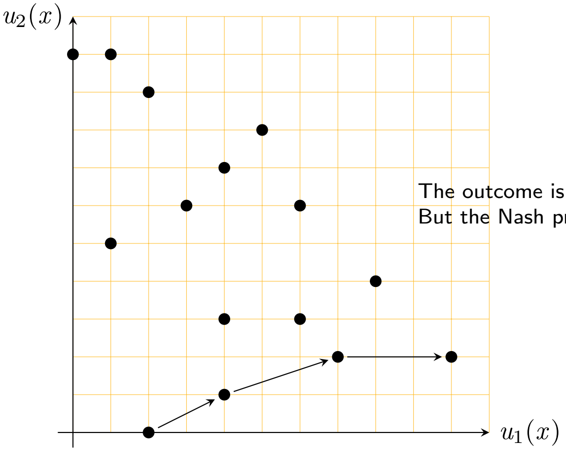
A first possible approach is to use a mediator.
The protocol is as follows (K is fixed a priori):

```
for t:=1 to K do
begin
  the mediator proposes an offer o ;
  agents votes on o (accept/refuse);
  if all agents accept, then current := o;
end;
```

So the protocol returns the latest unanimously accepted offer.

Essentially, the protocol starts from an offer, and performs Pareto improvements.

- Is the protocol guaranteed to reach a Pareto-optimal outcome?
- Is the protocol guaranteed to stop when having reached a Pareto optimal outcome?



The outcome is $\langle 10, 2 \rangle$
But the Nash product optimum is $\langle 5, 8 \rangle$

Single Text Mediated Protocol

This protocol may be problematic in some contexts:

- it requires a mediator (not always possible)
- requires many rounds of communication from all agents to the mediator
- it can reach outcomes with very low social welfare

Some extensions have been proposed to try to address some of these limitations:

- use of meta-heuristic techniques to avoid local optima (eg. simulated annealing)
- learning of agents preferences to guide the offer proposal from the mediator

Klein et al.. *Protocols for negotiating complex contracts*. IEEE Intelligent Systems.

Fallback Bargaining

Now we discuss a purely ordinal bargaining procedure.
Each agent ranks her preferred options. Let $top_i(k)$ be the ranking up to k for agent i.
The procedure is as follows:

- while no option is in *all* top(k) rankings, do $k \leftarrow k+1$

The compromise set (CS) is the output of this procedure.

Example:

agent 1: $o_1 \succ o_2 \succ o_3 \succ o_4$
agent 2: $o_2 \succ o_4 \succ o_1 \succ o_3$

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What is the compromise set? $CS = \{o_2\}$, a compromise of level 2.

Brams & Kilgour. *Fallback Bargaining*. Group Decision and Negotiation 2001.

Fallback Bargaining

What are the properties of the compromise set?

agent 1:	$o_1 \succ o_2 \succ o_3 \succ o_4$
agent 2:	$o_1 \succ o_2 \succ o_3 \succ o_4$
agent 3:	$o_1 \succ o_4 \succ o_2 \succ o_3$
agent 4:	$o_4 \succ o_3 \succ o_2 \succ o_1$

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What is the compromise set?

Does it seem a fair compromise? For most (if not all) voting rule, the chosen option would be a. (a is a Condorcet winner, in particular).

> *"(....) as unanimous consent is required in a bargaining situation, the choice of b seems (...) appropriate"*

- Are the options from CS Pareto-optimal?

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- Are Pareto-optimal options necessarily in CS?

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- Are the options from CS Pareto-optimal? Yes.
- Are Pareto-optimal options necessarily in CS? No.

CS selects Pareto-optimal options maximizing the min ranking of agents.

Brams & Kilgour. *Fallback Bargaining*. Group Decision and Negotiation 2001.

Multilateral Negotiation

Is it possible to simply extend the protocols used in the bilateral case? Let us consider the case of the monotonic concession protocols.

Remember:

- An agreement is reached iff one agent makes an offer that is at least as good for each other agent as their own proposal.

But for the notion of concession we run into trouble...

Endriss. *Monotonic Concession Protocols for Multilateral Negotiation*. AAMAS-06.

Multilateral Negotiation

For what it means to concede to many agents?

- Strong/Weak concession: make an offer strictly better for all / at least one other agent(s).
- Pareto concession: make an offer at least as good for all other agents and strictly better for at least one of them.
- Egalitarian/Utilitarian/Nash concession: make an offer such that the min/sum/product of utilities increases
- Egocentric concession: make an offer that is worse for yourself.

Termination is guaranteed (except for weak concessions)

Endriss. *Monotonic Concession Protocols for Multilateral Negotiation*. AAMAS-06.

- A concession criterion is deadlock-free iff it guarantees that at least one agent can make a concession satisfying the criterion at any stage during negotiation, until an agreement has been reached.

Example: Assume Pareto concessions are used.
Three possible outcomes.

round 1: $o_1 = \langle 3, 2, 1 \rangle$, $o_2 = \langle 1, 3, 2 \rangle$, $o_3 = \langle 2, 1, 3 \rangle$.

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round 1: $o_1 = \langle 3, 2, 1 \rangle$, $o_2 = \langle 1, 3, 2 \rangle$, $o_3 = \langle 2, 1, 3 \rangle$.
round 2: $o_1 = \langle 1, 3, 2 \rangle$, $o_2 = \langle 2, 1, 3 \rangle$, $o_3 = \langle 3, 2, 1 \rangle$.

No more concessions are possible. An agreement is reached (all agents enjoy utility 1 in their current offer, so any other offer is better).

- A concession criterion is deadlock-free iff it guarantees that at least one agent can make a concession satisfying the criterion at any stage during negotiation, until an agreement has been reached.

Example: Assume Pareto concessions are used.
Three possible outcomes.
round 1: $o_1 = \langle 2, 1, 3 \rangle$, $o_2 = \langle 3, 2, 1 \rangle$, $o_3 = \langle 1, 3, 2 \rangle$.

Multilateral Negotiation

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Example: Assume Pareto concessions are used.
Three possible outcomes.

round 1: $o_1 = \langle 2, 1, 3 \rangle$, $o_2 = \langle 3, 2, 1 \rangle$, $o_3 = \langle 1, 3, 2 \rangle$.
No more concessions are possible. No agreement is reached!
(all agents enjoy utility 2 in their current offer, so any other makes one of them worse off).

Contract-Based Negotiation

Instead of trying to deal with multilateral encounters, let us try to build on simple building blocks. We take inspiration from Contract-Net protocols.

- negotiation starts with an initial allocation
- agents asynchronously negotiate resources
- deals to move from one allocation to another, ie $\delta = (A, A')$
- deals can involve payments (utility transfer);
- agents accept deals on the basis of a rationality criterion, we assume myopic IR: $v_i(A') - v_i(A) > p(i)$

Contract-Based Negotiation

Different types of deals can be considered
"natural" restrictions on the type of exchanges allowed between agents, in particular:

- 1-deals: exchange of a single resource
- bilateral deal: exchange involving two agents
- clique deal: exchange among agents in a clique of neighbours

Different assumptions on the preference structures
"natural" restrictions/assumptions to be made on the preferences of all the agents of the system, in particular:

- monotonicity: $v_i(B_1) \leq v_i(B_2)$ when $B_1 \subseteq B_2$
- modularity: $v(S_1 \cup S_2) = v(S_1) + v(S_2) - v(S_1 \cap S_2)$

Contract-Based Negotiation

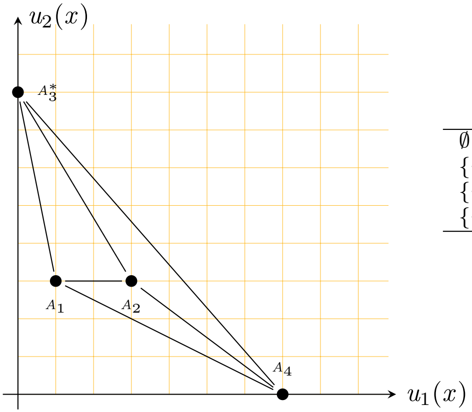
Some known results:

- a deal is IR (with money) iff it increases utilitarian social welfare (thus generates a surplus).
- allows to show that any sequence of IR deals converges to an allocation maximizing utilitarian social welfare
- however, may require very complex deals to be implemented during the negotiation (in fact, for any conceivable deal we may construct a scenario requiring exactly that deal).
- for modular domains, convergence is guaranteed for negotiations involving 1-deals only

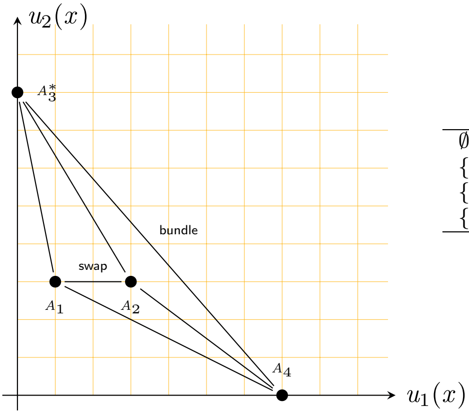
Sandholm. *Contract types for satisficing task allocation*. IEEE Symposium-1998.

Endriss et al.. *Negotiating socially optimal allocation of resources*. JAIR-2006.

Contract-Based Negotiation



	u_1	u_2
$\emptyset$	0	0
$\{r_1\}$	1	3
$\{r_2\}$	3	3
$\{r_1, r_2\}$	7	8



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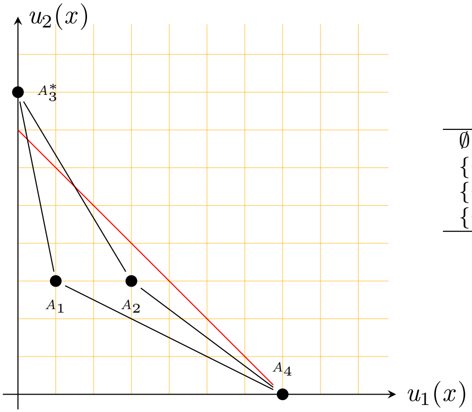

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Maximality of Modular wrt. Bilateral-deals

How far can we get with bilateral deals?
Assume (at least) 3 agents, and take an arbitrary non-modular valuation function:

$$v_1 = a + b.r_1 + c.r_2 + d.r_1.r_2$$

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Assume (at least) 3 agents, and take an arbitrary non-modular valuation function:

$$v_1 = a + b.r_1 + c.r_2 + d.r_1.r_2$$

We need to show that it is possible to construct two modular functions and select an initial allocation such that no bilateral deals would lead to optimal sw. Assuming $d > 0$ here, take:

$$v_2 = v_3 = (b + \frac{1}{3}d).r_1 + (c + \frac{1}{3}d).r_2$$

Initially (A_0), we allocate r_1 to agent 2 and r_2 to agent 3.
Hence, $sw(A_0) = a + b + c + \frac{2}{3}d < sw(A^*)$, where A^* is the allocation where agent 1 receives both objects.

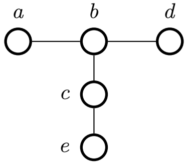
Chevaleyre et al.. *Simple Negotiation Schemes for Agents with Simple Preferences.* JAAMAS-2010.

Balanced Outcomes

Network Exchange Theory: agents can only negotiate with neighbours.

- agents are now located on a graph G
- each agent can reach an agreement with at most one neighbour
- each pair of agents negotiate over the division of 1 euro

Example:



Can you guess how the negotiation will unfold?
Which agreements are met, how the money is divided?

Kleinberg & Tardos. *Balanced Outcomes in Social Exchange Networks*. STOC-08.

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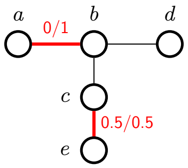


Intuition: b uses his "power" to have two potential agreements (a/d). c sees that b would not deal with him, so focus on e.

Kleinberg & Tardos. *Balanced Outcomes in Social Exchange Networks*. STOC-08.

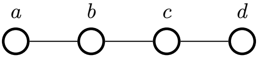
Balanced Outcomes

More precisely, we can define:

- an outcome is a pair $\langle M, \alpha \rangle$, where M is a matching (which agents agree on a deal), and values α_x for each agent x, with:
  - $\alpha_x + \alpha_y = 1$ when $(x, y) \in M$,
  - $\alpha_x = 0$ when $x \notin M$.

Let β_x be the best alternative for x, that is, $max\{1 - \alpha_y | (x, y) \in G\}$

- an outcome is stable if $\alpha_x \geq \beta_x$, for all x.



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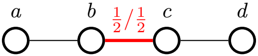

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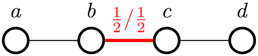

Is this multi-outcome stable? No. Eg. take b: $\alpha_b = \frac{1}{2}$, when $\beta_b = 1$.

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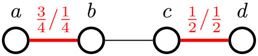

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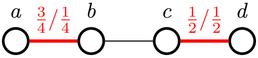

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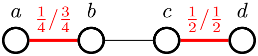

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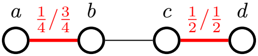

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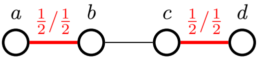

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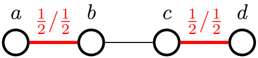
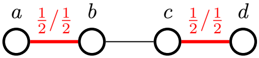


Is this multi-outcome stable? Yes!
But contradicted by experiments (b and c have more negotiation power)

Balanced Outcomes

The idea is to strengthen the notion of stability.

- A balanced outcome is an outcome such that, for all $(x, y) \in M$, (α_x, α_y) constitutes a Nash Bargaining Solution considering (β_x, β_y) as the disagreement outcome.



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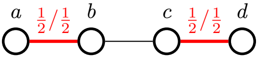

This is not a balanced outcome. Indeed take $(\alpha_a, \alpha_b) = (0.5, 0.5)$. Given $(\beta_a, \beta_b) = (0, 0.5)$, the surplus $1 - 0.5$ should be evenly divided, yielding $(\alpha_a, \alpha_b) = (0.25, 0.75)$.
But now given $(\beta_c, \beta_d) = (0.25, 0)$, the values of (α_c, α_d) should be modified... $\Rightarrow$ fixed-point definition

- Can you guess the balanced outcome here?

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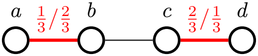


Gives rise to many questions:

- are balanced outcomes guaranteed to exist? (if not, when?)
- are these values rational?
- is it easy to compute these values?
- etc.

Kleinberg & Tardos. *Balanced Outcomes in Social Exchange Networks*. STOC-08.

Outline of this afternoon lecture.

- What is the role of argumentation in negotiation?
- What kind of arguments are valid in negotiation?
- How to integrate argumentation in negotiation?

Argumentation-based Negotiation

In a nutshell, argumentation-based negotiation allows an agent to convey additional information with its own offers, or responses to offers made by others.

Intuitively, argumentation-based negotiation can (in principle):

1. facilitate convergence to efficient outcomes, by adding arguments justifying why the current offer is refused (or accepted);

   > *"I can't accept this offer, because I really need both resources."*

2. make an outcome acceptable to the partner, by adding arguments likely to modify its preferences.

   > *"My proposal is 100 for this bike, because it was rated A^* in the recent survey."*

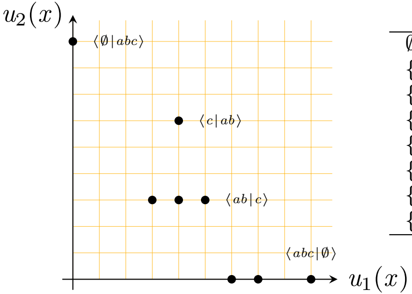
Rahwan et al.. *Argumentation-based Negotiation*. KER-2004.

Argumentation-based Negotiation

Some remarks:

1. only make sense if agents do not know the preferences of others
2. raises many very challenging questions:
   - what kind of arguments are allowed?
   - how are preferences of agents modified?

Argumentation for Preference Elicitation



	u_1	u_2
$\emptyset$	0	0
$\{a\}$	2	0
$\{b\}$	3	0
$\{c\}$	4	3
$\{a, b\}$	5	6
$\{b, c\}$	7	3
$\{a, c\}$	6	3
$\{a, b, c\}$	9	9

Agents do not know the preferences of others, so (assuming monotonicity) they only "see" the following ranking for the other agents.

$$\{a, b, c\} \succeq \{\{a, b\}, \{b, c\}, \{a, c\}\} \succeq \{\{a\}, \{b\}, \{c\}\} \succeq \emptyset$$

$$\{a, b, c\} \succ \{\{a, b\}, \{b, c\}, \{a, c\}\} \succ \{\{a\}, \{b\}, \{c\}\} \succ \emptyset$$

Take a MCP-like protocol.
We denote by C_i the potential minimal concessions (noted as the set of objects offered to the partner), given his current knowledge.

round	offer r_1	offer r_2	u_1	u_2	C_1	C_2
1	$\langle\{a, b, c\}, \emptyset\rangle$	$\langle\emptyset, \{a, b, c\}\rangle$	9,0	0,9	$\{a\}, \{b\}, \{c\}$	$\{a\}, \{b\}, \{c\}$
2	$\langle\{b, c\}, \{a\}\rangle$	$\langle\{c\}, \{a, b\}\rangle$	7,4	0,6	$\{b\}, \{c\}$	$\{a\}, \{b\}$

Argumentation for Preference Elicitation

$$\{a,b,c\} \succ \{\{a,b\},\{b,c\},\{a,c\}\} \succ \{\{a\},\{b\},\{c\}\} \succ \emptyset$$

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2	$\langle\{b,c\},\{a\}\rangle$	$\langle\{c\},\{a,b\}\rangle$	7,4	0,6	$\{b\},\{c\}$	$\{a\},\{b\}$

"This is not a concession because a and b are only valuable together to me!"
This discards b as a potential concession for agent 1.

3	$\langle\{a,b\},\{c\}\rangle$	$\langle\{c\},\{a,b\}\rangle$	5,4	3,6	$\{a,b\}$	$\{a\},\{b\}$
4	$\langle\{c\},\{a,b\}\rangle$	$\langle\{c\},\{a,b\}\rangle$	4,4	6,6	$\{b\}$	$\{a\},\{b\}$

Not that the same argument also discards $\{a,c\}$ and $\{b,c\}$ after round 3.
Agent 2 can perform this reasoning and sticks to his proposal.

Argumentation Changing Preferences

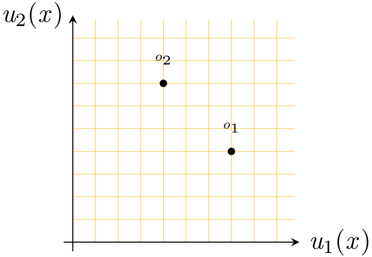
Abstractly, an argument will be “some information” conveyed during the negotiation, potentially modifying the preferences of other agents

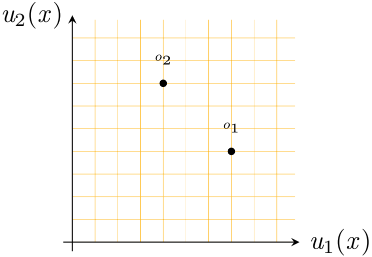
- information referring to the outcomes from the outcome set
- information referring to underlying goals of agents
- information referring to underlying goals, beliefs, etc. (eg. BDI)
- information referring to the overall context of the negotiation

So the granularity of the representation of agents’ mental states allows to express arguments of different nature.

Reason-based choice

There is evidence from economics that agents decide based on reasons they have at their disposal. It is possible to construct such justifications from the structure of the option set only.





Shafir, Simonson, & Tversky. *Reason-based Choice*. Cognition-1993.

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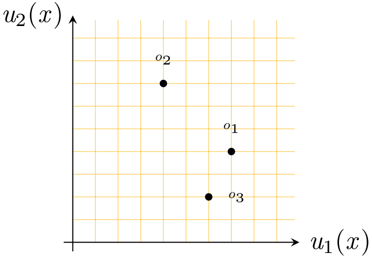

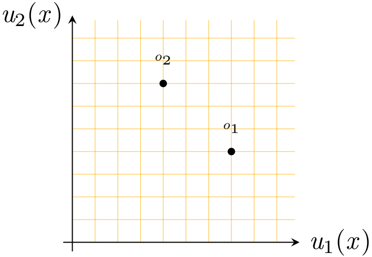

Dominance effect

Shafir, Simonson, & Tversky. *Reason-based Choice*. Cognition-1993.

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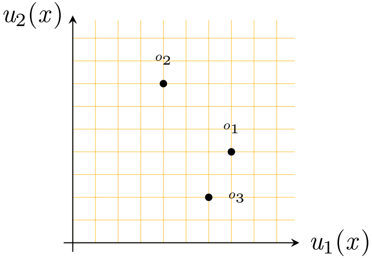

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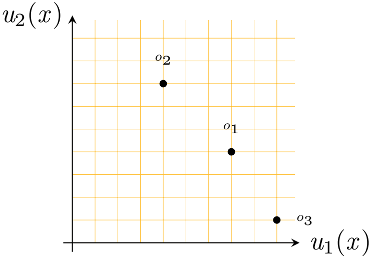


Compromise effect

Shafir, Simonson, & Tversky. *Reason-based Choice*. Cognition-1993.

Types of Arguments

Note that this violates some (variant of) independence axioms discussed in the first lecture! Do you see why?

Types of Arguments

Note that this violates some (variant of) independence axioms discussed in the first lecture! Do you see why?

- for the dominance effect, the argument is of the form: "I prefer o_1, because at least it dominates o_3".
- for the compromise effect, the argument is of the form: "I prefer o_1 because it is a compromise between o_2 and o_3"

In argumentation we often conceive arguments as referring to various elements of the context, including mental states of agents.
For instance, in (Kraus, 1998), the following types of arguments are considered, from weakest to strongest:

- appeal to prevailing practice
- counter-example
- appeal to past promise
- appeal to self-interest
- promise of future reward
- threat

Kraus, Sycara & Evenchik. *Reaching agreements through argumentation*. AIJ-1998.

The picture-hanging example

Agents are equipped with mental states, and are able to derive intentions and communicative acts (like requests). So the request is justified by a sequence of derivations concluding on the underlying intention

$$I_a(give(b, a, nail))$$

The request may be rejected because :

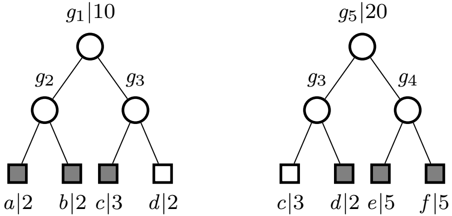
1. a conflicting intention can be build (e.g. b does not intend to give the nail, because it needs it for some other matter, like hanging a mirror)
2. an undercuting argument for one of premises justifying the request can be put forward (e.g. b may explain that a actually does not need the nail to hang the picture).

Parsons, Sierra, Jennings. *Agents that reason and negotiate by arguing*. JLC-1998.

Rahwan et al.. *Argumentation-based Negotiation*. KER-2004.

Interest-based Negotiation

- preferences of agents are based on goals they would like to satisfy
- agents can exchange information about their underlying goals
- doing so, they can profit from common goals, or propose new plans



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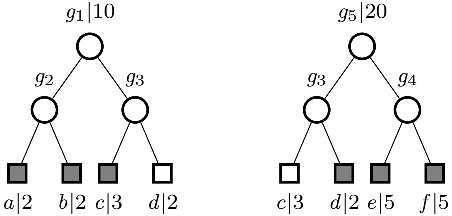

agent 1: "I would like to buy d for 2 euros"
agent 2: "Sorry. I can't accept this deal. What do you need d for?"
agent 1: "I would like to complete g_3"

Rahwan et al.. *On the benefits of using underlying goals in interest-based negotiation*. AAAI-2007.

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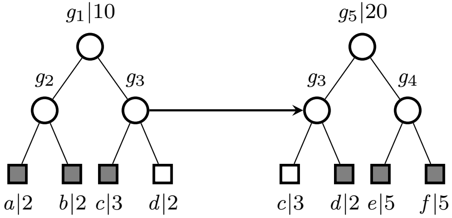

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Abstract Argumentation-Based Negotiation

Can we use abstract argumentation to support moves in negotiations?

We first distinguish:

- practical arguments: arguments supporting choices, decisions, offers
- epistemic arguments: arguments supporting beliefs

A common assumption is that practical arguments cannot attack epistemic arguments (to avoid "wishful thinking").

A key ingredient is the function $\mathcal{F}$ which returns, for an offer o, the (practical) arguments supporting it. These arguments "highlight positive features of the options they support".

Amgoud, Dimopoulos, Moraitis. *A unified and general framework for argumentation-based negotiation*. AAMAS-07.

Abstract Argumentation-Based Negotiation

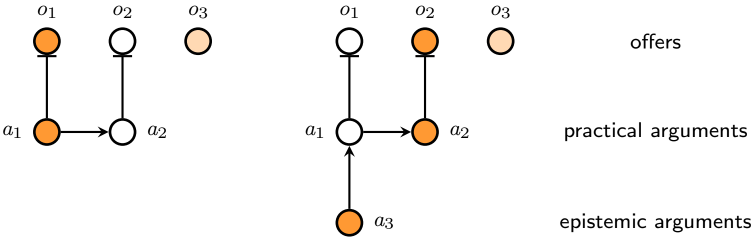
It is then possible to relate the status of offers to the status of its supporting arguments. More precisely:

- an offer o is acceptable iff there exists an argument $a \in \mathcal{F}(o)$ such that a is accepted.
- an offer o is rejected iff for all argument $a \in \mathcal{F}(o)$ such that a is accepted.
- an offer o is non-supported iff $\mathcal{F}(o) = \emptyset$.

A natural ordering is provided: acceptable $\succ$ non-supported $\succ$ rejected.

However note that this only distinguishes 3 classes of offers...

Abstract Argumentation-Based Negotiation



For agent 1, the set of accepted arguments is $\{a_1\}$.
Thus, o_1 is acceptable while o_2 is rejected, and o_3 is unsupported.

$$o_1 \succ o_3 \succ o_2$$

For agent 2, the set of accepted arguments is $\{a_3, a_2\}$.
Thus, o_2 is acceptable while o_1 is rejected, , and o_3 is unsupported.

$$o_2 \succ o_3 \succ o_1$$

Abstract ABN: Protocols

- to account for the dynamics, protocols allow the exchange of arguments.
- new arguments are integrated by the other agent in its theory (hypothesis of trust or verifiability of arguments)
- this in turn may affect the acceptability status of offers

In (Amgoud et al.), the notion of concession is defined as follows:

- o is a concession at round t iff there exists $o' \succ^t o$.

Amgoud, Dimopoulos, Moraitis. *A unified and general framework for argumentation-based negotiation*. AAMAS-07.

Argumentative Alternating-Offers

Now argumentative moves are allowed in the negotiation (see also Simon's course). Often as a subprotocol embedded in negotiation.

Take for instance the alternating-offers protocols. Now the possible moves become:

- propose, accept, refuse (counter-offer)
- argue, agree

Where, in short, argue allows to present arguments defending his own offer, or to counter-attack by putting forward arguments against the offer of the other agent. It is also possible to argue about rejections.

Amgoud et al.. *Arguments, dialogue, and negotiation*. ECAI-00.

Hadidi et al.. *Argumentative Alternating-Offers*. AAMAS-07.

Veenen, Prakken. *A protocol for arguing about rejections in negotiation*. COMMA-06.

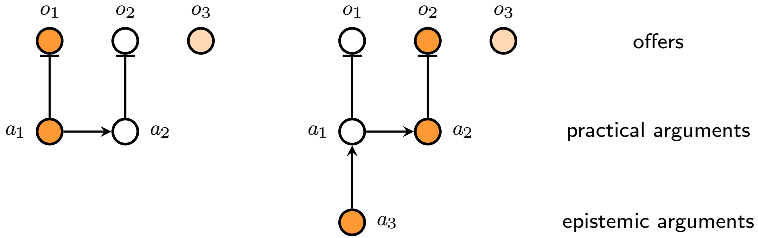
Quality of Outcomes

Note that since the preferences of agents are now dynamic, we often assess the quality of an outcome given the information exchanged so far.

- an outcome is t-acceptable iff it is acceptable to both agents given their theories at round t
- an outcome is t-Pareto iff it is Pareto-optimal given the theories of agents at round t
- an outcome is ideal iff the outcome is acceptable to both agents, were those agents merging their theories.

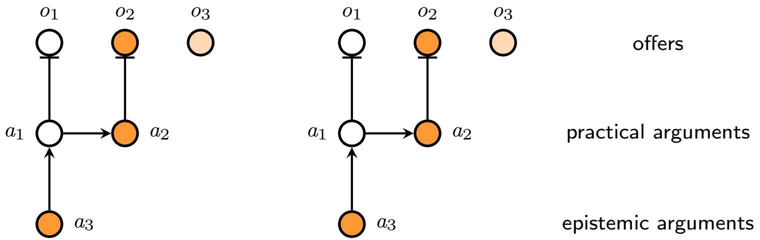
Amgoud and Vesic. *A formal analysis of the role of argumentation in negotiation dialogues*. JLC-2012.

Quality of Outcomes: Example



$t = 0$: $o_1 \succ o_3 \succ o_2$ and $o_2 \succ o_3 \succ o_1$
No offer is 0-acceptable, but o_3 is 0-Pareto.

Quality of Outcomes: Example



$t = 0$: $o_1 \succ o_3 \succ o_2$ and $o_2 \succ o_3 \succ o_1$
No offer is 0-acceptable, but o_3 is 0-Pareto.

If agent 2 utters argument a_3: $t = 1$: $o_2 \succ o_3 \succ o_1$ and $o_2 \succ o_3 \succ o_1$
Now offer o_2 is 1-acceptable (and so 1-Pareto).

Conclusion

This course was certainly not exhaustive but tried to convey some fundamental ideas...

- in particular: much richer representations (logic-based) give a much finer understanding of the type of arguments, goals, etc. which can be involved in negotiation

Many things remain to do...

- the added-value of argumentation in negotiation remains somewhat theoretical
- experimental results start to emerge, raises questions of strategies

Thanks!