Mult-Agent Negotiation

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Organization

- Introduction to negotiation behavior
- Multi-agent negotiation basics
- One-to-many negotiations
- Opponent modeling and machine learning

Negotiation: Etymology

- The term negotiation originated in 15th century Old French “negociacion”
- At the time, the term meant ``business, trade and traffic". Later on, its meaning became "to communicate in search of mutual agreement”
- Hence, the sense of term shifted from "doing business" to "bargaining about business"

Negotiation Definition

In his influential book, Dean Pruitt provides one of negotiation's most widely accepted definitions :

- Negotiation is the process by which a joint decision is made by two or more parties. The parties first verbalize contradictory demands and then move towards agreement by a process of concession making or search for new alternatives

Dean Pruitt,
Professor at GMU

Should I Negotiate?

- To illustrate the benefits of the negotiation, professor George-J.-Siedel from the university of Mechigan, conducted the following experiments:
  - Ask the students to go the city, walk into retail stores, fast food restaurants, and try to negotiate a lower price despite a fixed price (not into a market)
  - Results: 69% Successful in getting lower prices, 6% to 100% discount, with average 40%
  - Total savings: 1580$
- Therefore, negotiation can be always useful
- However, it can be a time-consuming, and uneasy task

Negotiation Issues

- The problem being negotiated, or the topic under discussion (e.g. car purchase) can be usually divided into issues (also called attributes).
  - Some negotiations involve only single issue (e.g. car price)
  - Others involve multiple issues (e.g. price and delivery time)
- Disagreement may be
  - On the value of each issue
  - The priority assigned to each issue
  - This divergence maybe a source of both agreement & disagreement

Possible issues: Price, color, brand, year, etc.

Negotiation: Types

- The degree of divergence between the negotiators may vary depending on many factors.
- In some negotiation cases it is possible that parties discover new alternatives, reduce their divergence, and establish win-win settlements.
- In other cases there is no place for compromise because the negotiators interests are strictly opposed

Types

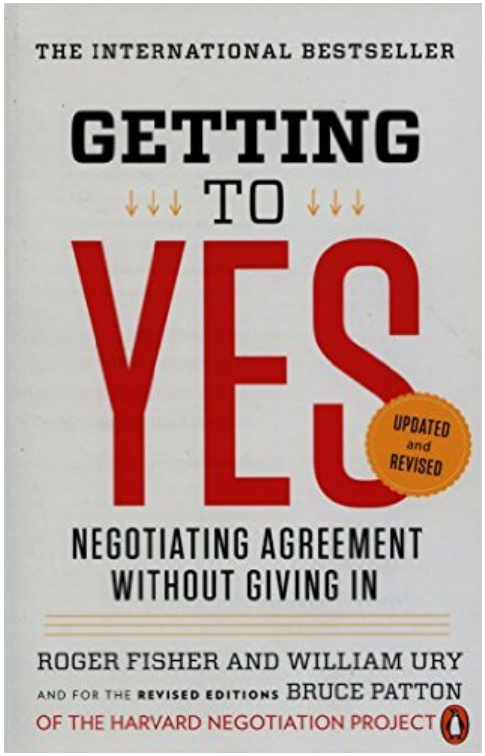
- Distributive (also called Position-based) negotiation
- Integrative (also called interest-based) negotiatin
- Mixed-motive negotiation

Distributive Negotiation

- A pure distributive negotiation is one where a gain for one party is a loss for the other
- That's why this type of negotiation is also called competitive, win-lose, zero-sum or pure-conflict, or Position-based negotiation
  Deals with the division of limited resources (fixed-pie)
- Each party seeks to improve its position by maximizing its share of the limited resource while minimizing the share acquired by the opponent
- No place for win-win settlements since winning is synonymous with forcing the opponent to concede

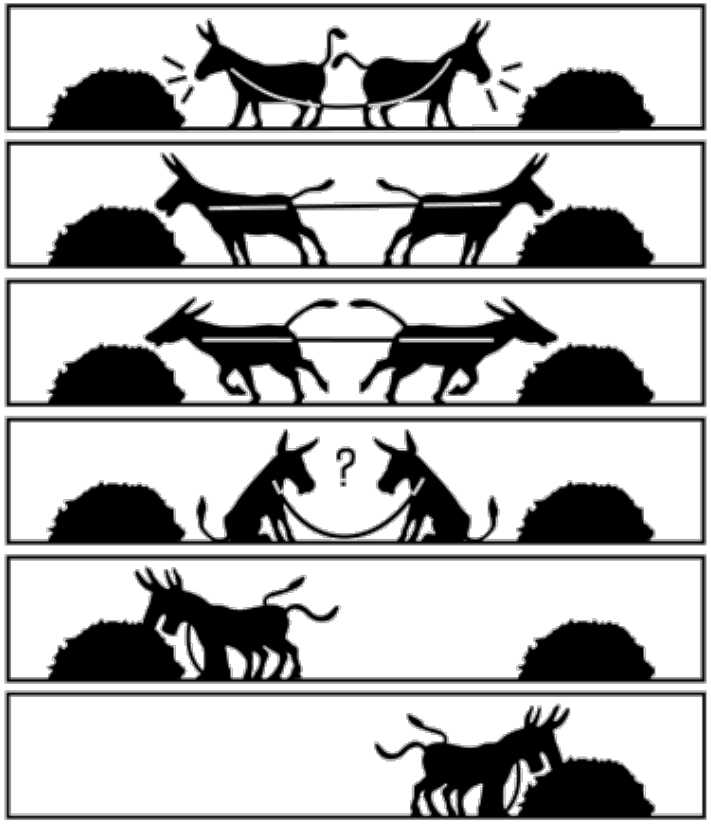
Integrative Negotiation

- Also called interest-based negotiation
- Parties are cooperative. The negotiation in this case is non-zero sum and parties can focus on common interests (not positions) and look for win-win settlements
- instead of quarreling about a (fixed pie), they exchange relevant information allowing them to integrate their interests and find out new possibilities of cooperation
- Consequently in this type negotiators tend to prefer tradeoff and compromises



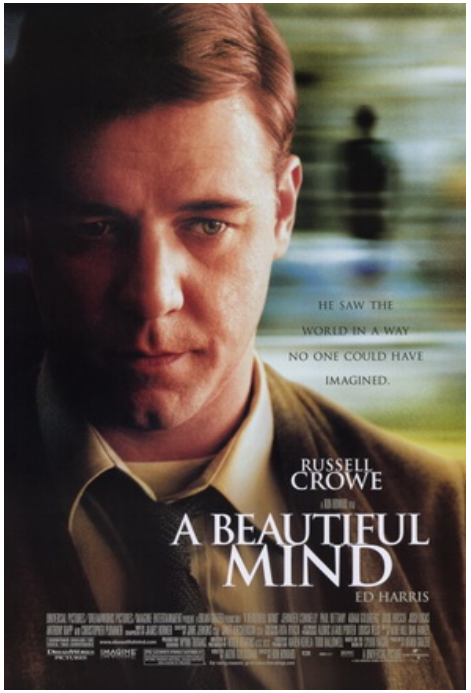
Orange Quarrel Drama

Integrative negotiation: Cooperation



Integrative negotiations: challenges

- Requires cooperation & cooperative attitudes
  - John Nash: Without cooperation, competition leads to non-optimal equilibrium
- Information sharing: parties need to share their preferences, concerns and goals
- Most of real life problems are not purely distributive
- Finding a solution that maximize the joint utility maybe non-feasible for humans
- May require a mediator (raises trust issues)



Quarrels in real scenarios

Mixed-motive Negotiation

- Some authors consider that purely distributive & integrative negotiations are theoretical extremities
- Any other negotiation can be situated in between these two extremities and therefore can be described as Mixed-Motive Negotiation
- This type of negotiation occurs when:
  - some of the settlement points are better for both parties than are others… and the integrative potential of negotiation is the increase in joint profit available to negotiators
- Therefore, negotiators usually combine tradeoffs and concessions. When tradeoffs fail to obtain an agreement they concede in order to reach agreement

Negotiation Strategy (1): Definition

- Also called negotiation tactic
- Negotiators must propose offers that correspond to their preferences. In case they reject the opponent's offer, they should come up with a counter-offer
- A negotiation strategy is a policy to generate the next offer
- It helps the bargainer to decide whether to concede or not (either propose an alternative i.e. a tradeoff or standstill)

Negotiation Strategy (2):Tradeoffs

- In multi-issue negotiation
- A negotiator, triesto shift one issue in the supposed direction of opponents favor while shifting the other in his own favor
- Tries to find a cooperative, win-win solution

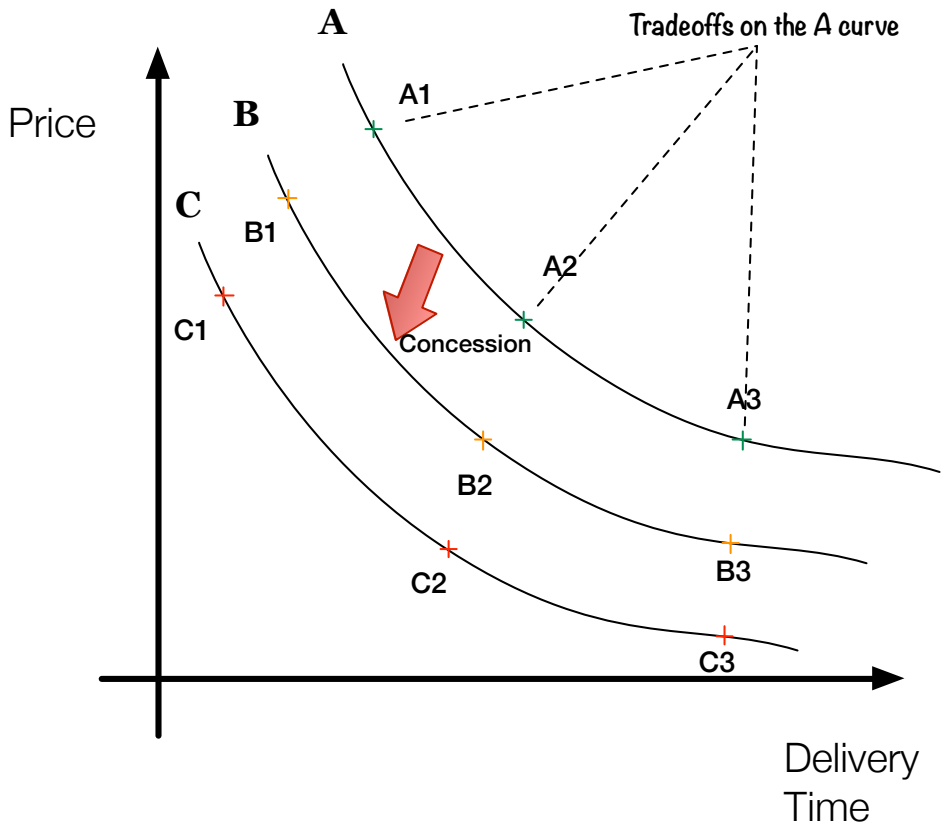
Why « *supposed* » ?

Because, without information sharing, a negotiator does not know what is the real preferred valeu of his opponent for a given issue

Negotiation Strategy (3): Concessions

- Tradeoffs are not always enough to reach an agreement
- It is common for both parties or one of them to concede in order to strike such an agreement
- Pruitt defines concession as:
  - « A change of offer in the supposed direction of the other party's interests that reduces the level of benefit sought »
- Concession benefits:
  - They can hasten agreement
  - Prevent the opponent from leaving the negotiation
  - Encourage him or her to replicate the concession

Tradeoffs vs Concessions



Negotiation Strategy (4): Limit & Goal

Limit

- A bargainer ultimate position, the level of benefit (or utility) beyond which he or she is unwilling to concede
- Also called reservation value
- Any agreement with a lower value is worse than no agreement

Goal

- the value towards which a negotiator is striving because he considers it attainable
- Also called preferred value

Negotiation Strategy (5): Example

- Usually a negotiator does not reveal neither his limit nor his goal. Instead, he asks for high demand levels in order to prevent the opponent from detecting his limit
- Otherwise all possible deals yielding a value better than the limit would be threatened

Example of a seller:

- Real goal: 2000$
- Declared goal: 3000$
- Limit: 1200$

Negotiation Strategy (6): Influence Factors

- In practice, a negotiation strategy is influenced by multiple and complex factors including :
  - past experiences of a similar negotiation, gender, culture, the existence of alternatives, mediators, time pressure, and reactions to the opponent behavior
- However, when dealing negotiations among autonomous agents, only some of these factors are relevant

Negotiation Strategy (7): Time pressure

- It is the negotiators' desire to end the negotiation quickly
- Is caused by the cost incurred by continued negotiation, the need to get the final product quickly, or the fear of an imminent time deadline or the fear of opponent leaving the negotiation
- It usually pushes bargainers to make faster concessions
- Modeled well in MAS

The Dayton agreement signed in 1995 to end-Yugoslavian civil war: the American mediator has fixed 19 november as a theoritical deadline (17 days conference) and a hard deadline was to find agreement before thanksgiving day (Nov 23)

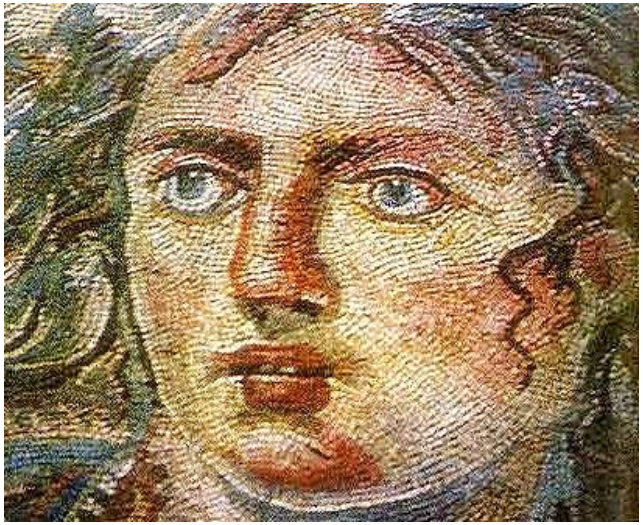
Negotiation Strategy (7): Reactions to Opponent Behavior

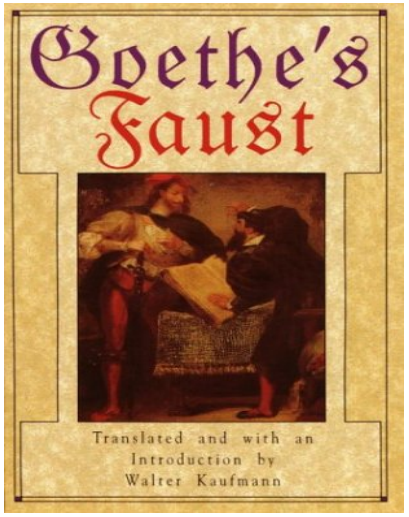
- Basing one's own negotiation behavior on the opponent's behavior is a common strategy both among human and among autonomous agents

- Two major types of reactions:
  - Matching :or imitation in which if one party demands more, the other demands become larger. The opposite is also true. If one makes importance concessions the other reacts by making similar ones (likely in integrative negotiations)
  - Mismatching: concessions from one party causes the opponent to become convinced that the other is desperate to reach an agreement. The latter strategy is called tracking (likely in distributive negotiations)

Human Negotiation: Conclusion

Human Negotiation : an ancient practice, a science and art

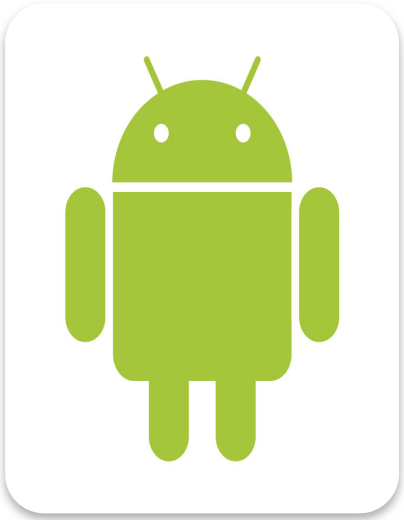




Multi-Agent Negotiations

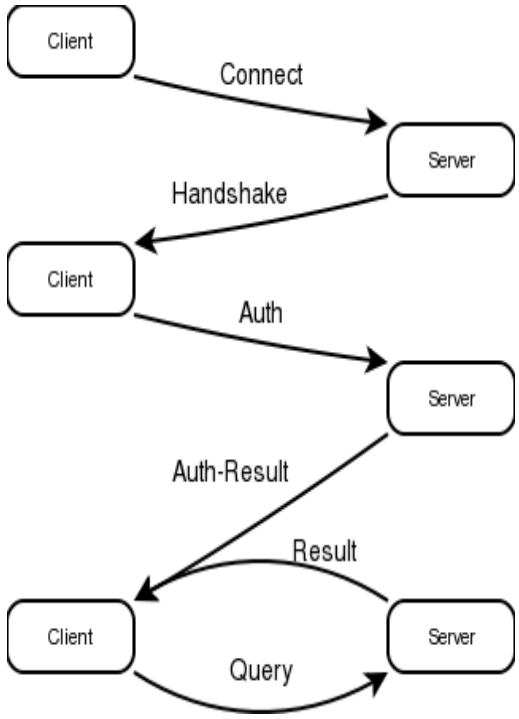
Multi-Agent Negotiations

- Appeared about three decades ago
- Agent-agent negotiation, or human-agent negotiation
- Takes inspiration from Human Negotiation behavior
- Agents may outperform humans in their search for optimal solutions notability in highly multi-issue negotiation



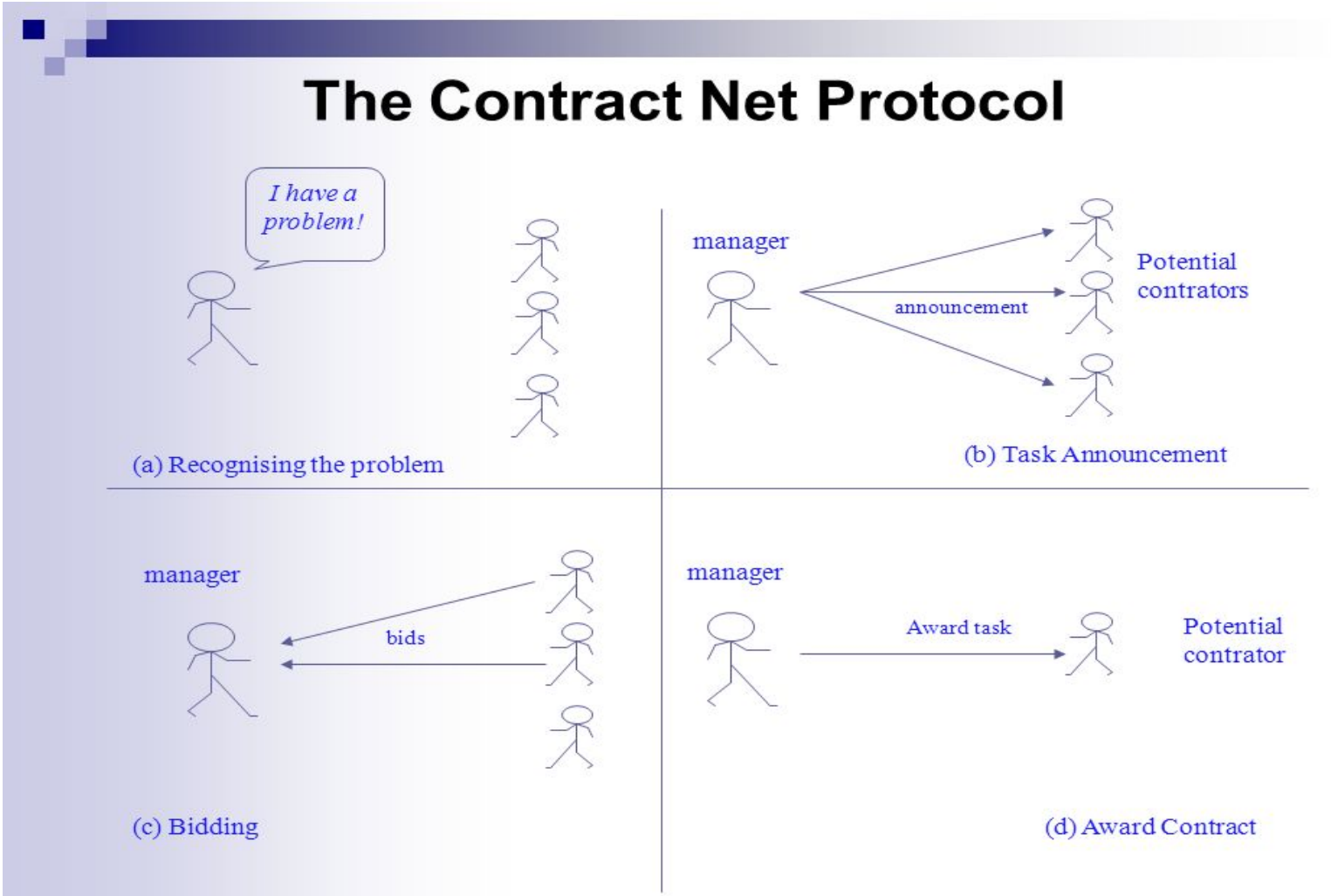
Negotiation Protocol (1): Definiton

- A negotiation protocol is the set of rules that governs the interactions during a negotiation session (also called a thread)
- It covers:
  - The types of participants, including third parties (a broker)
  - Possible negotiation states:
    - When negotiation is terminated, still open, etc
  - Events that may alter negotiation states (e.g. offer accepted)
  - valid actions of negotiators (e.g. proposing counter-offers, leaving the negotiation process, etc.)



Negotiation Protocol: Contract Net

- Proposed in 1980 by Reid Smith



Alternate Offer Protocol

- Many different versions
- Complete & incomplete information
- When the agent receives an offer from its opponent, it can:
  - Quit the negotiation session
  - Accept the offer
  - Propose a counter offer with or without a concession
- Can use time deadline, etc.
- The standard form of alternate offer protocol can be enhanced to support application specific needs. For instance to support one-to-many negotiations

Monotonic Concession Protocol

- Is a variety of Alternate Offer Protocol:
- In the beginning of the negotiation session, agents are required to disclose information about their preferences concerning the negotiation issues:
  - E.g. I'm interested in price, more than delivery time
- Offers proposed by each agent must be a sequence of concessions *i.e.* each consecutive offer has less utility for the agent than the previous one
- Standstill are not possible

One Step Negotiation Protocols

- This Protocol has only one round, where the two agents propose a deal, and they must accept
- Exercise:
  - Suppose that three agents are participating in multi-lateral negotiation sesssions
  - The agents should accept an offer that maximizes the product of their utilities
    - Agent *A* proposes an offer with U_A=0.9, U_B=0.1, U_C=0.1
    - Agent B proposes an offer with U_A=0.4, U_B=0.7, U_C=0.4
    - Agent C proposes an offer with U_A=0.5, U_B=0.5, U_C=0.5
  - Which offer will be chosen according to this protocol?
  - What is the best strategy if this protocol is used ?
  - What are the advantages and disadvantages of this protocol ?

Negotiation Object

- The topic under discussion in the negotiation process or the range of issues over which agreement must be reached
- An object may be composed of one issue or attribute (e.g. price) or it may cover multiple issues (price, quality, delivery time, etc.)
- An agent makes an offer to its opponent when it assigns a value to each one of the attributes describing the object being negotiated
  - Formally, an offer o^t_i, sent from the agent *i* to its opponent at *t time* is:

$$o_i^t = \{v_1^t, v_2^t, v_3^t \ldots v_n^t\}$$

- Whenever a negotiation process deals with multiple issues, negotiators might become interested in making tradeoffs since the importance of a given issue may differ from one party to another.
  - In some negotiation negotiators can send a burst containing several offers:

$$b_i^t = \{o_1^t, o_2^t, \ldots, o_N^t\}$$

Agent Decision Model

- the negotiation protocol defines what is the set of possible actions that can be taken during a negotiation session:
- An agent's decision model allows the agent to :
  - Evaluate the value of an offer received from the opponent
  - Decide whether it is acceptable
  - Determine what to do next
- These are respectively
  - Utility function/ Preference Relationships
  - Acceptance condition
  - Negotiation strategy

Agent Decision Model: Utility Function

- Utility function is a concept borrowed from microeconomics that encodes the preferences of an agent and quantifies its satisfaction
  - It determines the benefit obtained from a received (or proposed) offer

- If an agent is interested in several offers, its utility is likely to be a weighted sum of issue-wise utility functions:

$$M(o_i^t) = \sum_{j=1}^{j=J} w_j \times \mu_j(v_j^t)$$

- Where: o is the offer received from the opponent, w_j is the weight assigned to the attribute j and μ is the utility function of the attribute j
- w_j expresses how much importance the agent gives to the issue j

Agent Decision Model: Preference Relationships

- A logic that describes the possible alternatives
  - A+B: A and B are equally preferred by the agent
  - A>B: A is strictly preferred than B by the agent
  - A>=B: A is preferred than B by the agent
  - e.g. I prefer a blue car to a black car, blue and red are equally preferred
- Challenges:
  - These preferences should be complete, they should cover all the possible alternatives
  - Typically it is assumed that these preferences are transitive

Remarks

- Utility functions are complete: they assign a numerical value to each alternative
- Utility function provide cardinal preference structure that quantifies the utility of each alternative

Agent Decision Model: Acceptance Condition

- In order to accept or reject an offer, an agent a_i relies on its Aspiration Rate AR_{ai}^{t}
  - It reflects how much utility an agent expects to obtain at the negotiation cycle *t*
- An agent a_i accepts an offer iff:

$$AR_{a_i}^{t} \leq M_{a_i}(O_{a_l}^{t})$$

- M is the utility function of the agent a_i
- AR is the aspiration rate of the agent a_i at the time *t*
- AR in [0:1], AR= 1, the agent expects the best
- O is the offer received at time *t* from the opponent b_l

Exercice:

- Suppose that we have a buyer agent Its utility functions are defined as follows:

$$M(o_i^t) = \sum_{j=1}^{j=J} w_j \times \mu_j(v_j^t)$$

  - Suppose that the service under discussion involved two issues:
    - Price, its weight is 0.75
    - Quality, its weight is 0.25
  - Suppose that the issue-wise utility function are defined as follows for quality and price respectively:

$$\mu_{quality}(q) \frac{q - RQ}{PQ - RQ} \qquad \mu_{price}(p) = \frac{RP - p}{RP - PP}$$

- Where RQ= 1, PQ=10 are respesctively the preferred and reservation quality and RP=5, PP=1 are the prefferred and reservation price
- p and q are respectively the price and quality received from the seller
- Suppose that the current aspiration rate of the buyer is 0.8 and the buyer receives an offer o={q=6, p=4}, is this offer acceptable ?
- Generate a counter offer that correspends to this aspiration rate, can you generate several tradeoffs ?

Agent Decision Model: Negotiation Strategy

Concession

- The agent accepts to reduce its Aspiration Rate
- Thus, it accepts offers with lower utility
- Several types
  - Time-based Concessions (TBC)
  - Behavior-based Concessions (BBC)
  - Resource-Based concession (RBC)

Tradeoffs

- The agent retains its aspiration rate
- Shifts one issue in its favor while shifting the other in the opponent favor
  - I will pay you more money if deliver my item faster

Agent Decision Model: Concession Strategies

- When an agent concedes, it accepts to reduce it aspiration rate. Therefore it becomes ready to accept less beneficial offers
- The concession made the agent a_i is defined as follows:

$$AR_{a_i}^{t} = AR_{a_i}^{t-1} - \Delta AR_{a_i}^{t}$$

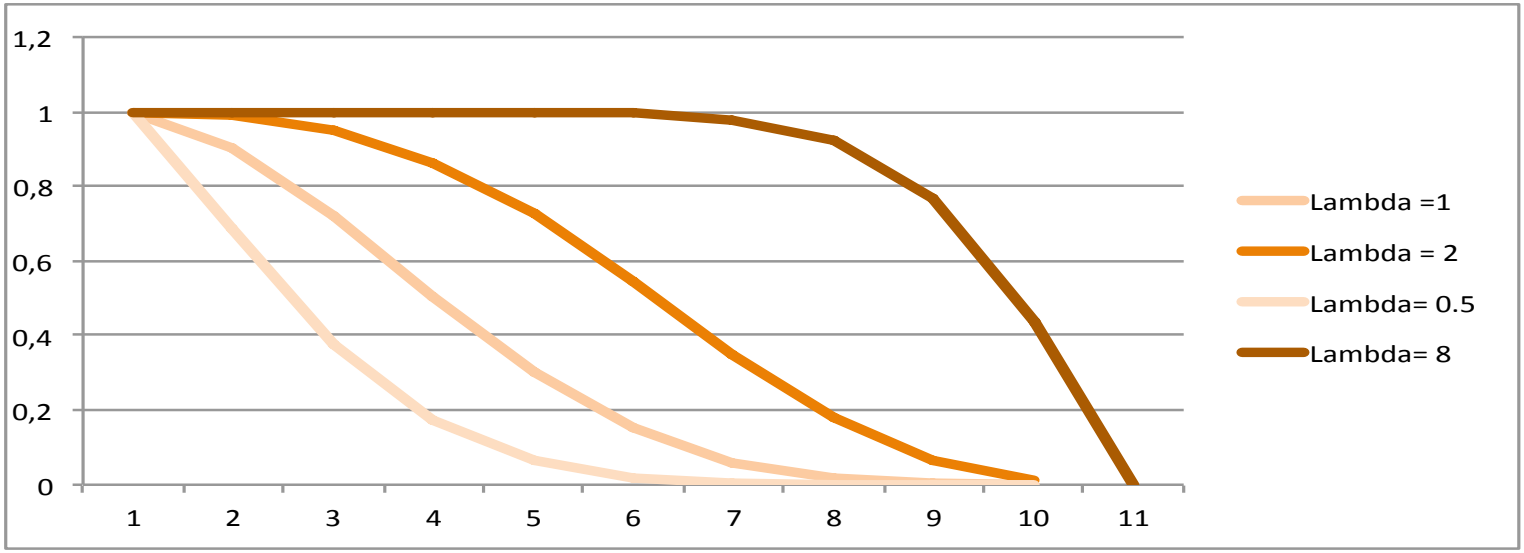
$\Delta AR_{a_i}^{t}$ Is the concession made by the agent, next slides presents The different types of concession strategies

1)Time-based Concession Strategies

- Used to model the time pressure
  - An agent has a timedeadline T_{ai}
- Different types, the most common:

$$\Delta AR_{a_i}^t = AR_{a_i}^t \times \left(\frac{t}{T_{a_i}}\right)^{\lambda}$$

- λ reprsents the concession behavior
  - $\lambda < 1$ concilliatory agent
  - $\lambda = 1$ linear agent
  - $\lambda > 1$ Boulware or concervative agent



Behavior-Based Concessions

- It is about reacting to the opponent behavior,
- Inspired from matching and mismatching
  - Tit-for-tat concession: $\Delta AR^t_{a_i} \propto \Delta AR^t_{a_l}$

- Where the agent a_j is the opponent of the agent a_i
  - Mismatching: $\Delta AR^t_{a_i} \propto \frac{1}{\Delta AR^t_{a_j}}$

Question

- How to measure the opponent concession ?

Tradeoff Strategies

- In multi-issue negotiation, the probability that negotiators have identical preferences across all issues is small. Therefore, it may be profitable to trade these issues off against one another to create joint gain

- Hence, it is possible for an agent to abstain from conceding while still making a possibly interesting offer to its opponent
  - Thus, the agent does not reduce its aspiration rate but it produces a new offer with roughly the same utility
  - If the agent does not know the preferences of the opponent, this is only a guess

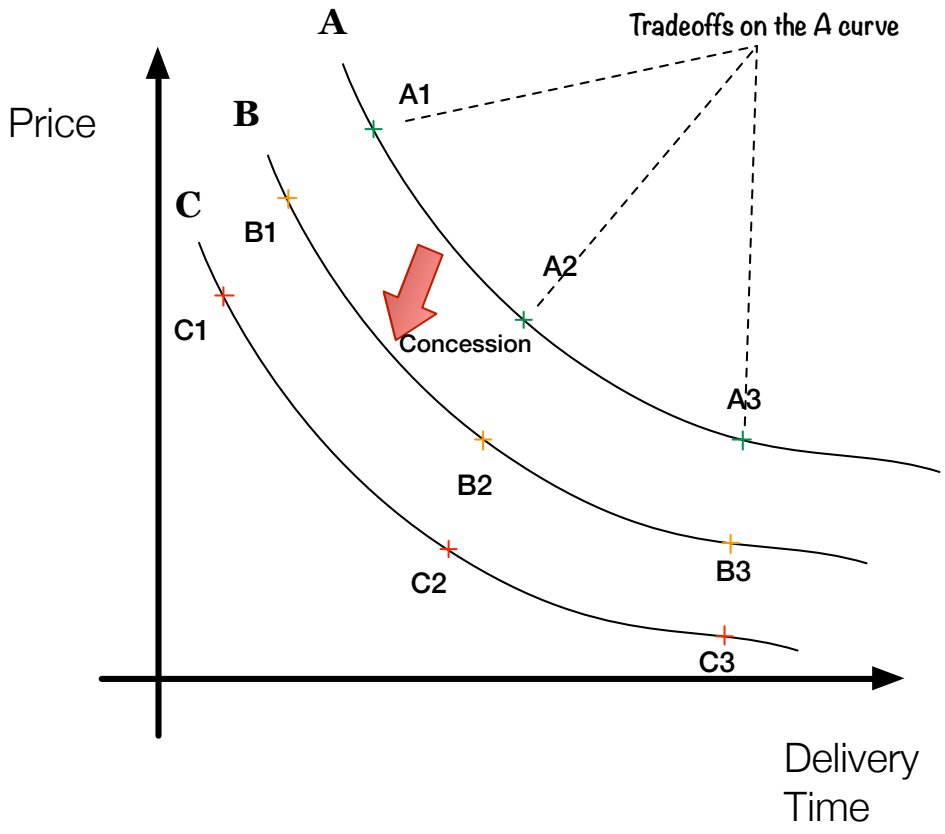
- tradeoffs are more common in integrative negotiations. In this type of negotiations, negotiators might even partially reveal their preferences hereby transforming the negotiation process into a kind of joint problem solving

- Tradeoffs are less common in distributive negotiation where the fixed-pie perception is dominant and where negotiators tend to view the negotiation process as a pie-slicing task

Meta (or combined) Strategy

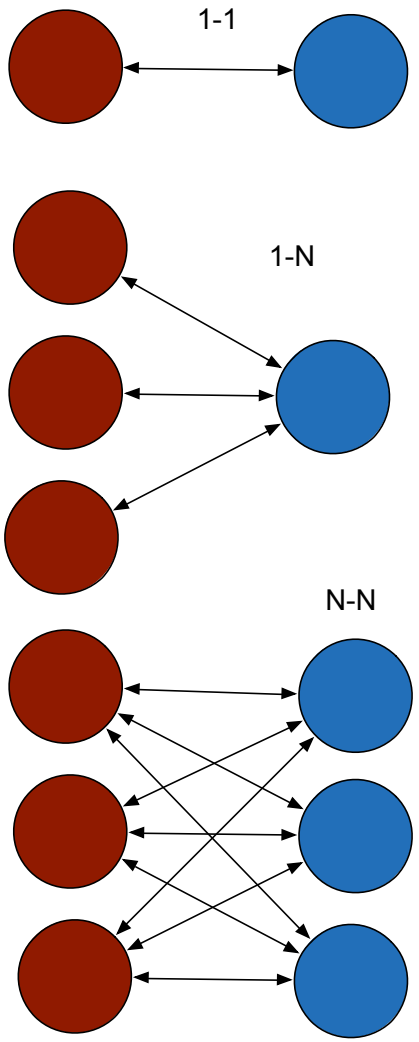
- Relying on tradeoffs solely yields a relatively lower success rate
- Using only concession, may not find the best win-win agreement
- A meta-strategy can be used to combine tradeoffs and concessions
  - Such a combination between concessions and tradeoffs allows an agent to exploit the current aspiration rate as much as possible by proposing several offers situated on the current
  - If no agreement is found in a given time deadline (hence a deadlock), then the agent makes a concession hereby moving to a lower aspiration rate curve

Tradeoffs & Concessions



Negotiation Cardinality

- Based of their cardinality, negotiation sessions can be classified into:
  - One-to-one (or dyadic): one agent negotiates with exactly one agent
  - One-to-many: where many agents negotiate with just one agent
  - Many-to-many negotiations: is the most complex scenario where many agents negotiate with many other agents



One-to-many Negotiations

Motivation

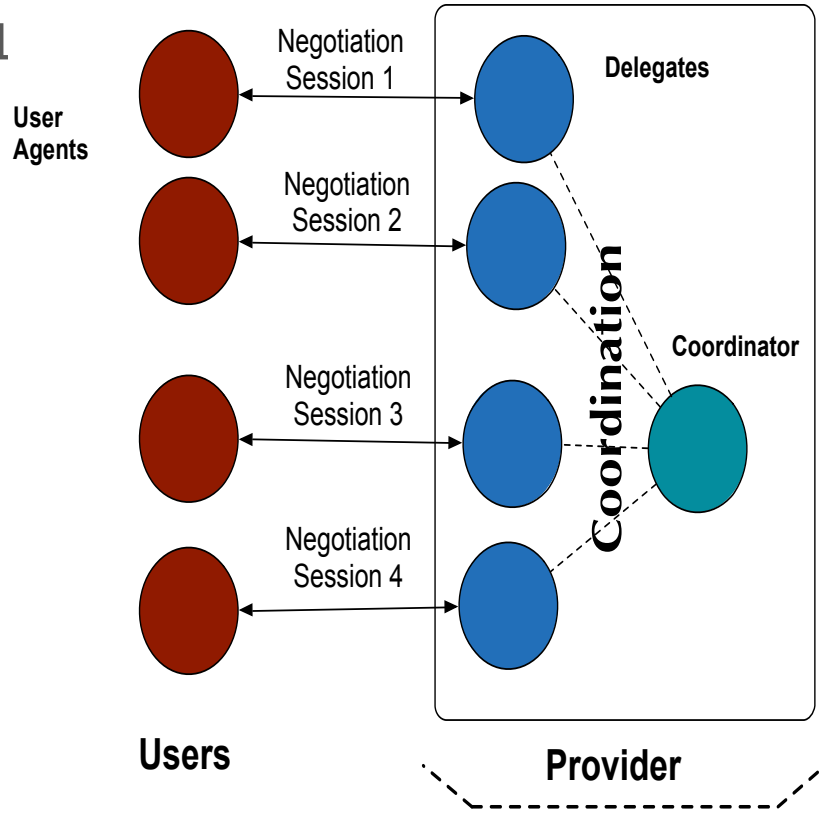
- Auctions (ordinary and reverse, or double-sided auction protocols)
- used to be the classic approach to handle one-to-many negotiations. However, this approach suffers from important shortcomings:
  - participating agents cannot exchange two-way offers and counter-offers
  - auctions do not allow agents to employ different negotiation strategies with different opponents
  - one-to-many negotiation approaches have been proposed in order to overcome these limitations

Remark

- Auctions in MAS remain a hot research topic. But it is beyond the scope of this presentation

Basic Architecture

- Rahwan *et al.* proposed one of the first architectures in 2002
- Represents one-to-many negotiations as many 1-1 negotiations coordinated by a coordinator
- The party negotiating with several opponents is represented by 2 types
  - A coordinator agent
  - Delegate agents
- Uses two types of strategies
  - Negotiation in 1-1 sessions
  - Overall coordination strategy



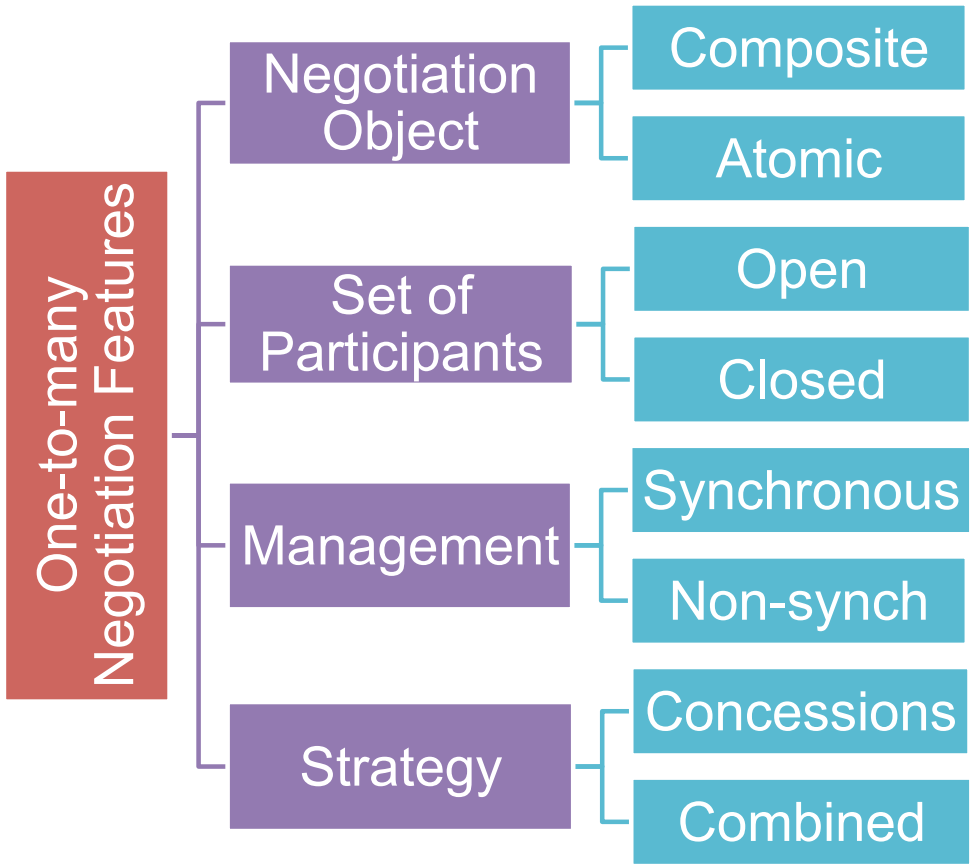
Applications

- Concurrent negotiations:
  - One buyer negotiating with multiple competing sellers
  - One seller negotiating with multiple competing buyers
- Service composition
  - A service composition mechanism that creates a composite service from several atomic services each proposed by an *atomic seller*
- *Service provider:*
  - *A service provider negotiating with its clients (e.g. cloud provider, SaaS, etc.)*

Important

- The aim and the scope of the used coordination/ negotiation strategies depends on the application

Classification



Classification: Negotiation Object (1)

- *Atomic object:*
  - The aim of the party negotiating with multiple opponent is only to find the best (only one) agreement with one of its opponents and abort all other agreements
  - Most of works in the literature address this case
  - Coordinator task is to adapt the delegate negotiation strategies to maximize the obtained utility:
    - Once a *good* agreement is reached, the coordinator modifies the negotiation strategy of all the ongoing delegate so that any new agreement is necessarily better than the reached one
    - Coordinator classifies opponents into *conceders* and *non-conceders* and then adjust delegate negotiation strategies
  - Used when one buyer negotiation with competing sellers or one seller negotiates with competing buyers

Classification: Negotiation Object (2)

- Composite object:
  - In this case the goal of the agent negotiating with multiple opponent is reach agreement with more than one (maybe all) of its opponents
  - Typically, the coordination strategy seeks to maximize the number of agreements
    - Use surplus redistribution
  - Used in service composition and mashups
    - e.g. a buyer wants to buy several atomic services to compose a *composite service.*

Classification: Set of Participant

- Open:
  - Participants can enter/leave the system when they desire
- Closed:
  - Participants are defined a priori. They are known before the outset of the negotiation
  - New agents cannot enter the negotiation sessions
- Most of existing works in the literature assume *closed* set of participants

Classification: Management & Strategy

- Management
  - Synchronous:
    - the *single* agent must wait to receive the offers from all its opponents before it reacts
    - Sessions are synchronized
  - Non Synchronous:
  - Sessions are not synchronized
- Strategy
  - Only concessions
  - Combined

Opponent Modeling

Motivation

- Often, the preferences of the opponent, its negotiation time deadline and its decision model are not disclosed
- For this reason, modeling the opponent is important to understand his/her actions and behavior
- Benefits:
  - Reach win-win settlements: infering information about the opponent decision model increase the chances of joint gain
  - Avoid exploitation: non-adaptive agents can be exploited (given enough history records), since their behavior become predictable
  - Minimize negotiation cost and avoid non-agreement

Learning Methods

- Bayesian Learning
- Non-Linear Regression
- Kernel Density Estimation
- Artificial Neural Networks

Remark

- Main reference for this section is: Tim Baarslag et al: Learning about the opponent in automated bilateral negotiation: a comprehensive survey of opponent modeling techniques

Bayesian Learning (1)

- Used to identify the most likely hypothesis H_i out of a set of hypotheses
  - In agent negotiation a hypothesis can be:
    - The opponent is a considers, the opponent is more interested in quality than price, the time deadline of the opponent is approaching, etc.

$$P(H_i \mid E) = \frac{P(E \mid H_i) \times P(H_i)}{\sum_{j=1}^{n} P(E \mid H_j) \times P(H_j)}$$

  - Thus, an agent forulates a set of independent hypotheses about its opponent
  - Each time a new evidence is observed, the equation is used to validate existing hypotheses
  - The agent can conclude which H is the most probable

Bayesian Learning (2): Challenges

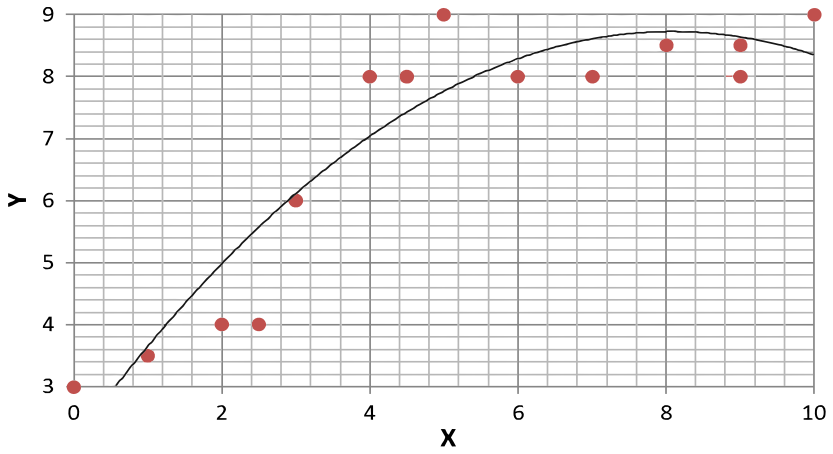
- Initializing the learning algorithm choosing the right input
  - A suitable representation of the opponent preferences
  - Defining initial hypothesis

  These tasks are not straightforward and may lead to imprecise results

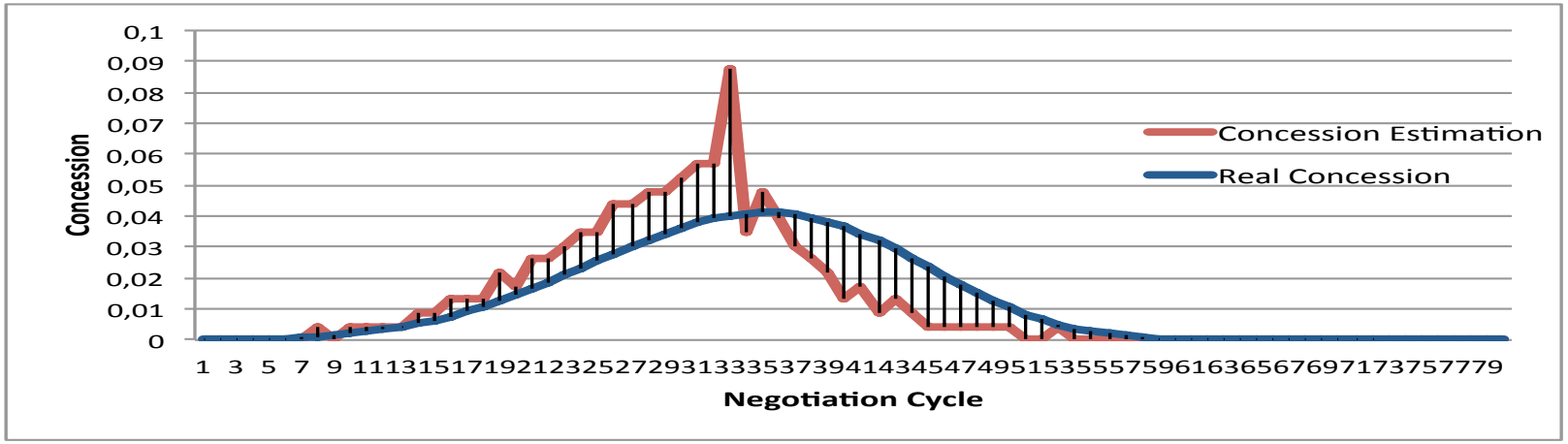
- Complexity:
  - Even a simple negotiation scenario requires a set of hypotheses for each negotiation issue (the weight of the issue, the reservation value for the issue, etc.). This leads to a number of hypothesis exponential with the number of issues because issues are interrelated

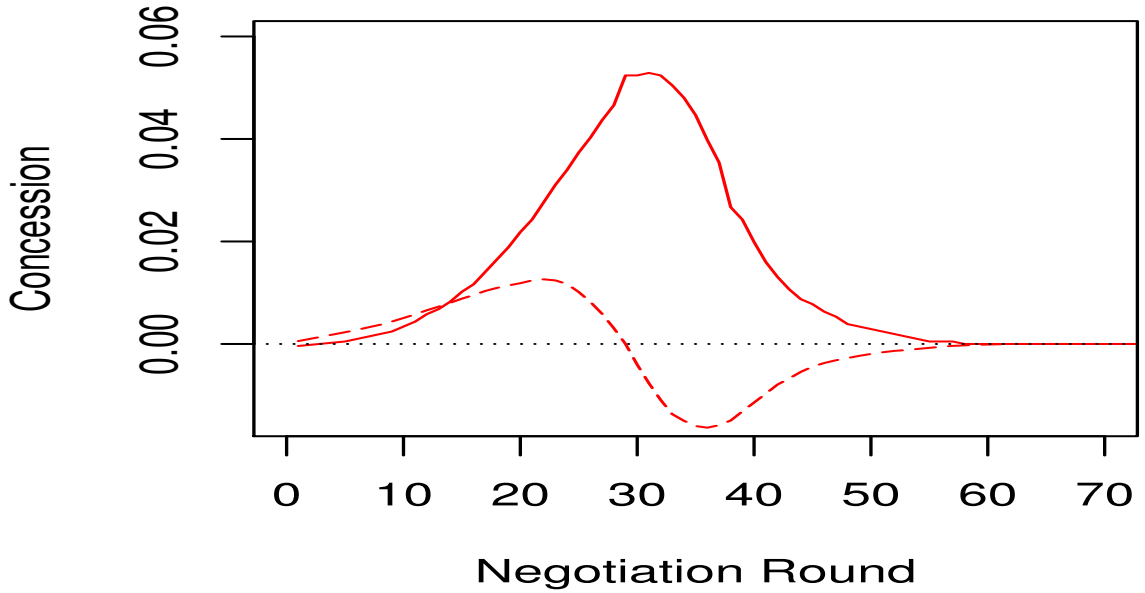
Non-linear regression

- Non-linear regression is used to derive a function which best matches a set of observational sample data
- It is employed when we expect the data to display a certain functional relationship between input and output
- In negotiation, this can be used to estimate the opponent's future behavior (e.g. time deadline) from the negotiation history assuming that the opponent's bidding strategy uses a known formula with unknown parameters

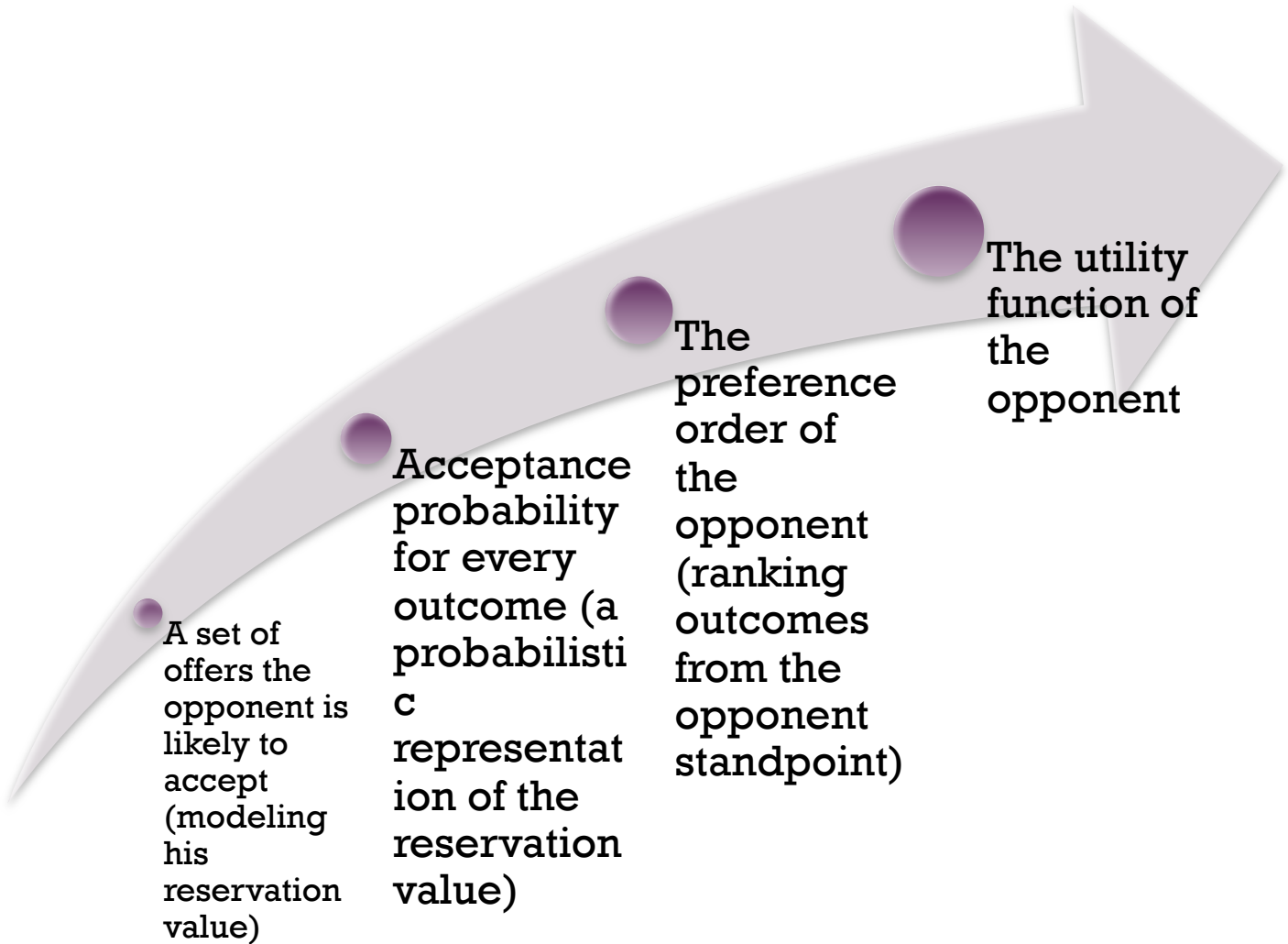


Non-linear Regression: Example





Model Granularity



The Quality of the Opponent Model

- Measuring the quality of the constructed model of the opponent is useful to:
  - Assess the usefulness of the model
  - Compare different models
  - Adjust the model to achieve better results
- Two main approach
  - Accuracy: how closely the proposed model resembles reality
  - Performance: measures the performance gain when the model is used
- Problem
  - Existing works measure their proposed models in their own settings

Negotiations: research venues

- Agent negotiation is remains to be a hot research topic
- Main conferences:
  - AAMAS: International Conference on Antonomous Agents and Multiagent Sytems
  - Group Decision and Negotiation
- Journals:
  - JAAMAS
  - Group Decision and Negotiation
- Workshops:
  - International Workshop on Agent-based Complex Automated Negotiations

ANAC

- is an annual event held with AAMAS
- brings together researchers from the negotiation community and provides unique benchmarks for evaluating practical negotiation strategies in multi-issue domains
- Incomplete information about the opponent
- Who is the winner :
  - Highest average utility
  - Highest social welfare: the agent should also offer good utility to the opponent
  - Agent Likeability Category: in human-agent negotiation

Negotiation: Research Trends

- Negotiation with argumentations
- Negotiation with ethics
- Human-agent negotiations
- Applications:
  - Negotiation for grid computing resource management
  - Negotiation for cloud computing resource management
  - Negotiation for Smart Grids resource management
  - E-commerce
  - User modeling & personalization
  - Smart environments