

Automated negotiation

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Negotiations

- ▶ “A discussion in which interested parties **exchange** information and come to an agreement.” — Davis and Smith, 1977

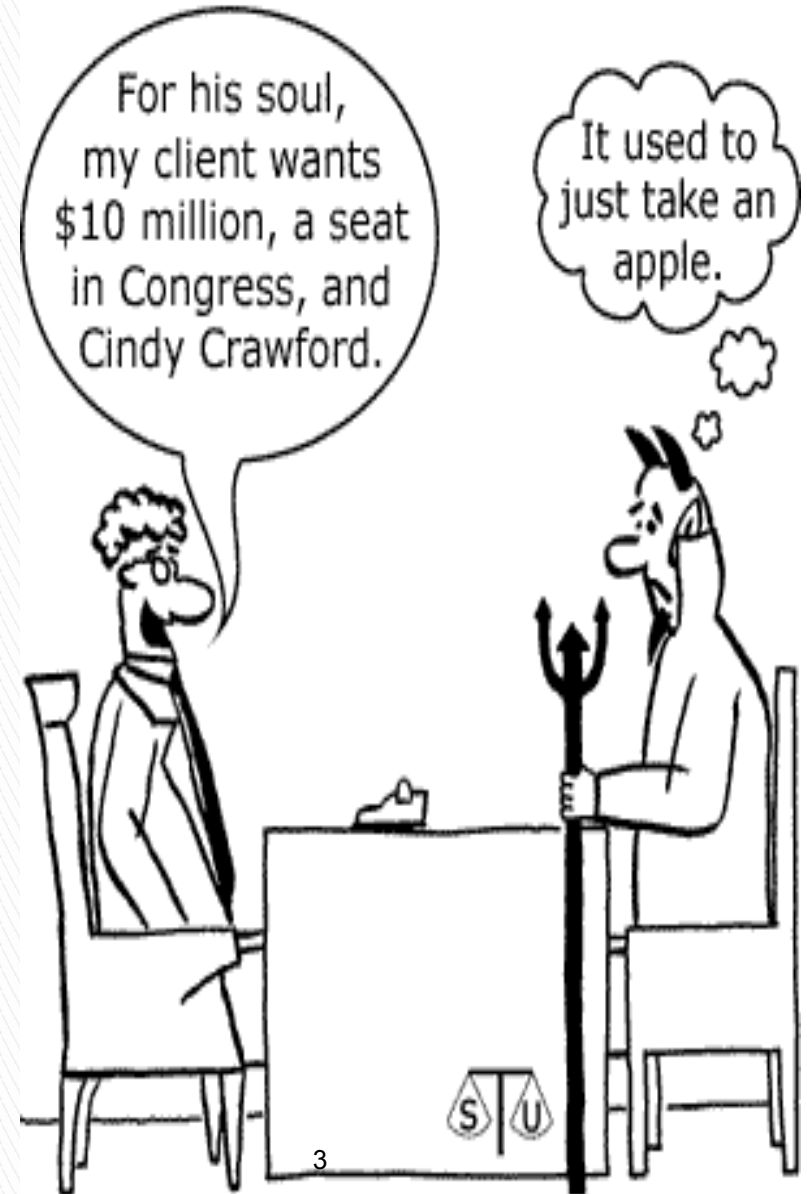


Negotiations

Stu's Views

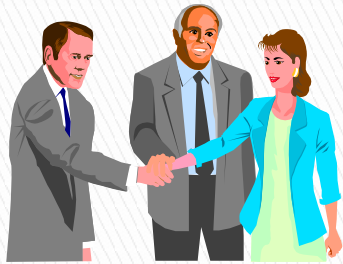
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NEGOTIATION is an interpersonal decision-making process necessary whenever we cannot achieve our objectives single-handedly.



Automated Negotiation

PART 1: Coordination and cooperation of automated agents



Agent environments

- ▶ **Teams of agents** that need to coordinate joint activities; problems: distributed information, distributed decision solving, local conflicts.
- ▶ **Open agent environments** acting in the same environment; problems: need motivation to cooperate, conflict resolution, trust, distributed and hidden information.

Open Agent Environments

- ▶ Consist of:
 - Automated agents developed by or serving different people or organizations.
 - People with a variety of interests and institutional affiliations.
- ▶ The computer agents are “self-interested”; they may cooperate to further their interests.
- ▶ The set of agents is not fixed.

Open Agent Environments (examples)

▶ Agents support people

- Collaborative interfaces
- CSCW: Computer Supported Cooperative Work systems
- Cooperative learning systems

■ Agents act as proxies for people

- Military support systems

■ Coordinating schedules

■ Patient care-delivery systems

■ Online auctions

■ Groups of agents act autonomously alongside people

- Simulation systems for education and training
- Computer games and other forms of entertainment
- Robots in rescue operations
- Software personal assistants

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Examples

- ▶ Monitoring **electricity** networks (Jennings)
- ▶ Distributed **design** and **engineering** (Petrie et al.)
- ▶ Distributed **meeting scheduling** (Sen & Durfee)
- ▶ Teams of robotic systems acting in **hostile environments** (Balch & Arkin, Tambe)
- ▶ Collaborative **Internet-agents** (Etzioni & Weld, Weiss)
- ▶ Collaborative **interfaces** (Grosz & Ortiz, Andre)
- ▶ Information agent on the **Internet** (Klusck)
- ▶ Cooperative **transportation** scheduling (Fischer)
- ▶ Supporting **hospital** patient scheduling (Decker & Jin)
- ▶ Intelligent Agents for Command and Control (Sycara)

Types of agents

- ▶ Fully rational agents
- ▶ Bounded rational agents

Using other disciplines' results

- ▶ No need to start from scratch!
- ▶ Required modification and adjustment; AI gives insights and complimentary methods.
- ▶ Is it worth it to use formal methods for multi-agent systems?



Negotiating with rational agents

- ▶ Quantitative decision making
 - Maximizing expected utility
 - Nash equilibrium, Bayesian Nash equilibrium
- ▶ Automated Negotiator
 - Model the scenario as a game
 - The agent computes (if complexity allows) the equilibrium strategy, and acts accordingly.

(Kraus, Strategic Negotiation in Multiagent Environments, MIT Press 2001).



Short introduction to game theory



Game Theory studies situations of strategic interaction in which each decision maker's plan of action depends on the plans of the other decision makers.

Decision Theory (reminder)

(How to make decisions)

- ▶ Decision Theory =
Probability theory + Utility Theory
(deals with chance) (deals with outcomes)
- ▶ Fundamental idea
 - The MEU (Maximum expected utility) principle
 - Weigh the utility of each outcome by the probability that it occurs

Basic Principle

- ▶ Given probability $P(\text{out}_1 | A_i)$, utility $U(\text{out}_1)$,
 $P(\text{out}_2 | A_i)$, utility $U(\text{out}_2) \dots$

- ▶ Expected utility of an action A_i :

$$EU(A_i) = \sum U(\text{out}_j) * P(\text{out}_j | A_i)$$

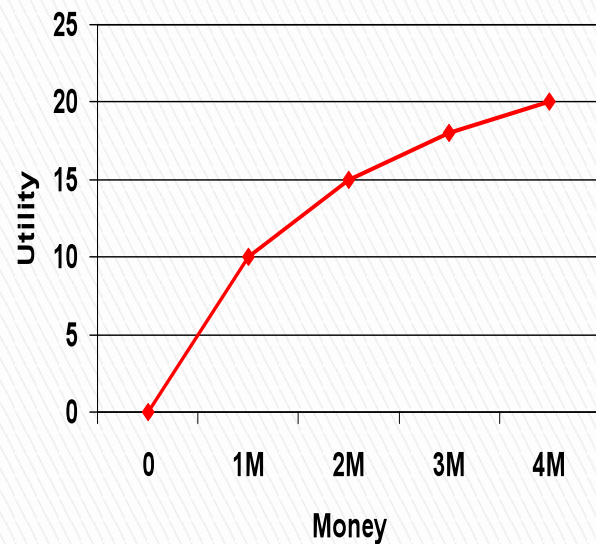
$$\text{out}_j \in \text{OUT}$$

- ▶ Choose A_i such that maximizes EU

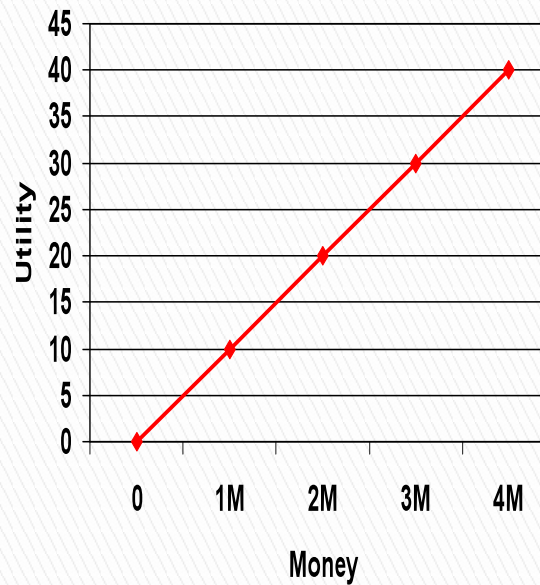
$$\text{MEU} = \underset{A_i \in A_c}{\operatorname{argmax}} \sum_{\text{out}_j \in \text{OUT}} U(\text{out}_j) * P(\text{out}_j | A_i)$$

Risk Averse, Risk Neutral Risk Seeking

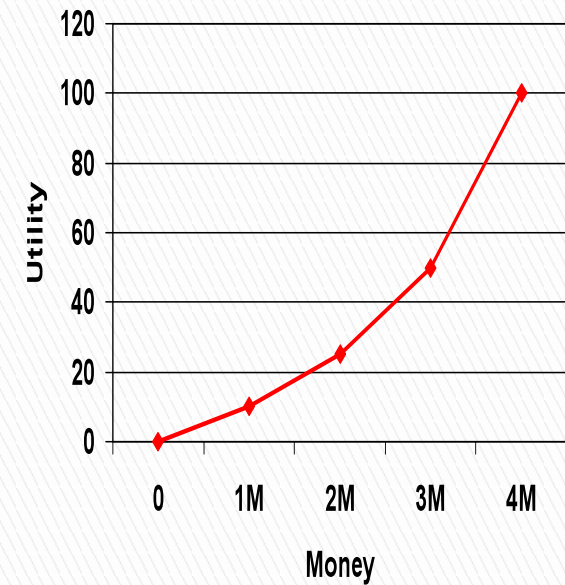
RISK AVERSE



RISK NEUTRAL



RISK SEEKER



Game Description

- ▶ Players
 - Who participates in the game?
- ▶ Actions / Strategies
 - What can each player do?
 - In what order do the players act?
- ▶ Outcomes / Payoffs
 - What is the outcome of the game?
 - What are the players' preferences over the possible outcomes?

Game Description (cont)

▶ Information

- What do the players know about the parameters of the environment or about one another?
- Can they observe the actions of the other players?

▶ Beliefs

- What do the players believe about the unknown parameters of the environment or about one another?
- What can they infer from observing the actions of the other players?

Strategies and Equilibrium

- ▶ Strategy
 - Complete plan, describing an action for every contingency
- ▶ Nash Equilibrium
 - Each player's strategy is a best response to the strategies of the other players
 - Equivalently: No player can improve his payoffs by changing his strategy alone
 - Self-enforcing agreement. No need for formal contracting
- ▶ Other equilibrium concepts also exist

Classification of Games

- ▶ Depending on the timing of move
 - Games with simultaneous moves
 - Games with sequential moves
- ▶ Depending on the information available to the players
 - Games with perfect information
 - Games with imperfect (or incomplete) information
- ▶ We concentrate on non-cooperative games
 - Groups of players cannot deviate jointly
 - Players cannot make binding agreements

Games with Simultaneous Moves and Perfect Information

- ▶ All players choose their actions simultaneously or just independently of one another
- ▶ There is no private information
- ▶ All aspects of the game are known to the players
- ▶ Representation by game matrices
- ▶ Often called normal form games or strategic form games

Matching Pennies

$1 \setminus 2$	H	T
H	$1, -1$	$-1, 1$
T	$-1, 1$	$1, -1$

Example of a zero-sum game.
Strategic issue of competition.

Prisoner's Dilemma

- ▶ Each player can *cooperate* or *defect*

		Column	
		cooperate	defect
Row	cooperate	-1,-1	-10,0
	defect	0,-10	-8,-8

Main issue: Tension between social optimality and individual incentives.

Coordination Games

- ▶ A supplier and a buyer need to decide whether to adopt a new purchasing system.

		Buyer	
		new	old
Supplier	new	20,20	0,0
	old	0,0	5,5

Battle of sexes

		Wife	
		football	shopping
Husband	football	2,1	0,0
	shopping	0,0	1,2

The game involves both the issues of coordination and competition

Definition of Nash Equilibrium

- ▶ A game has n players.
- ▶ Each player i has a strategy set S_i
 - This is his possible actions
- ▶ Each player has a payoff function
 - $p_i: S \rightarrow \mathbb{R}$
- ▶ A strategy t_i in S_i is a *best response* if there is no other strategy in S_i that produces a higher payoff, given the opponent's strategies

Definition of Nash Equilibrium

- ▶ A *strategy profile* is a list $(s_1, s_2, \dots, s_n)$ of the strategies each player is using
- ▶ If each strategy is a best response given the other strategies in the profile, the profile is a *Nash equilibrium*
- ▶ Why is this important?
 - If we assume players are rational, they will play Nash strategies
 - Even less-than-rational play will often *converge* to Nash in repeated settings

An Example of a Nash Equilibrium

		Column	
		a	b
Row	a	1,2	0,1
	b	2,1	1,0

(b,a) is a Nash equilibrium:

Given that column is playing a, row's best response is b Given that row is playing b, column's best response is a

Mixed strategies

- ▶ Unfortunately, not every game has a pure strategy equilibrium.
 - Rock-paper-scissors
- ▶ However, every game has a mixed strategy Nash equilibrium
- ▶ Each action is assigned a probability of play
- ▶ Player is indifferent between actions, given these probabilities

Mixed Strategies

		Wife	
		football	shopping
Husband	football	2,1	0,0
	shopping	0,0	1,2

Mixed strategy

- ▶ Instead, each player selects a probability associated with each action
 - Goal: utility of each action is equal
 - Players are indifferent to choices at this probability
- ▶ a =probability husband chooses football
- ▶ b =probability wife chooses shopping
- ▶ Since payoffs must be equal, for husband:
 - $b \cdot 1 = (1-b) \cdot 2 \quad b = 2/3$
- ▶ For wife:
 - $a \cdot 1 = (1-a) \cdot 2 = 2/3$
- ▶ In each case, expected payoff is $2/3$
 - $2/9$ of time go to football, $2/9$ shopping, $5/9$ miscoordinate
- ▶ If they could synchronize ahead of time they could do better.

Rock paper scissors

		Column		
Row		rock	paper	scissors
	rock	0,0	-1,1	1,-1
	paper	1,-1	0,0	-1,1
	scissors	-1,1	1,-1	0,0

Setup

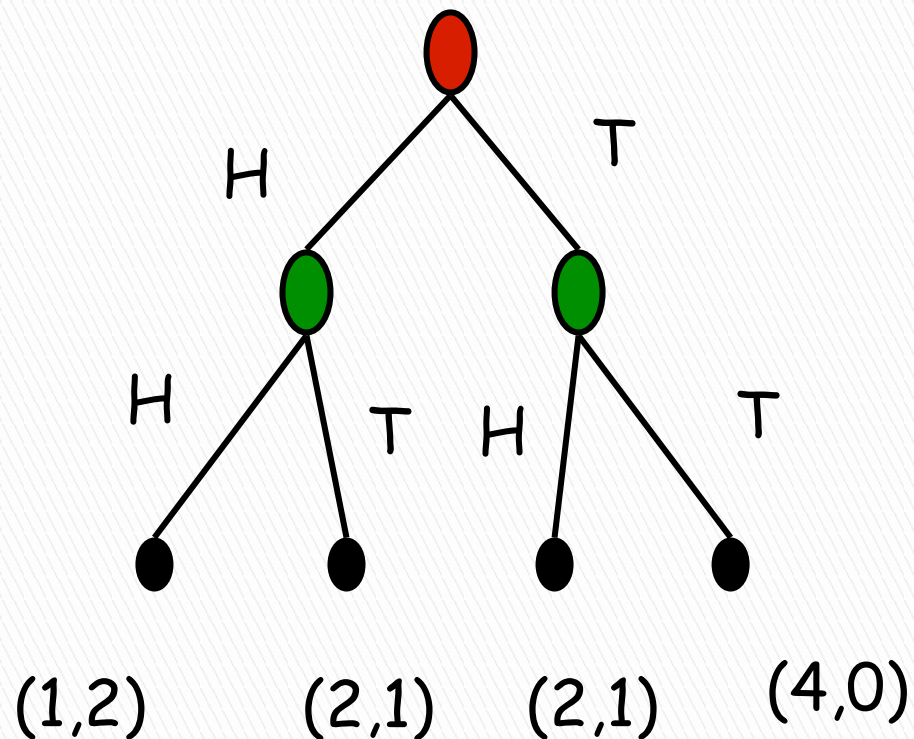
- ▶ Player 1 plays rock with probability p_r , scissors with probability p_s , paper with probability $1-p_r-p_s$
- ▶ $Utility_2(\text{rock}) = 0 \cdot p_r + 1 \cdot p_s - 1(1-p_r-p_s) = p_s + p_r - 1$
- ▶ $Utility_2(\text{scissors}) = 0 \cdot p_s + 1 \cdot (1-p_r-p_s) - 1p_r = 1 - 2p_r - p_s$
- ▶ $Utility_2(\text{paper}) = 0 \cdot (1-p_r-p_s) + 1 \cdot p_r - 1p_s = p_r - p_s$
- ▶ Player 2 wants to choose a probability for each action so that the expected payoff for each action is the same.

Setup

$$q_r(2 p_s + p_r - 1) = q_s(1 - 2p_r - p_s) = (1 - q_r - q_s) (p_r - p_s)$$

- It turns out (after some algebra) that the optimal mixed strategy is to play each action 1/3 of the time
- Intuition: What if you played rock half the time? Your opponent would then play paper half the time, and you'd lose more often than you won
- So you'd decrease the fraction of times you played rock, until your opponent had no 'edge' in guessing what you'll do

Extensive Form Games



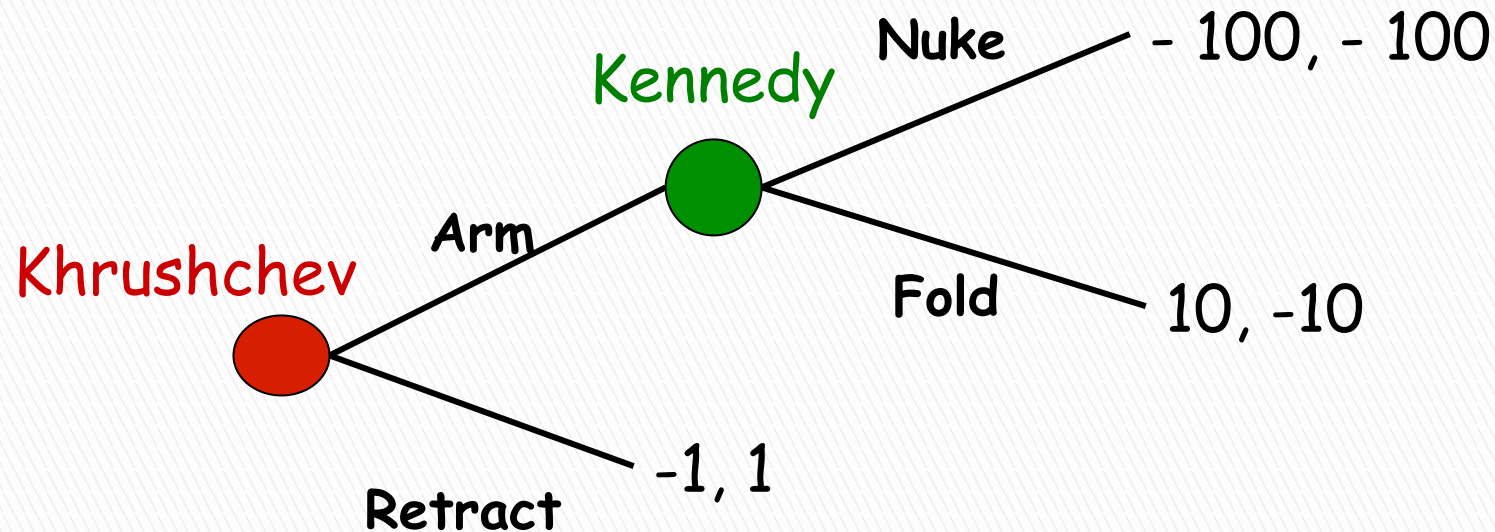
Any finite game of perfect information has a pure strategy Nash equilibrium. It can be found by backward induction.

Chess is a finite game of perfect information. Therefore it is a “trivial” game from a game theoretic point of view.

Extensive Form Games - Intro

- ▶ A game can have complex temporal structure
- ▶ Information
 - set of players
 - who moves when and under what circumstances
 - what actions are available when called upon to move
 - what is known when called upon to move
 - what payoffs each player receives
- ▶ Foundation is a game tree

Example: Cuban Missile Crisis

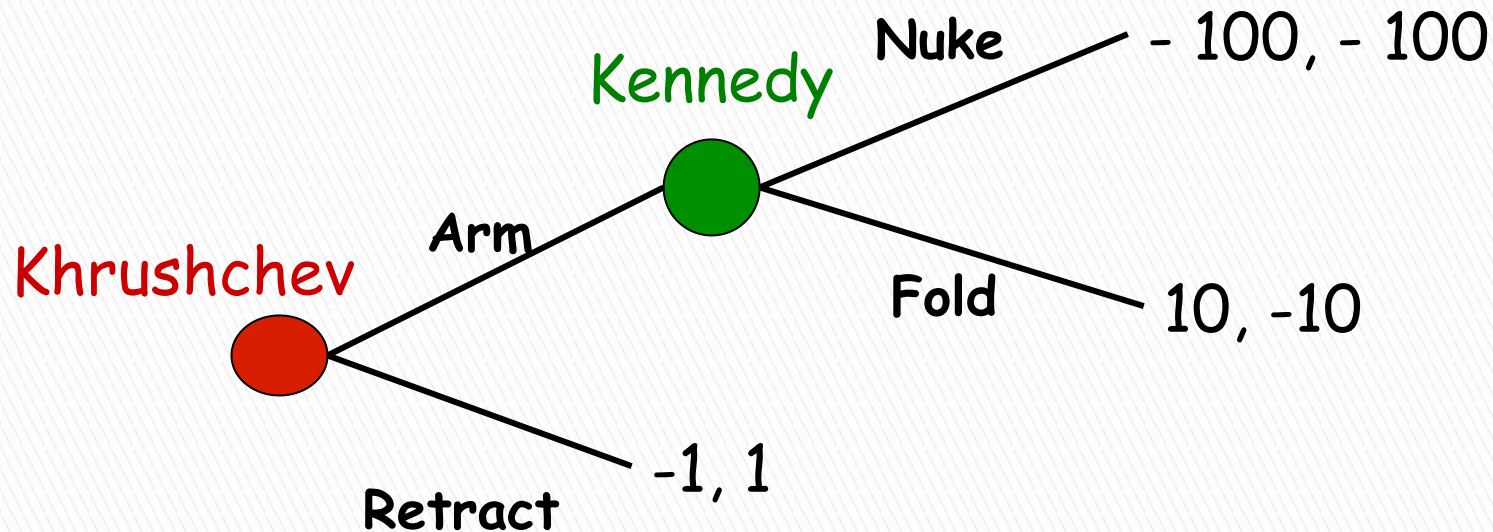


Pure strategy Nash equilibria: (Arm, Fold) and (Retract, Nuke)

Subgame perfect equilibrium & credible threats

- ▶ Proper subgame = subtree (of the game tree) whose root is alone in its information set
- ▶ Subgame perfect equilibrium
 - Strategy profile that is in Nash equilibrium in every proper subgame (including the root), whether or not that subgame is reached along the equilibrium path of play

Example: Cuban Missile Crisis



Pure strategy Nash equilibria: (Arm, Fold) and (Retract, Nuke)

Pure strategy subgame perfect equilibria: (Arm, Fold)

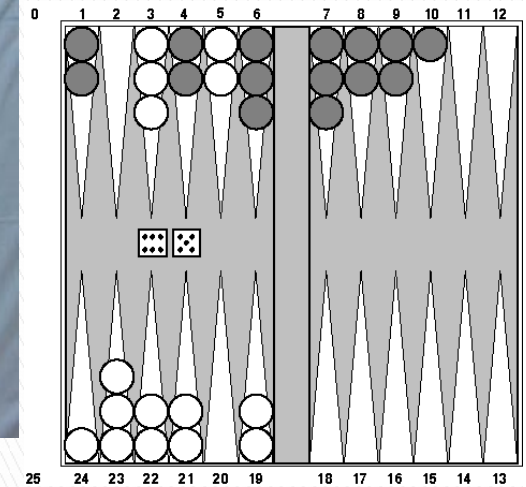
Conclusion: Kennedy's Nuke threat was not credible.

Type of games

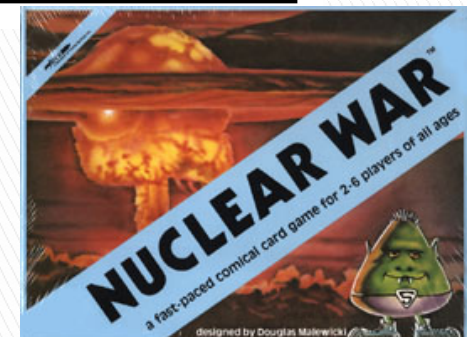
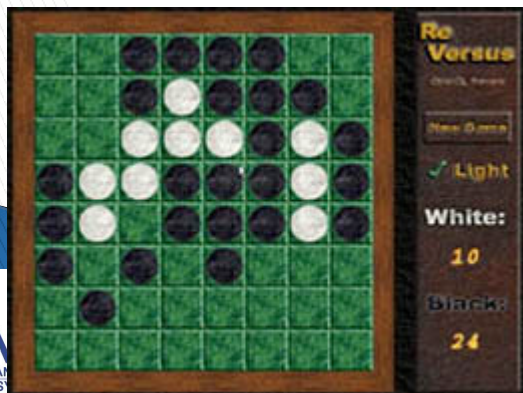
The board set for play



Red to play



	deterministic	chance
perfect information	chess, checkers, go, othello	backgammon monopoly
imperfect information	Diplomacy	bridge, poker, scrabble nuclear war



Take it or leave it deals

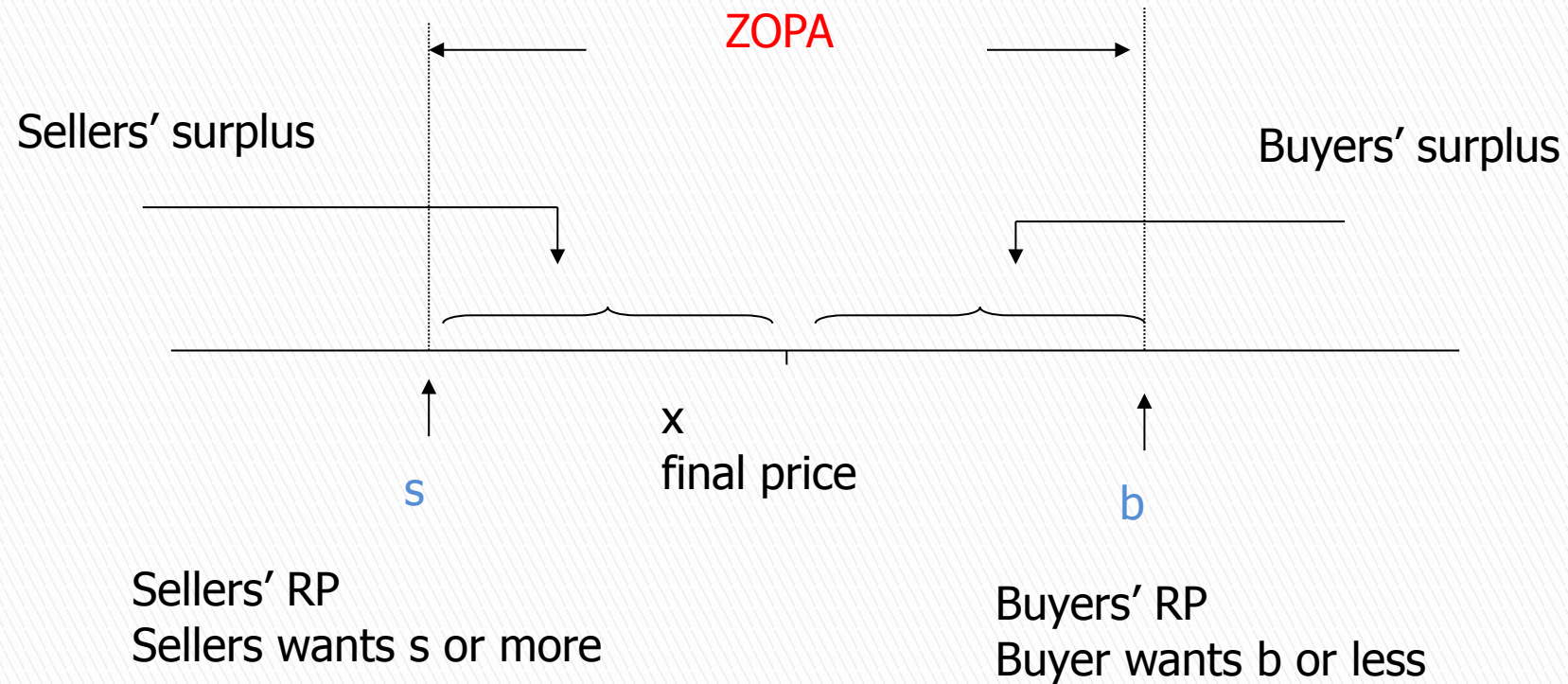
- The rules of the game:
 1. You will be randomly paired up with someone in the other section; this pairing will remain **completely anonymous**.
 2. One of you will be chosen (by coin flip) to be either the **Proposer** or the **Responder** in this experiment.
 3. The **Proposer** gets to make an offer to split \$100 in some proportion with the Responder. So the proposer can offer \$x to the responder, proposing to keep \$100-x for themselves.
 4. The **Responder** must decide what is the lowest amount offered by the proposer that he / she will accept; i.e. “I will accept any offer which is greater than or equal to \$y.”
 5. If the responder accepts the offer made by the proposer, they split the sum **according to the proposal**. If the responder rejects, both parties lose their shares.

AN EXAMPLE OF Buyer/Seller negotiation

Acme Manufacturing and a supplier, Best Parts Company, are negotiating an agreement under which Best Parts will make and deliver 10,000 specified widgets over a period of six months. Acme's purchasing manager has been instructed to get the lowest possible price, so she's pushing for \$1.75 per widget. Best Parts's sales manager, on the other hand, is trying to maximize the price his employer receives; he's asking for \$2.00 per widget. Neither is willing to discuss anything but price.

In the end, Acme Manufacturing gets its price. With several potential sellers to turn to, its purchasing manager holds out until the other side, which lacks other sales outlets, caves in and takes \$1.75 per widget.

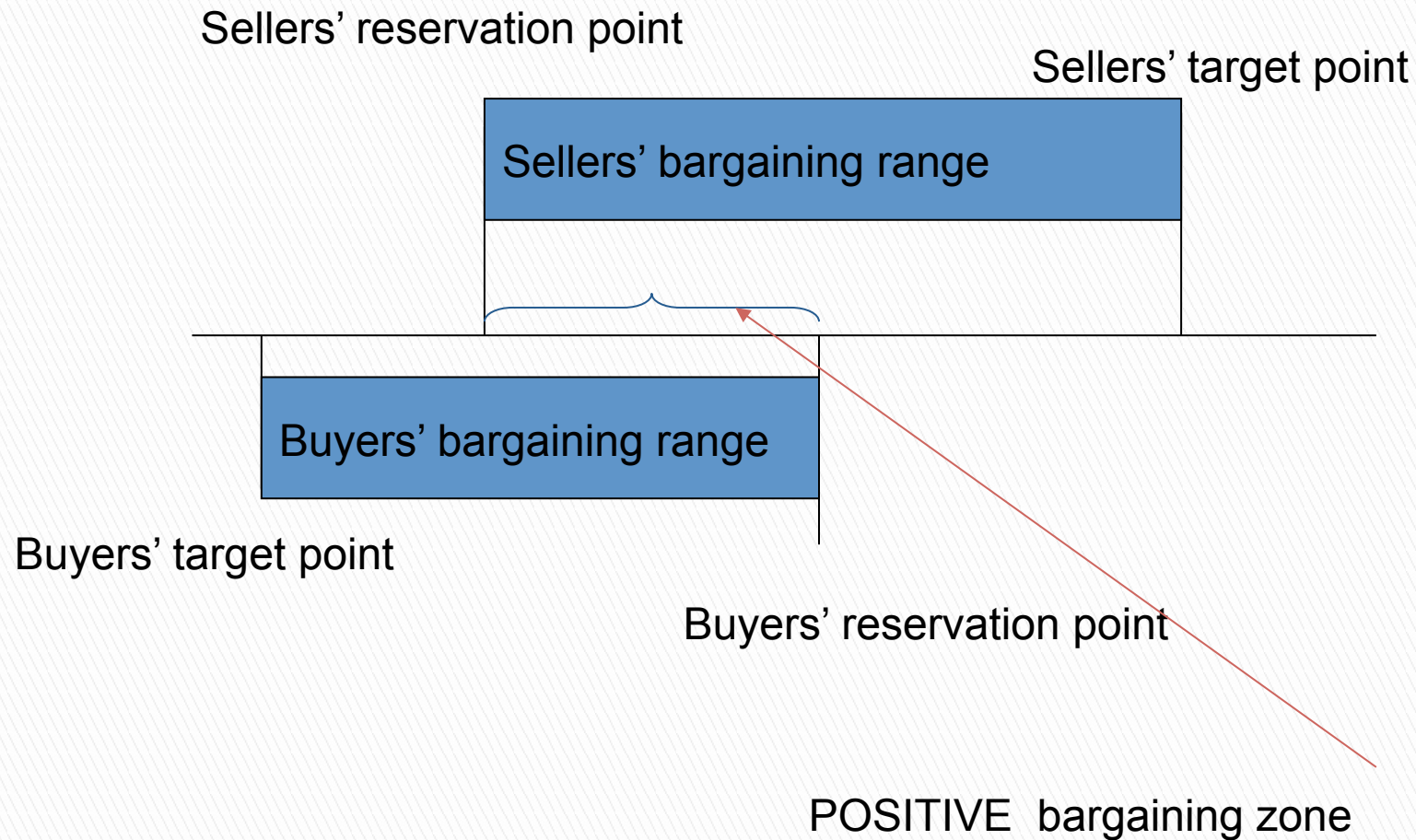
BARGAINING



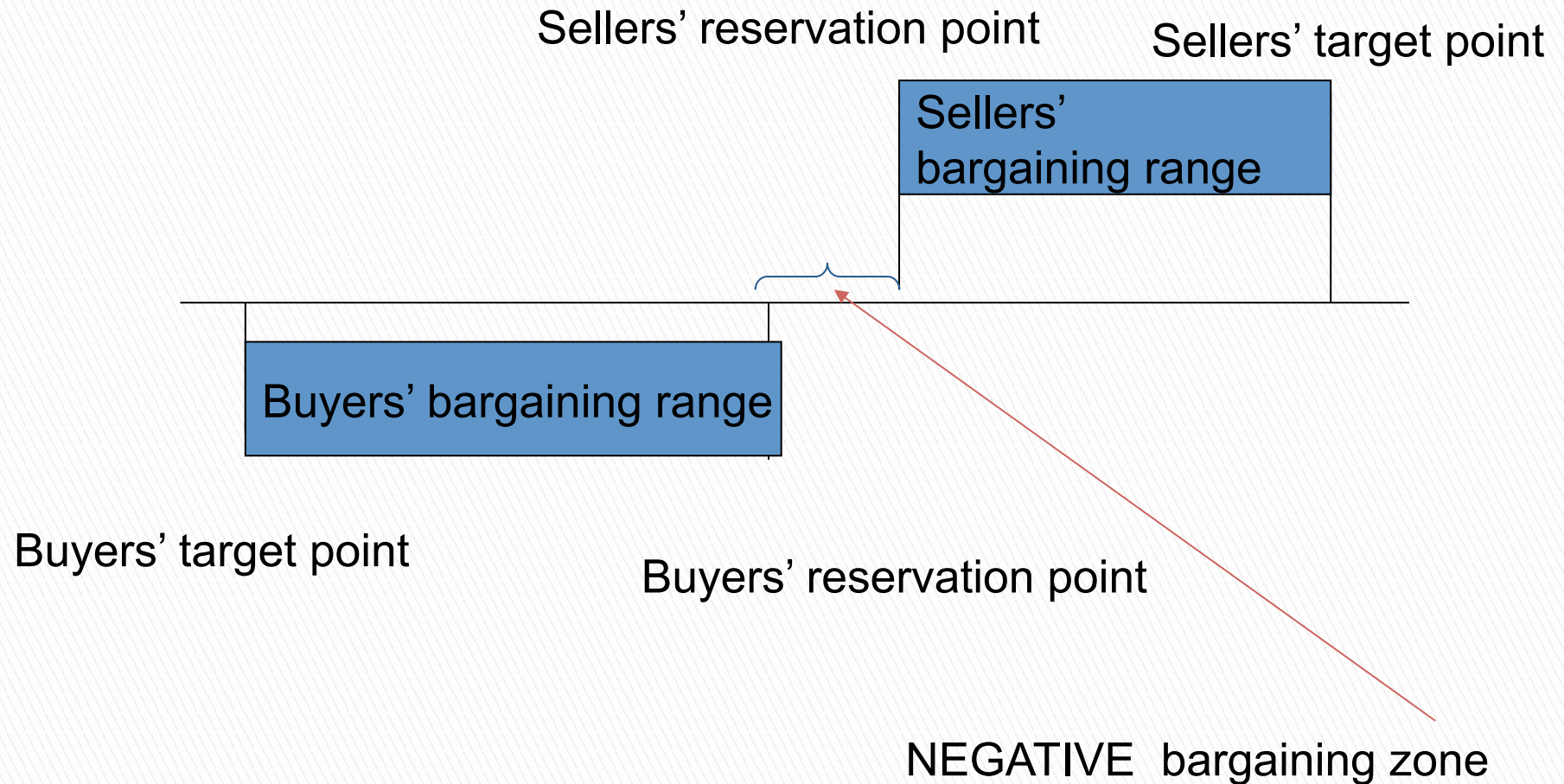
BARGAINING

- If $b < s \rightarrow$ **negative bargaining zone**,
no possible agreements
- If $b > s \rightarrow$ **positive bargaining zone**,
agreement possible
- $(x-s)$ sellers' surplus;
- $(b-x)$ buyers' surplus;
- The surplus to divide independent on 'x' –
constant-sum game!

POSITIVE BARGAINING ZONE



NEGATIVE BARGAINING ZONE



Single issue negotiation

- Agents a and b negotiate over a pie of size 1
- Offer: (x,y) , $x+y=1$
- Deadline: n and Discount factor: δ
- Utility: $U_a((x,y), t) = x \delta^{t-1}$ if $t \leq n$
▶ $U_b((x,y), t) = y \delta^{t-1}$
• 0 otherwise
- The agents negotiate using Rubinstein's *alternating offer's protocol*

Alternating offers protocol

<u>Time</u>	<u>Offer</u>	<u>Respond</u>
1	a (x1,y1)	b (accept/reject)
2	b (x2,y2)	a (accept/reject)
-		
-		
n		

Equilibrium strategies

How much should an agent offer if there is only one time period?

Let $n=1$ and a be the first mover

Agent a 's offer:

Propose to keep the whole pie $(1,0)$; agent b will accept this

Equilibrium strategies for $n = 2$

$\delta = 1/4$

first mover: a

Offer: (x, y)

x : a 's share;

y : b 's share

Optimal offers obtained using backward induction

Time	Offering agent	Offer	Utility
1	$a \rightarrow b$	$(3/4, 1/4)$	$3/4; 1/4$
2	$b \rightarrow a$	$(0, 1)$	$0; 1/4$

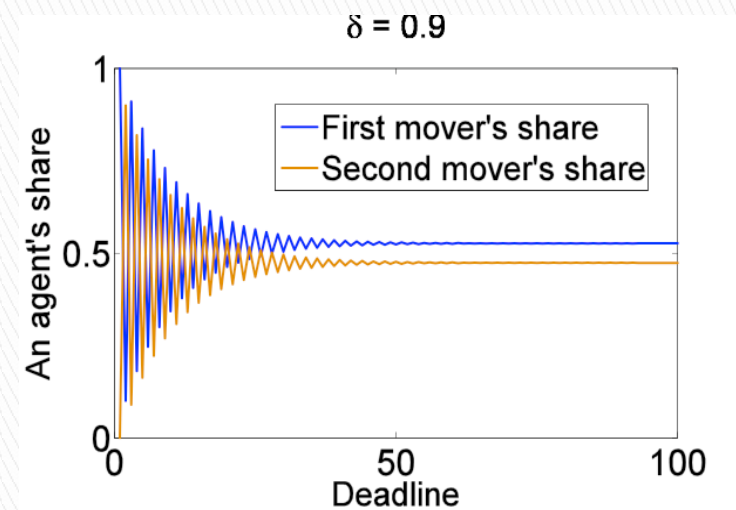
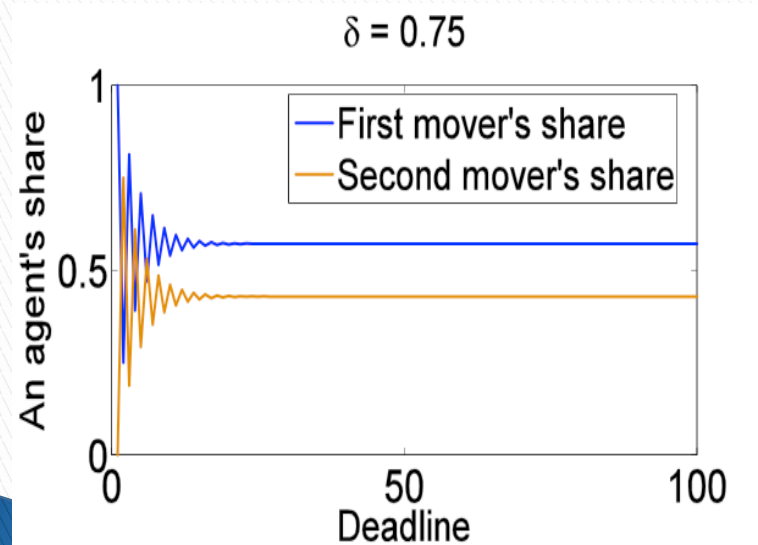
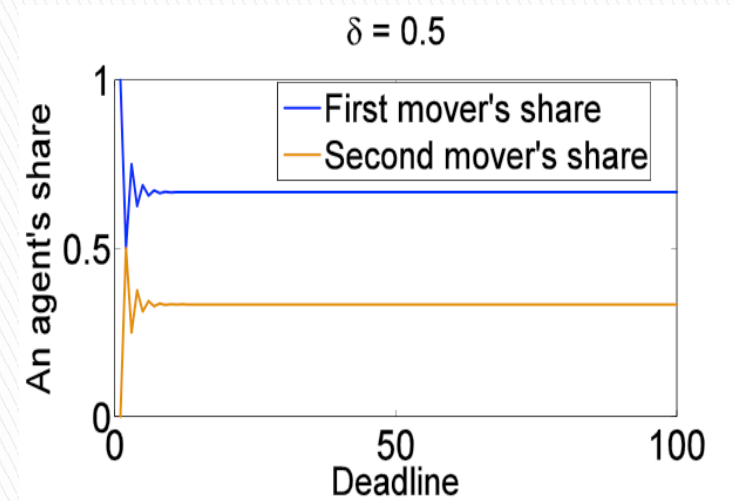
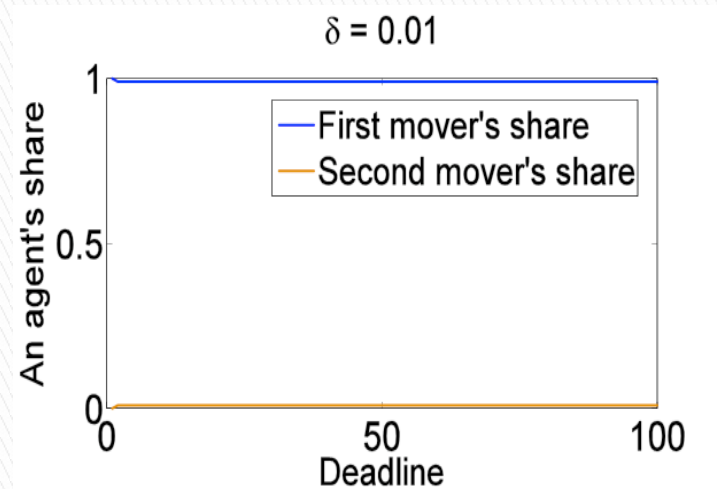
Agreement

The offer $(3/4, 1/4)$ forms a P.E. Nash equilibrium

Effect of discount factor and deadline on the equilibrium outcome

- What happens to first mover's share as δ increases?
- What happens to second mover's share as δ increases?
- As deadline increases, what happens to first mover's share?
- Likewise for second mover?

Effect of δ and deadline on the agents' shares



Multiple issues

- Set of issues: $S = \{1, 2, \dots, m\}$. Each issue is a pie of size 1
- The issues are divisible
- Deadline: n (for all the issues)
- Discount factor: δ_c for issue c
- Utility: $U(x, t) = \sum_c U(x_c, t)$

Multi-issue procedures

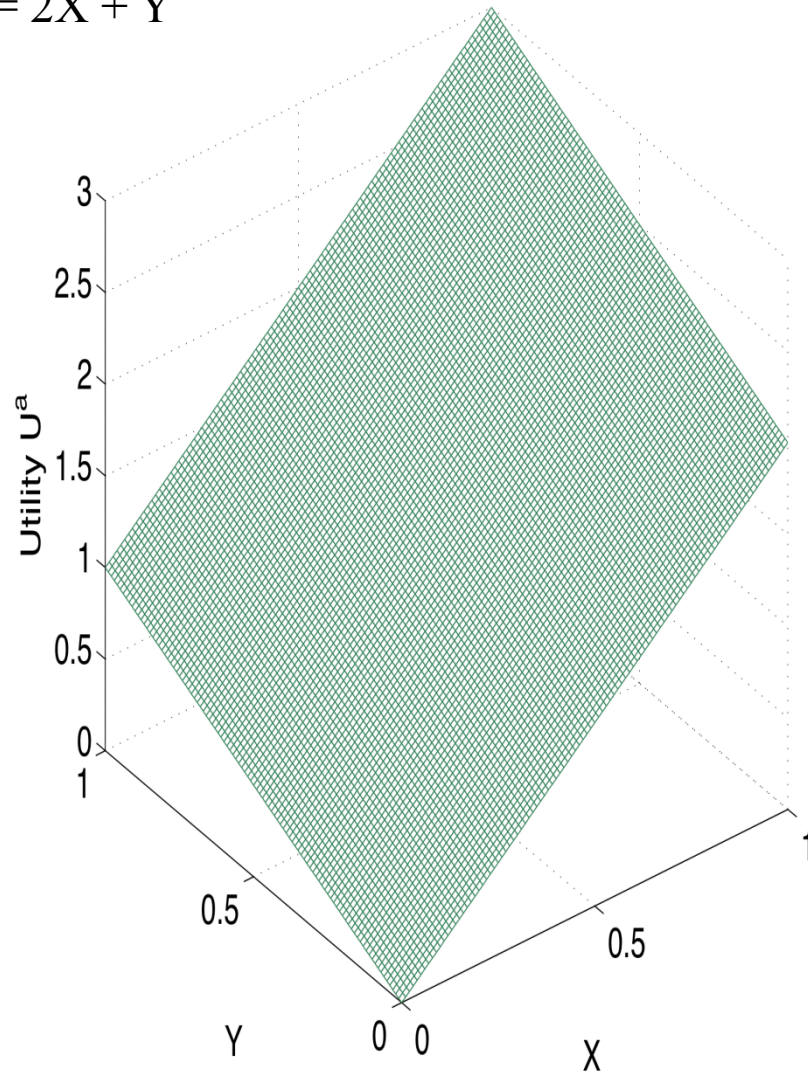
- Package deal procedure: The issues are bundled and discussed together as a package
- Simultaneous procedure: The issues are negotiated in parallel but independently of each other
- Sequential procedure: The issues are negotiated sequentially one after another

Package deal procedure

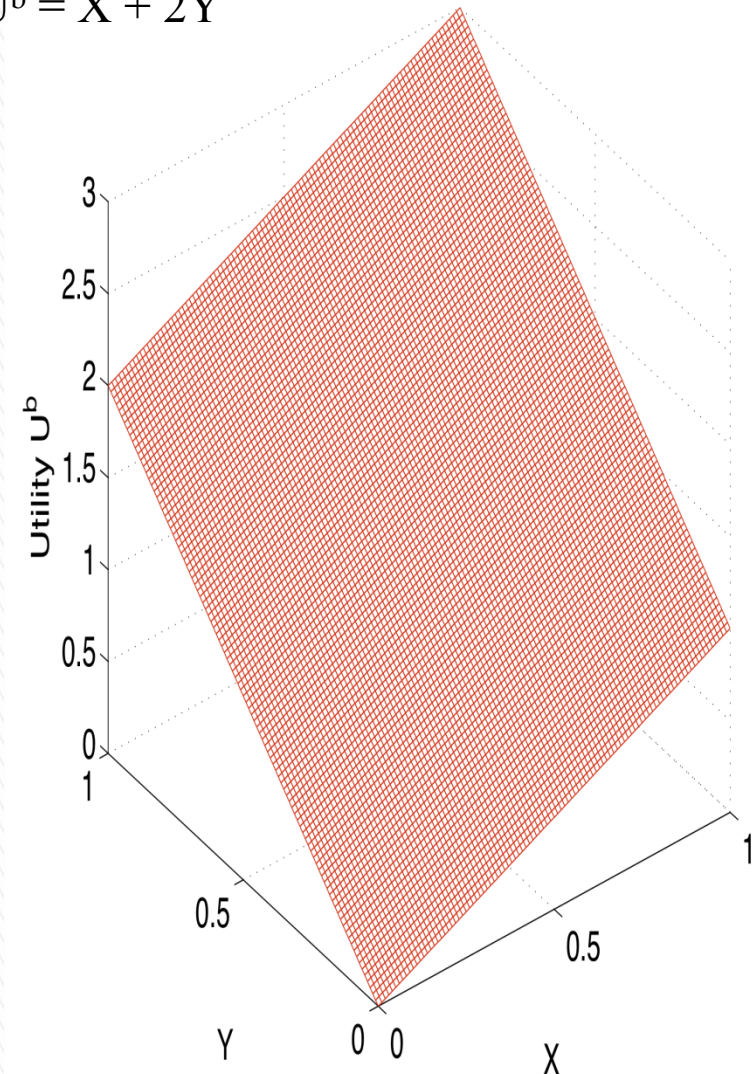
- Issues negotiated using alternating offer's protocol
- An offer specifies a division for each of the m issues
- The agents are allowed to accept/reject a complete offer
- The agents may have different preferences over the issues
- The agents can make **tradeoffs** across the issues to maximize their utility – this leads to Pareto optimal outcome

Utility for two issues

$$U^a = 2X + Y$$

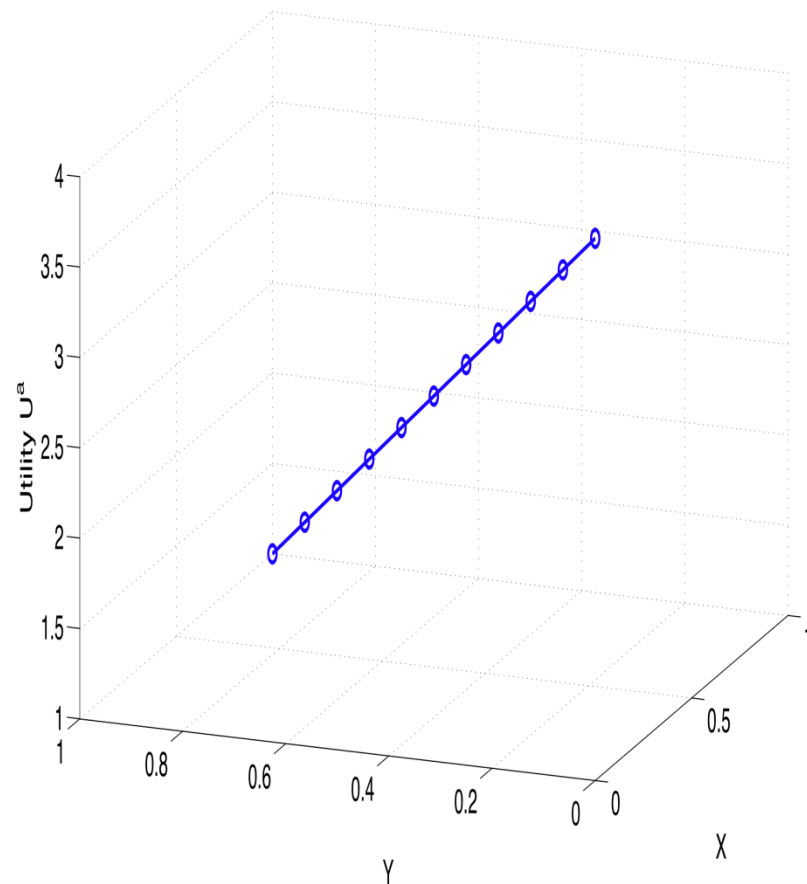
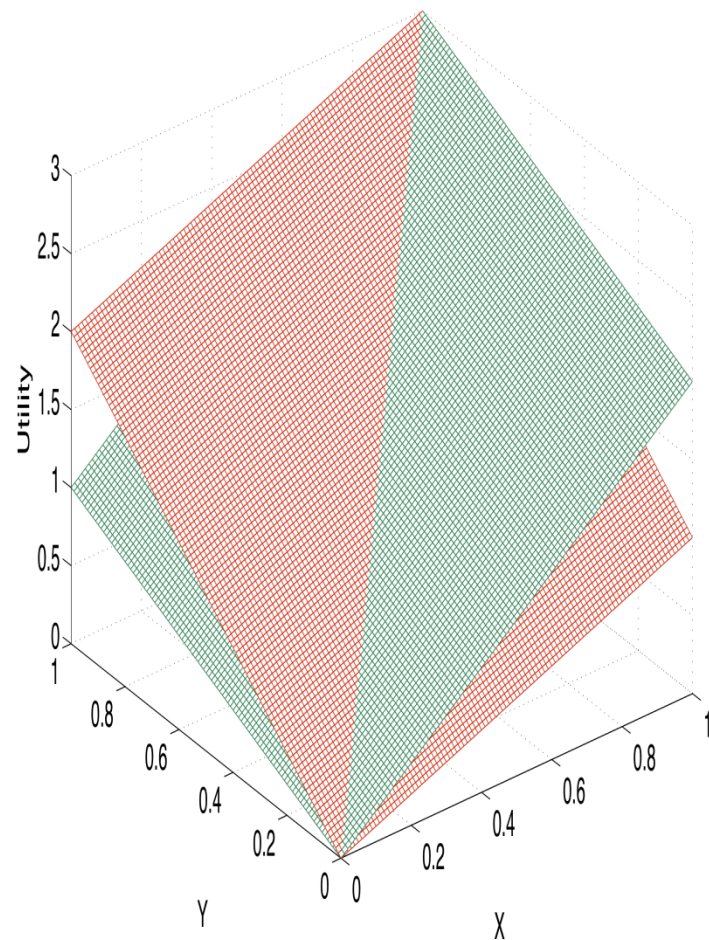


$$U^b = X + 2Y$$



Making tradeoffs

What is a 's utility for $U^b = 2$



$U^b = 2$

Example for two issues

DEADLINE: $n = 2$

DISCOUNT FACTORS: $\delta_1 = \delta_2 = 1/2$

UTILITIES: $U^a = 1/2^{t-1} (x_1 + 2x_2)$; $U^b = 1/2^{t-1} (2y_1 + y_2)$

Agreement

Time	Offering agent	Package Offer
1	$a \rightarrow b$	$[(1/4, 3/4); (1, 0)]$ OR $[(3/4, 1/4); (0, 1)]$
2	$b \rightarrow a$	$[(0, 1); (0, 1)]$ $U^b = 1.5$

The outcome is not symmetric

P.E. Nash equilibrium strategies

For $t = n$

The offering agent takes 100 percent of all the issues

The receiving agent accepts

For $t < n$ (for agent a):

OFFER $[x, y]$ s.t. $U^b(y, t) = EQ_{UB}(t+1)$ If more than one such $[x, y]$ perform trade-offs across issues to find best offer	RECEIVE $[x, y]$ If $U^a(x, t) \geq EQ_{UA}(t+1)$ ACCEPT else REJECT
---	--

$EQ_{UA}(t+1)$ is a 's equilibrium utility for $t+1$

$EQ_{UB}(t+1)$ is b 's equilibrium utility for $t+1$

Making trade-offs – divisible issues

Agent a 's trade-off problem at time t :

TR: Find a package $[x, y]$ to

Maximize $\sum_{c=1}^m k_c^a x_c$

Subject to $\sum_{c=1}^m k_c^b y_c \geq EQ_{UB}(t+1)$
 $0 \leq x_c \leq 1; 0 \leq y_c \leq 1$

This is the fractional knapsack problem

Making trade-offs – divisible issues

Agent a 's perspective (time t)

Agent a considers the m issues in the increasing order of k^a/k^b and assigns to b the maximum possible share for each of them until b 's cumulative utility equals $EQ_{UB}(t+1)$

Equilibrium strategies

For $t = n$

The offering agent takes 100 percent of all the issues

The receiving agent accepts

For $t < n$ (for agent a)

OFFER $[x, y]$ s.t. $U^b(y, t) = EQ_{UB}(t+1)$ If more then one such $[x, y]$ perform trade-offs across issues to find best offer	RECEIVE $[x, y]$ If $U^a(x, t) \geq EQ_{UA}(t+1)$ ACCEPT else REJECT
---	--

Equilibrium solution

- An agreement on all the m issues occurs in the first time period
- Time to compute the equilibrium offer for the first time period is $O(mn)$
- The equilibrium solution is Pareto-optimal (an outcome is Pareto optimal if it is impossible to improve the utility of both agents simultaneously)
- The equilibrium solution is not unique, it is not symmetric

Making trade-offs – indivisible issues

Agent a 's trade-off problem at time t is to find a package $[x, y]$ that

$$\text{Maximize } \sum_{c=1}^m k_c^a x_c$$

$$\text{S.t. } \sum_{c=1}^m k_c^b y_c \geq EQ_{UB}(t+1) \quad x_c : 0 \text{ or } 1; \quad y_c : 0 \text{ or } 1$$

For indivisible issues, this is the integer knapsack problem

Key points

- Single issue:
 - Time to compute equilibrium is $O(n)$
 - The equilibrium is not unique, it is not symmetric
- Multiple divisible issues: (exact solution)
 - Time to compute equilibrium for $t=1$ is $O(mn)$
 - The equilibrium is Pareto optimal, it is not unique, it is not symmetric
- Multiple indivisible issues: (approx. solution)
 - There is an FPTAS to compute approximate equilibrium
 - The equilibrium is Pareto optimal, it is not unique, it is not symmetric

Example: Negotiation on data allocation in multi-server environment

R. Azulay-Schwartz and S. Kraus. Negotiation On Data Allocation in Multi-Agent Environments. Autonomous Agents and Multi-Agent Systems journal 5(2):123-172, 2002.

Cooperative Web Servers

- The Data and Information System component of the Earth Observing System (EOSDIS) of NASA is a distributed knowledge system which supports archival and distribution of data at multiple and independent servers.

Cooperative Web Servers- cont.

- Each data collection, or file, is called a dataset. The datasets are huge, so each dataset has only one copy.
- The current policy for data allocation in NASA is static: old datasets are not reallocated; each new dataset is located by the server with the nearest topics (defined according to the topics of the datasets stored by this server).

Related Work - File Allocation Problem



The original problem:

How to distribute files among computers, in order to optimize the system performance.

Our problem:

How can self-motivated servers decide about distribution of files, when each server has its own objectives.

Environment Description

- There are several information servers. Each server is located at a different geographical area.
- Each server receives queries from the clients in its area, and sends documents as responses to queries. These documents can be stored locally, or in another server.

Environment Description



Basic Definitions

- **SERVERS:**
the set of the servers.
- **DATASETS:**
the set of datasets (files) to be allocated.
- **Allocation:**
a mapping of each dataset to one of the servers. The set of all possible allocation is denoted by Allocs .
- **U:** the utility function of each server.

The Conflict Allocation

- ☹ If at least one server **opts out**💣 of the negotiation, then the conflict allocation *conflict_alloc* is implemented.
- ☹ We consider the conflict allocation to be the static allocation. (each dataset is stored in the server with closest topics).

Utility Function

- $U_{server}(alloc, t)$ specifies the utility of *server* from $alloc \in Allocs$ at time t .
- It consists of
 - The utility from the assignment of each dataset.
 - The cost of negotiation delay.

$$U_{server}(alloc, 0) = \sum_{x \in DATASETS} V_{server}(x, alloc(x)).$$

Parameters of utility

- *query price*: payment for retrieved documents.
- *usage(ds,s)*: the expected number of documents of dataset *ds* from clients in the area of server *s*.
- *storage costs, retrieve costs, answer costs.*



Cost over time

- Cost of communication and computation time of the negotiation.
- Loss of unused information: new documents can not be used until the negotiation ends.
- Datasets usage and storage cost are assumed to decrease over time, with the same discount ratio $(p-1)$.
- Thus, there is a constant discount ratio of the utility from an allocation:

$$U_{server}(alloc, t) = \delta^t * U_{server}(alloc, 0) - t * C.$$

Assumptions

- Each server prefers any agreement over continuation of the negotiation indefinitely.
- The utility of each server from the conflict allocation is always greater or equal to 0.
- *OFFERS* - the set of allocations that are preferred by all the agents over opting out.

Negotiation Analysis - Simultaneous Responses

- Simultaneous responses:
A server, when responding, is not informed of the other responses.
- Theorem:
For each offer $x \in OFFERS$, there is a subgame-perfect equilibrium of the bargaining game, with the outcome x offered and unanimously accepted in period 0.

Choosing the Allocation

- The designers of the servers can agree in advance on a joint technique for choosing x
- giving each server its conflict utility
- maximizing a social welfare criterion
 - the sum of the servers' utilities.
 - Or the generalized Nash product of the servers' utilities:
 $\Pi (Us(x)-Us(conflict))$

Experimental Evaluation

- How do the parameters influence the results of the negotiation?
- *vcost(alloc)*: the variable costs due to an allocation (excludes storage_cost and the gains due to queries).
- *vcost_ratio*: the ratio of *vcosts* when using negotiation, and *vcosts* of the static allocation.

Effect of Parameters on The Results

- As the number of servers grows, *vcost_ratio* increases (more complex computations) 😞.
- As the number of datasets grows, *vcost_ratio* decreases (negotiation is more beneficial) 😊.
- Changing the mean usage did not influence *vcost_ratio* significantly 😐, but *vcost_ratio* decreases as the standard deviation of the usage increases 😊.

Influence of Parameters - cont.

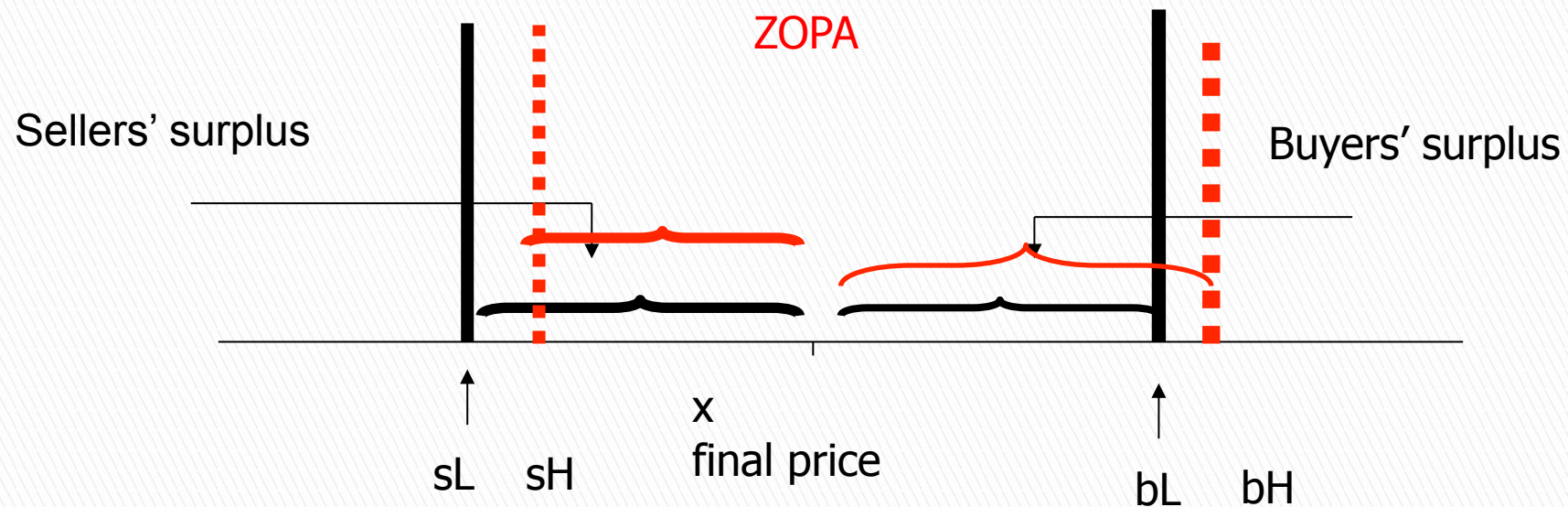
- When the standard deviation of the distances between servers increases, *vcost_ratio* decreases 😊.
- When the distance between servers increases, *vcost_ratio* decreases 😊.
- In the domains tested,
 - *answer_cost* ★ *vcost_ratio* ★ 😞.
 - *storage_cost* ★ *vcost_ratio* ★ 😞.
 - *retrieve_cost* ★ *vcost_ratio* ★ 😊.
 - *query_price* ★ *vcost_ratio* ★ 😊.

Incomplete Information

- Each server knows:
 - The usage frequency of all datasets, by clients from its area
 - The usage frequency of datasets stored in it, by all clients



BARGAINING



Sellers' RP
Sellers wants s or more

Buyers' RP
Buyer wants b or less

Definition of a Bayesian game

- N is the set of players.
- Ω is the set of the states of nature.
- A_i is the set of actions for player i . $A = A_1 \times A_2 \times \dots \times A_n$
- T_i is the type set of player i . For each state of nature, the game will have different types of players (one type per player).
- $u: \Omega \times A \rightarrow R$ is the payoff function for player i .
- p_i is the probability distribution over Ω for each player i , that is to say, each player has different views of the probability distribution over the states of the nature. In the game, they never know the exact state of the nature.

Solution concepts for Bayesian games

- A (Bayesian) **Nash equilibrium** is a strategy profile and *beliefs specified for each player about the types of the other players* that maximizes the expected utility for each player given their beliefs about the other players' types and given the strategies played by the other players.

Incomplete Information - cont.

- A revelation mechanism:
 - First, all the servers report simultaneously all their private information:
 - for each dataset, the past usage of the dataset by this server.
 - for each server, the past usage of each local dataset by this server.
 - Then, the negotiation proceeds as in the complete information case.

Incomplete Information - cont.

- Lemma:

There is a Nash equilibrium where each server tells the truth about its past usage of remote datasets, and the other servers usage of its local datasets.

- Lies concerning details about local usage of local datasets are intractable.

Summary: negotiation on data allocation

- We have considered the data allocation problem in a distributed environment.
- We have presented the utility function of the servers, which expresses their preferences.
- We have proposed using a negotiation protocol for solving the problem.
- For incomplete information situations, a revelation process was added to the protocol.

Fair Coalition Structures Through Bargaining for coalitional resource games

Coalition games

- Coalitional game: agents can benefit from cooperation
- Issues in coalitional games
 - Coalition structure generation:
 - Which coalition should I join?
 - The partitioning of a group of agents into coalitions
 - Solving the optimization problem of each coalition
 - Dividing the value of the solution for each coalition

Coalitional Resource Games (CRGs)

- $Ag = \{A1, \dots, An\}$ is a set of agents;
- $G = \{g1, \dots, gm\}$ is a set of possible goals;
- $R = \{r1, \dots, rt\}$ is a set of resources;
- $G_i \subseteq G$ is a set of goals of agent i
- $en : Ag \times R \rightarrow N$ is an endowment function
- $req : G \times R \rightarrow N$ is a requirement function
- Coalition structure:
 - Agents, Goals, Resources contribution
- Agents prefer coalition in which their goals is satisfied and they contribute as few resources as possible.

Example

- Agents: {A1,A2,A3}; Goals: {g1,g2,g3}
- Resources: {r1,r2,r3,r4} G1={g1} G2={g2,g3} G3={g1,g3}

req(...)	r1	r2	r3	r4
g1	4	3	14	0
g2	0	0	3	3
g3	0	2	3	0

en(...)	r1	r2	r3	r4
a1	4	3	0	0
a2	0	3	3	0
a3	0	0	11	3

{A2,A3}, {g2,g3} A2: r2:2 A3: r3:6 r4: 3

{A1,A2,A3} {g1} A1:r1:4, r2:3 A2:r3 3 A3: r3 11

Negotiation protocol

- Choose an ordering $A_1, \dots, A_n$ of Ag .
- *Time t :*
 - A_t proposes a cooperation structure for agents
 - $A_t, A_{t+1}, \dots, A_n$
 - A_i responds:
 - **rejects:** A_t forms the singleton coalition $\{A_t\}$ in the final coalition structure.
 - **accepts** the offer
 - **makes a counteroffer** that cannot decrease the utility that an agent A_j , preceding A_i in the ordering obtains from earlier offers

Protocol: intuition

- Balances the power given to the proposers and the responders:
- The responders can reject the offer, in which case the proposer gets nothing from negotiation.
- The proposer has the power to choose *which offer to make*

Example (cont)

- Order: A1,A2,A3
- A1 offers {A1,A2,A3} {g1} A1:r1:4, r2:3 A2:r3 3
A3: r3 11
 - A2 → rejects
- A2 offers {A2,A3}, {g2,g3} A2: r2:2
 - A3: r3:6 r4: 3
- A1 → accepts
- Result {g1},{g2,g3}

Conclusions of negotiations for CRG

- ▶ Perfect equilibrium strategies can be found in is exponential time only in the number of goals
- ▶ The resulting coalition satisfies desirable properties:
 - Individual rationality
 - Pareto Optimality
 - Dummy agent is not successful
 - Interchangeable agents obtains the same expected utility

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