CHAPTER 15: BARGAINING

Multiagent Systems

http://www.csc.liv.ac.uk/˜mjw/pubs/imas/

Overview

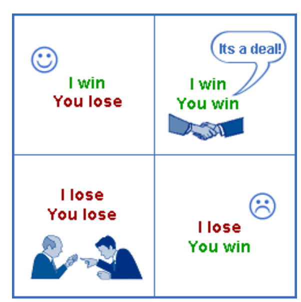
- How do agents *reach agreements* when they are self interested?
- In an extreme case (zero sum encounter) no agreement is possible — but in most scenarios, there is potential for *mutually beneficial agreement on matters of common interest*.

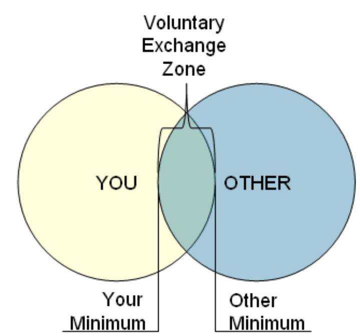
Overview

- The capabilities of:
  - *negotiation* and
  - *argumentation*

  are central to the ability of an agent to reach such agreements.

Two pictures that summarise negotiation





Mechanisms, Protocols, and Strategies

- Negotiation is governed by a particular *mechanism*, or *protocol*.
- The mechanism defines the “rules of encounter” between agents.
- *Mechanism design* is designing mechanisms so that they have certain desirable properties.
  - Properties like Pareto efficiency
- Given a particular protocol, how can a particular *strategy* be designed that individual agents can use?

Auctions versus Negotiation

- Auctions are *only* concerned with the allocation of goods: richer techniques for reaching agreements are required.
- *Negotiation* is the process of reaching agreements on matters of common interest.

- Any negotiation setting will have four components:
  - A negotiation set: possible proposals that agents can make.
  - A protocol.
  - Strategies, one for each agent, which are private.
  - A rule that determines when a deal has been struck and what the agreement deal is.

  Negotiation often proceeds in a series of rounds, with proposals at every round.

- There are a number of aspects of negotiation that make it complex.
- Multiple issues
  - Number of possible deals is exponential in the number of issues.

    (Like the number of bundles in a combinatorial auction)
  - Hard to compare offers across multiple issues

    The car salesman problem
- Multiple agents
  - One-to-one negotiation

- Many-to-one negotiation
- Many-to-many negotiation

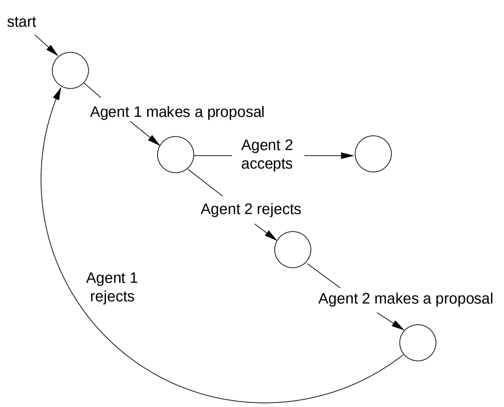
- At the simple end there isn't much to distinguish negotiation from auctions.

Negotiation for Resource Division

- We will start by looking at Rubinstein's *alternating offers* model.
- This is a one-to-one protocol.
- Agents are 1 and 2, and they negotiate over a series of rounds:

$$0, 1, 2, \ldots$$

- In round 0, Agent 1 makes an offer x^0.
- Agent 2 either accepts A, or rejects R.
- If the offer is accepted, then the deal is implemented.
- If not, we have round 1, and Agent 2 makes an offer.



- The rules of the protocol don't mean that agreement will ever be reached.
  - Agents could just keep rejecting offers.
- If there is no agreement, we say the result is the *conflict deal* Θ.
- We make the following basic assumptions:
  - Disagreement is the worst ouctome
    Both agents prefer any agreement to none.
  - Agents seek to maximise utility
    Agents prefer to get larger utility values
- With this basic model, we get some odd results.

- Consider we are *dividing a pie*...

- Model this as some resource with value 1, that is divided into two parts.
  - Each part is between 0 and 1.
  - The two parts sum to 1

  so a proposal is $(x, 1-x)$
- The set of possible deals is:

$$\{(x, 1-x) : 0 \leq x \leq 1\}$$

- If you are Agent 1, what do you offer?

- Let's assume that we will only have one round.
  Ultimatum game
- Agent 1 has all the power.
- If Agent 1 proposes $(1, 0)$, then this is still better for Agent 2 than the conflict deal.
- Agent 1 can do no better than this either.
- So we have a Nash equilibrium.

- If we have two rounds, the power passes to Agent 2.
- Whatever Agent 1 proposes, Agent 2 rejects it.
- Then Agent 2 proposes $(0, 1)$.
- Just as before this is still better for Agent 1 than the conflict deal and so it is accepted.
- A bit of thought shows that this will happen any time there is a fixed number of rounds.

- What if we have an indefinite number of rounds.
- Let's say that Agent 1 uses this strategy:

  Always propose $(1, 0)$ and always reject any offer from Agent 2
- How should Agent 2 respond?
- If she rejects, then there will never be agreement.
  - Conflict deal
- So accept. And there is no point in not accepting on the first round.

- In fact, whatever $(x, 1-x)$ agent 1 proposes here, immediate acceptance is the Nash equilibrium so long as Agent 2 *knows* what Agent 1's strategy is.

Impatient players

- Since we have an infinite number of Nash equilibria, the solution concept of NE is too weak to help us.
- Can get unqiue results if we take time into account.

  For any outcome x and times $t_2 > t_1$, both agents prefer x at time t_1.
- A standard way to model this impatience is to discount the value of the outcome.
- Each agent has δ_i, $i \in \{1, 2\}$, where $0 \leq \delta < 1$.
- The closer δ_i is to 1, the more patient the agent is.

- If agent i is offered x, then the value of the slice is:
  - x at time 0
  - $\delta_i x$ at time 1
  - $\delta_i^2 x$ at time 2.

    ⋮
  - $\delta^k x$ at time k
- Now we can make some progress with the fixed number of rounds.
- A 1 round game is still an ultimatum game.

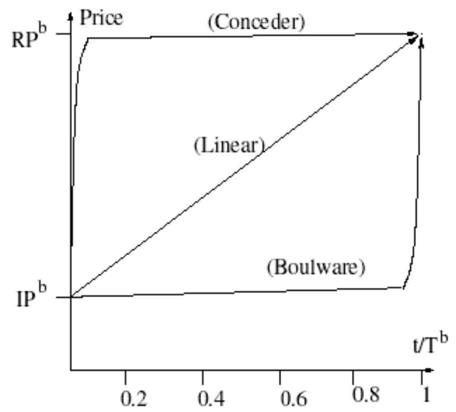
- A 2 round game means Agent 2 can play as before, but if so, will only get δ_2.
  Gets the whole pie, but it is worth less.

- Agent 1 can take this into account.
- If Agent 1 offers:
  $$(1-\delta_2, \delta_2)$$
  then Agent 2 might as well accept — can do no better.
- So this is now a Nash equilibrium.

- In the general case, agent 1 makes the proposal that gives Agent 2 what Agent 2 would be able to enforce in the second round.
- Agent 1 gets:
  $$\frac{1-\delta_2}{1-\delta_1\delta_2}$$
- Agent 2 gets:
  $$\frac{\delta_2(1-\delta_1)}{1-\delta_1\delta_2}$$
- Note that the more patient either agent is, the more pie they get.

Heuristic approach

- The approach we just talked about relies on strageic thinking about the other player.
- A simpler approach is to use some heuristic approximation of how the value of the pie varies for the players.
- Some common approximations:
  - Linear
  - Boulware
  - Conceder
- We can see what these look like for buyers.



- Linear
  - Linear increase from initial price at the start time to reserve price at the deadline.
- Boulware
  - Very slow increase until close to deadline and then an exponential increase.
- Conceder
  - Inital exponential increase to close to the reserve price and then not much change.

Negotiation in Task-Oriented Domains

Imagine that you have three children, each of whom needs to be delivered to a different school each morning. Your neighbour has four children, and also needs to take them to school. Delivery of each child can be modelled as an indivisible task. You and your neighbour can discuss the situation, and come to an agreement that it is better for both of you (for example, by carrying the other's child to a shared destination, saving him the trip). There is no concern about being able to achieve your task by yourself. The worst that can happen is that you and your neighbour won't come to an agreement about setting up a car pool, in which case you are no worse off than if you were alone. You can only benefit (or do no worse) from your neighbour's tasks. Assume, though, that one of my children and one of my neigbours's children both go to the same school (that is, the cost of carrying out these two deliveries, or two tasks, is the same as the cost of carrying out one of them). It obviously makes sense for both children to be taken together, and only my neighbour or I will need to make the trip to carry out both tasks.

TODs Defined

- A task-oriented domain (TOD) is a triple

$$\langle T, Ag, c \rangle$$

  where:
  - T is the (finite) set of all possible tasks;
  - $Ag = \{1, \ldots, n\}$ is set of participant agents;
  - $c : \wp(T) \rightarrow \mathbb{R}^+$ defines *cost* of executing each subset of tasks:
- An *encounter* is a collection of tasks

$$\langle T_1, \ldots, T_n \rangle$$

  where $T_i \subseteq T$ for each $i \in Ag$.

Deals in TODs

- Given encounter $\langle T_1, T_2 \rangle$, a *deal* will be an allocation of the tasks $T_1 \cup T_2$ to the agents 1 and 2.
- The *cost* to i of deal $\delta = \langle D_1, D_2 \rangle$ is $c(D_i)$, and will be denoted $cost_i(\delta)$.
- The *utility* of deal δ to agent i is:

$$utility_i(\delta) = c(T_i) - cost_i(\delta).$$

- The *conflict deal*, Θ, is the deal $\langle T_1, T_2 \rangle$ consisting of the tasks originally allocated.
  Note that

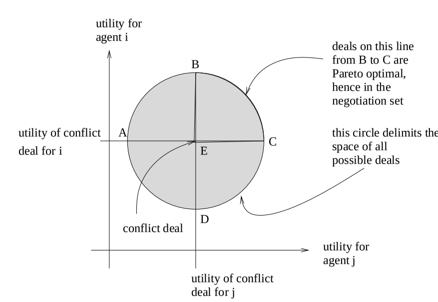
$$utility_i(\Theta) = 0 \quad \text{for all } i \in Ag$$

- Deal δ is *individual rational* if it gives positive utility.

The Negotiation Set

- The set of deals over which agents negotiate are those that are:
  - individual rational
  - pareto efficient.
- Individually rational: agents won't be interested in deals that give negative utility since they will prefer the conflict deal.
- Pareto efficient: agents can always transform a non-Pareto efficient deal into a Pareto efficient deal by making one agent happier and none of the others worse off.

The Negotiation Set Illustrated



The Monotonic Concession Protocol

Rules of this protocol are as follows. . .

- Negotiation proceeds in rounds.
- On round 1, agents simultaneously propose a deal from the negotiation set.
- Agreement is reached if one agent finds that the deal proposed by the other is at least as good or better than its proposal.
- If no agreement is reached, then negotiation proceeds to another round of simultaneous proposals.

- In round $u + 1$, no agent is allowed to make a proposal that is less preferred by the other agent than the deal it proposed at time u.
- If neither agent makes a concession in some round $u > 0$, then negotiation terminates, with the conflict deal.

The Zeuthen Strategy

Three problems:

- What should an agent's first proposal be?
  Its most preferred deal
- On any given round, *who should concede*?
  The agent least willing to risk conflict.
- If an agent concedes, then *how much* should it concede?
  Just enough to change the balance of risk.

Willingness to Risk Conflict

- Suppose you have conceded a *lot*. Then:
  - Your proposal is now near to conflict deal.
  - In case conflict occurs, you are not much worse off.
  - You are *more willing* to risk confict.
- An agent will be *more willing* to risk conflict if the difference in utility between its current proposal and the conflict deal is *low*.

Nash Equilibrium Again. . .

The Zeuthen strategy is in Nash equilibrium: under the assumption that one agent is using the strategy the other can do no better than use it himself. . .

This is of particular interest to the designer of automated agents. It does away with any need for secrecy on the part of the programmer. An agent's strategy can be publicly known, and no other agent designer can exploit the information by choosing a different strategy. In fact, it is desirable that the strategy be known, to avoid inadvertent conflicts.

Deception in TODs

Deception can benefit agents in two ways:

- *Phantom and Decoy tasks*.
  Pretending that you have been allocated tasks you have not.
- *Hidden tasks*.
  Pretending *not* to have been allocated tasks that you have been.

Summary

- This lecture has looked at different mechanisms for reaching agreement between agents.
- We started by looking at negotiation, where agents make concessions and explore tradeoffs.
- Finally, we looked at argumentation, which allows for more complex interactions and can be used for a range of tasks that include negotiation.