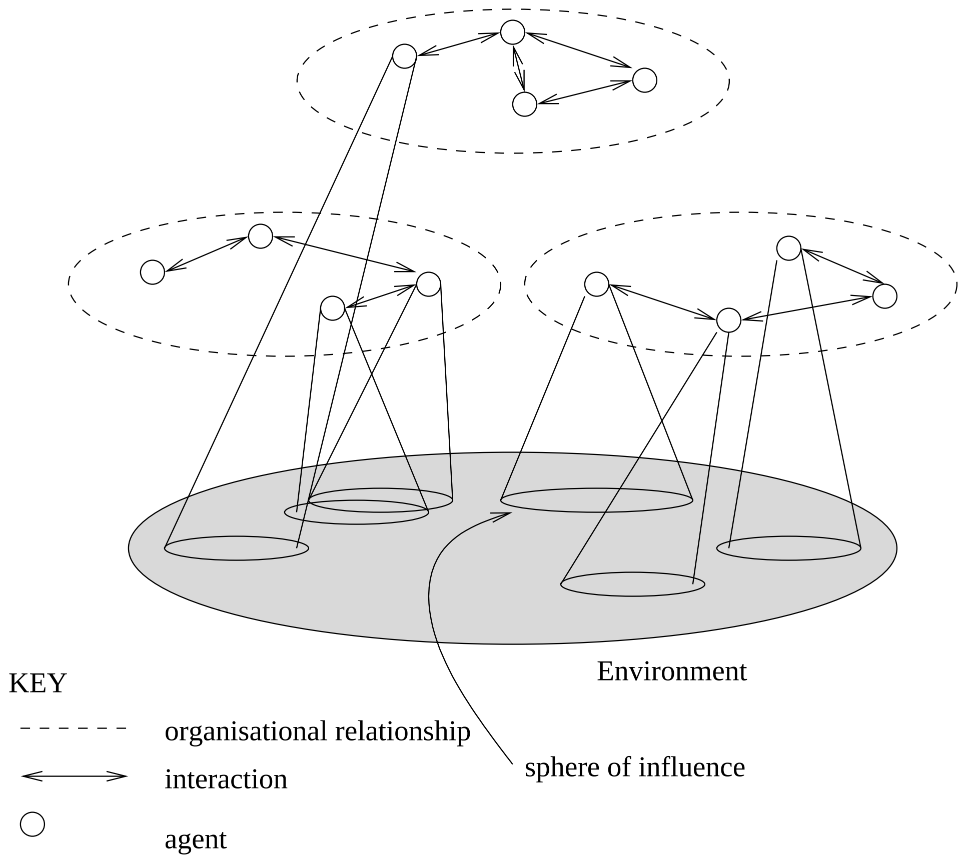
LECTURE 8: MULTIAGENT INTERACTIONS

An Introduction to Multiagent Systems

CIS 716.5, Spring 2005

What are Multiagent Systems?



Thus a multiagent system contains a number of agents . . .

- . . . which interact through communication . . .
- . . . are able to act in an environment . . .
- . . . have different “spheres of influence” (which may coincide). . .
- . . . will be linked by other (organisational) relationships.

Utilities and Preferences

- Assume we have just two agents: $Ag = \{i, j\}$.
- Agents are assumed to be *self-interested*: they *have preferences over how the environment is*.
- Assume $\Omega = \{\omega_1, \omega_2, \ldots\}$ is the set of "outcomes" that agents have preferences over.
- We capture preferences by *utility functions*:

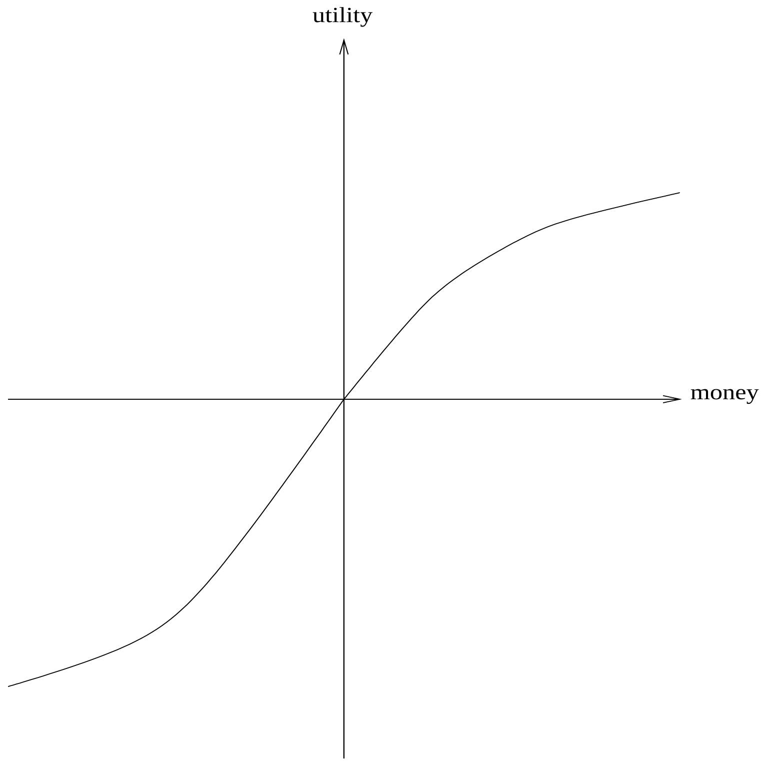
$$u_i : \Omega \to \mathbb{R}$$
$$u_j : \Omega \to \mathbb{R}$$

- Utility functions lead to *preference orderings* over outcomes:

$$\omega \succeq_i \omega' \quad \text{means} \quad u_i(\omega) \geq u_i(\omega')$$
$$\omega \succ_i \omega' \quad \text{means} \quad u_i(\omega) > u_i(\omega')$$

What is Utility?

- Utility is *not* money (but it is a useful analogy).
- Typical relationship between utility & money:



Multiagent Encounters

- We need a model of the environment in which these agents will act...
  - agents simultaneously choose an action to perform, and as a result of the actions they select, an outcome in Ω will result;
  - the *actual* outcome depends on the *combination* of actions;
  - assume each agent has just two possible actions that it can perform C ("cooperate") and "D" ("defect").
- Environment behaviour given by *state transformer function*:

$$\tau : \underbrace{Ac}_{\text{agent } i\text{'s action}} \times \underbrace{Ac}_{\text{agent } j\text{'s action}} \to \Omega$$

- Here is a state transformer function:

$$\tau(D,D) = \omega_1 \quad \tau(D,C) = \omega_2 \quad \tau(C,D) = \omega_3 \quad \tau(C,C) = \omega_4$$

(This environment is sensitive to actions of both agents.)

- Here is another:

$$\tau(D,D) = \omega_1 \quad \tau(D,C) = \omega_1 \quad \tau(C,D) = \omega_1 \quad \tau(C,C) = \omega_1$$

(Neither agent has any influence in this environment.)

- And here is another:

$$\tau(D,D) = \omega_1 \quad \tau(D,C) = \omega_2 \quad \tau(C,D) = \omega_1 \quad \tau(C,C) = \omega_2$$

(This environment is controlled by j.)

Rational Action

- Suppose we have the case where *both* agents can influence the outcome, and they have utility functions as follows:

$$u_i(\omega_1) = 1 \quad u_i(\omega_2) = 1 \quad u_i(\omega_3) = 4 \quad u_i(\omega_4) = 4$$
$$u_j(\omega_1) = 1 \quad u_j(\omega_2) = 4 \quad u_j(\omega_3) = 1 \quad u_j(\omega_4) = 4$$

- With a bit of abuse of notation:

$$u_i(D,D) = 1 \quad u_i(D,C) = 1 \quad u_i(C,D) = 4 \quad u_i(C,C) = 4$$
$$u_j(D,D) = 1 \quad u_j(D,C) = 4 \quad u_j(C,D) = 1 \quad u_j(C,C) = 4$$

- Then agent i's preferences are:

$$C,C \succeq_i C,D \quad \succ_i \quad D,C \succeq_i D,D$$

- "C" is the *rational choice* for i.

  (Because i prefers all outcomes that arise through C over all outcomes that arise through D.)

Payoff Matrices

- We can characterise the previous scenario in a *payoff matrix*

		i defect	i coop
j	defect	1	4
		1	1
	coop	1	4
		4	4

- Agent i is the *column player*.
- Agent j is the *row player*.

Solution Concepts

- How will a rational agent will behave in any given scenario? Play. . .
  - dominant strategy;
  - Nash equilibrium strategy;
  - Pareto optimal strategies;
  - strategies that maximise social welfare.

Dominant Strategies

- Given any particular strategy s (either C or D) agent i, there will be a number of possible outcomes.
- We say s_1 *dominates* s_2 if every outcome possible by i playing s_1 is preferred over every outcome possible by i playing s_2.
- A rational agent will never play a dominated strategy.
- So in deciding what to do, we can *delete dominated strategies*.
- Unfortunately, there isn't always a unique undominated strategy.

Nash Equilibrium

- In general, we will say that two strategies s_1 and s_2 are in Nash equilibrium (NE) if:
  1. under the assumption that agent i plays s_1, agent j can do no better than play s_2; and
  2. under the assumption that agent j plays s_2, agent i can do no better than play s_1.
- *Neither agent has any incentive to deviate from a NE.*
- Unfortunately:
  1. *Not every interaction scenario has a* pure strategy *NE.*
  2. *Some interaction scenarios have more than one NE.*

Pareto Optimality

- An outcome is said to be *Pareto optimal* (or *Pareto efficient*) if there is no other outcome that makes one agent *better off* without making another agent *worse off*.
- If an outcome is Pareto optimal, then at least one agent will be reluctant to move away from it (because this agent will be worse off).
- If an outcome ω is *not* Pareto optimal, then there is another outcome ω' that makes *everyone* as happy, if not happier, than ω.
  "Reasonable" agents would agree to move to ω' in this case. (Even if I don't directly benefit from ω', you can benefit without me suffering.)

Social Welfare

- The social welfare of an outcome ω is the sum of the utilities that each agent gets from ω:

$$\sum_{i \in Ag} u_i(\omega)$$

- Think of it as the "total amount of money in the system".
- As a solution concept, may be appropriate when the whole system (all agents) has a single owner (then overall benefit of the system is important, not individuals).

Competitive and Zero-Sum Interactions

- Where preferences of agents are diametrically opposed we have *strictly competitive* scenarios.
- Zero-sum encounters are those where utilities sum to zero:

$$u_i(\omega) + u_j(\omega) = 0 \quad \text{for all } \omega \in \Omega.$$

- Zero sum implies strictly competitive.
- Zero sum encounters in real life are very rare . . . but people tend to act in many scenarios as if they were zero sum.

The Prisoner's Dilemma

Two men are collectively charged with a crime and held in separate cells, with no way of meeting or communicating.

They are told that:

- if one confesses and the other does not, the confessor will be freed, and the other will be jailed for three years;
- if both confess, then each will be jailed for two years.

Both prisoners know that if neither confesses, then they will each be jailed for one year.

- Payoff matrix for prisoner's dilemma:

		i	
		defect	coop
j	defect	2 2	1 4
	coop	4 1	3 3

- Top left: If both defect, then both get punishment for mutual defection.
- Top right: If i cooperates and j defects, i gets sucker's payoff of 1, while j gets 4.
- Bottom left: If j cooperates and i defects, j gets sucker's payoff of 1, while i gets 4.
- Bottom right: Reward for mutual cooperation.

What Should You Do?

- The *individual rational* action is *defect*.

  This guarantees a payoff of no worse than 2, whereas cooperating guarantees a payoff of at most 1.
- So defection is the best response to all possible strategies: both agents defect, and get payoff = 2.
- But *intuition* says this is *not* the best outcome:

  Surely they should both cooperate and each get payoff of 3!

Solution Concepts

- There is no dominant strategy (in our sense).
- (D, D) is the only Nash equilibrium.
- All outcomes *except* (D, D) are Pareto optimal.
- (C, C) maximises social welfare.

- This apparent paradox is *the fundamental problem of multi-agent interactions*.

  It appears to imply that *cooperation will not occur in societies of self-interested agents*.
- Real world examples:
  - nuclear arms reduction ("why don't I keep mine. . . ")
  - free rider systems — public transport;
  - in the UK — television licenses.
- The prisoner's dilemma is *ubiquitous*.
- Can we recover cooperation?

Arguments for Recovering Cooperation

- Conclusions that some have drawn from this analysis:
  - the game theory notion of rational action is wrong!
  - somehow the dilemma is being formulated wrongly
- Arguments to recover cooperation:
  - We are not all machiavelli!
  - The other prisoner is my twin!
  - The shadow of the future. . .

The Iterated Prisoner's Dilemma

- One answer: *play the game more than once*.

  If you know you will be meeting your opponent again, then the incentive to defect appears to evaporate.

- *Cooperation is the rational choice in the infinititely repeated prisoner's dilemma.*

  (Hurrah!)

Backwards Induction

- But... suppose you both know that you will play the game exactly n times.

  On round $n-1$, you have an incentive to defect, to gain that extra bit of payoff...

  But this makes round $n-2$ the last "real", and so you have an incentive to defect there, too.

  This is the *backwards induction* problem.

- Playing the prisoner's dilemma with a fixed, finite, pre-determined, commonly known number of rounds, defection is the best strategy.

Axelrod’s Tournament

- Suppose you play iterated prisoner’s dilemma against a *range* of opponents . . .

  What strategy should you choose, so as to maximise your overall payoff?
- Axelrod (1984) investigated this problem, with a computer tournament for programs playing the prisoner’s dilemma.

Strategies in Axelrod's Tournament

- ALLD:

  "Always defect" — the *hawk* strategy;

- TIT-FOR-TAT:

  1. On round $u = 0$, cooperate.
  2. On round $u > 0$, do what your opponent did on round $u - 1$.

- TESTER:

  On 1st round, defect. If the opponent retaliated, then play TIT-FOR-TAT. Otherwise intersperse cooperation & defection.

- JOSS:

  As TIT-FOR-TAT, except periodically defect.

Recipes for Success in Axelrod's Tournament

Axelrod suggests the following rules for succeeding in his tournament:

- *Don't be envious*:

  Don't play as if it were zero sum!

- *Be nice*:

  Start by cooperating, and reciprocate cooperation.

- *Retaliate appropriately*:

  Always punish defection immediately, but use "measured" force — don't overdo it.

- *Don't hold grudges*:

  Always reciprocate cooperation immediately.

Game of Chicken

- Consider another type of encounter — the *game of chicken*:

		i	
		defect	coop
	defect	1	2
j		1	4
	coop	4	3
		2	3

(Think of James Dean in *Rebel without a Cause*: swerving = coop, driving straight = defect.)

- Difference to prisoner's dilemma:

Mutual defection is most feared outcome.

(Whereas sucker's payoff is most feared in prisoner's dilemma.)

Solution Concepts

- There is no dominant strategy (in our sense).
- Strategy pairs (C, D)) and (D, C)) are Nash equilibriums.
- All outcomes except (D, D) are Pareto optimal.
- All outcomes except (D, D) maximise social welfare.

Other Symmetric 2 x 2 Games

- Given the 4 possible outcomes of (symmetric) cooperate/defect games, there are 24 possible orderings on outcomes.
  - $CC \succ_i CD \succ_i DC \succ_i DD$
    Cooperation dominates.
  - $DC \succ_i DD \succ_i CC \succ_i CD$
    Deadlock. You will always do best by defecting.
  - $DC \succ_i CC \succ_i DD \succ_i CD$
    Prisoner's dilemma.
  - $DC \succ_i CC \succ_i CD \succ_i DD$
    Chicken.
  - $CC \succ_i DC \succ_i DD \succ_i CD$
    Stag hunt.

Summary

- This lecture has looked at agent interactions, and one approach to characterising them.
- The approach we have looked at here is that of *game theory*, a powerful tool for analysing interactions.
- We looked at solution concepts of Nash equilibrium and Pareto optimality.
- We then looked at the classic Prisoner's Dilemma, and how the game can be analysed using game theory.
- We also looked at the iterated Prisoner's Dilemma, and other canonical 2×2 games.