CogSysI Lecture 11: Rational Decisions

Intelligent Agents
WS 2004/2005

Part III: Multi-Agent Systems

Rational Decisions
An intelligent agent is a computer system with the ability to perform actions independently, autonomously, and flexible (on behalf of a user or an owner).

Flexibility means: being reactive, pro-active, social.

A multi-agent system (MAS) consists of several agents which interact. Such agents must have the ability to cooperate, coordinate and negotiate.

(see slides of Jörg Müller, Siemens AG, Lecture at LMU Munic, 2003)
Demands and Examples

- Performing a useful activity on behalf of humans or organizations (cleaning roboter)
- Coexist/interact with humans (cleaning roboter)
- Be aware of social rules and norms (transportation robot)
- Coordinate activities (team of cleaning robots)
- Cooperate or compete (RoboCup)
- Entertain or educate people (games, tutor systems)
Acting Autonomously

- acting independently in an environment, controlling one's own state
Acting Reactively

- If the environment of a program is static (known in advance), the program cannot fail (Compile-Time, Runtime).

- In the real world, changes occur, information is incomplete (dynamic system).

- A reactive system continuously interacts with its environment and reacts in time to changes.

- Example: Java-Listener

- Reactive systems can be modelled relatively straight-forward: e.g. as stimulus-response rules.
Acting Pro-activly

- means: generate goals autonomously, try to reach goals
- not only event-driven behavior but: act on one’s own initiative
Acting Socially

- Real world is a multi-agent environment
- When trying to reach goals, others must be taken into account
- Some goals can only be reached through cooperation
- In some situations exit conflicts and competition (e.g. internet auctions)
- Social skills of agents: ability to model goals of other agents when trying to reach one’s own (local) goals, ability to interact (i.e. cooperate and coordinate)
Further Features

- Mobility: ability to move in a computer net or in another environment
- Adaptivity/learning: Improving performance over time
- Rationality: do not act in a way which hinders to fulfill one’s goals
A Model for MA Interaction

Multiagent Interaction = Encounter

\[ Ag = \{1, 2, \ldots\} \]

In the following: \(|Ag| = 2\) with \(Ag = \{i, j\}\)

Interactions produce results:
Set of resulting states: \(\Omega = \{\omega_1, \omega_2, \ldots\}\)

Agents have preferences over states.
Preference and Utility

- Utility Function: $\Omega \rightarrow \mathbb{R}$
- Each agent has its own utility function $u_i, u_j$
- Utility functions induce preference orders over states:
  
  $\omega \geq_i \omega' \rightarrow u_i(\omega) \geq u_i(\omega')$
  
  $\omega >_i \omega' \rightarrow u_i(\omega) > u_i(\omega')$

- A useful metaphor for utility is money
- Theoretical background is game theory (as investigated and used in economics)
MA Interaction cont.

- Model of the Environment
  - Agent $i$ and $j$ select an action simultaneously.
  - Result of $(a_i, a_j)$ is a state in $\Omega$.
  - The result depends on the combination of actions.

- Simplification:
  Each agent can only choose between two actions
  $a \in Ac$

  - $C$ (Cooperate)
  - $D$ (Defect)

- Environment changes are defined by a state transition function:

$$\tau : Ac \times Ac \rightarrow \Omega$$
State Transitions

- No agent can influence the environment
  \[ \tau(D, D) = \tau(C, D) = \tau(D, C) = \tau(C, C) = \omega_1 \]

- Agent $j$ controls the environment
  \[ \tau(D, D) = \tau(C, D) = \omega_1, \tau(D, C) = \tau(C, C) = \omega_2 \]

- Environment is sensitive wrt actions of both agents
  \[ \tau(D, D) = \omega_1, \tau(C, D) = \omega_2, \tau(D, C') = \omega_3, \tau(C, C') = \omega_4 \]
Rational Actions

Reasoning and planning agents: calculative/computational rationality

First step: deliberation – what goal should be achieved forming an intention

Second step: Means-End-Analysis – how should the goal be achieved

Intention: agent commits itself to a task, inconsistent intentions can be blocked by an active intention

Agents belief that their intentions can be fulfilled and do not belief that they cannot fulfill their intentions (rationality)

Model: Belief, desire, intention Semantics (BDI)

In the following: Focus on multi-agent interactions (games)
Rational Actions in MAS

- Assume that environment can be influenced by both agents.
- Utility function $u(\omega)$ with $\omega$ represented as action tuple:
  
  $u_i(D, D) = 1; u_i(D, C) = 1; u_i(C, D) = 4; u_i(C, C) = 4$
  
  $u_j(D, D) = 1; u_j(D, C) = 4; u_j(C, D) = 1; u_j(C, C) = 4$

- Preference of agent $i$:
  
  $$(C, C) \succeq_i (C, D) \succeq_i (D, C) \succeq_i (D, D)$$

- $C$ is the rational decision for $i$, because it prefers all states where it selects $C$.

- This is the basic model of game theory.

- Representation in payoff matrices.
## Payoff Matrix

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>j</td>
<td>Defect</td>
<td>Cooperate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>j</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cooperate</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Dominant Strategies

- Strategy: Decision function by which an agent selects an action

- A strategy $s_1$ dominates another strategy $s_2$ if an agent prefers each possible outcome of strategy $s_1$ over each possible outcome of strategy $s_2$

- A rational agent will never select a strategy which is dominated by another strategy (such strategies can be excluded when actions are selected)

- Unfortunatly, there exists not always a distinct dominant strategy

- Pareto-optimality: an outcome is pareto optimal, if there is no other outcome all agents would prefer
Nash-Equilibrium

- Two strategies $s_1$ and $s_2$ are in a Nash-equilibrium if:
  - Under assumption that agent $i$ plays $s_1$, $s_2$ is the rational choice of agent $j$
  - Under assumption that agent $j$ plays $s_2$, $s_1$ is the rational choice of agent $j$

- If we have two strategies in Nash-equilibrium, no agent has an incentive to change its strategy

- Obtaining a Nash-equilibrium is desirable, because it is an effort to switch strategies and strategy switches might danger stability of a system
Analysis of game theoretic scenarios

- Nash-equilibrium is an important tool for analyzing game theoretic scenarios
- If each player has a dominant strategy, the combination of those strategies is called dominant strategy equilibrium
- Solution of a game: the rational strategy of each agent
- Each dominant strategy equilibrium is a Nash equilibrium
- Nash’s theorem: there are equilibrium strategies even if there is no dominant strategy
- Nash equilibrium is a necessary condition for an optimal solution (but is it also sufficient?)
### Coordination Games

- **Acme**, a video game hardware manufacturer must decide whether its next game machine will use CD or DVD.

- **Best**, a video software producer must decide whether to produce its next game on CD or DVD.

<table>
<thead>
<tr>
<th></th>
<th>Acme DVD</th>
<th>CD</th>
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<tr>
<td>Best DVD</td>
<td>9</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>-1</td>
</tr>
<tr>
<td>CD</td>
<td>-3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>-1</td>
<td>5</td>
</tr>
</tbody>
</table>
Example cont.

- No dominant strategy

- Two Nash equilibria: (CD, CD) and (DVD, DVD)
  if one player moves to a different strategy unilaterally, he will be worse off

- One Pareto-optimal solution: (DVD, DVD)

- If payoff for CD and DVD would be equal, there would be two Pareto-optimal solutions

→ guess or communicate

→ coordination game
Zero-sum games

- If preference orders of two agents are diametral, we have a strongly competitive scenario:

\[ \omega \geq_i \omega' \rightarrow \omega' \geq_j \omega \]

- An interaction is called zero-sum interaction, if

\[ u_i(\omega) + u_j(\omega) = 0 \text{ for all } \omega \in \Omega \]

- All zero-sum interactions are competitive!
Prisoner’s Dilemma

- Two people are accused of complicity in a criminal act
- They are in two different prison cells and cannot communicate
- The attorney guarantees:
  - If one confesses the crime and the other not, the first will be free, the other goes 5 years to prison
  - If both confess, both go for 3 years to prison
- Both know that they go 2 years to prison if none of them confesses
## Prisoner’s Dilemma

<table>
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<th>i</th>
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<tbody>
<tr>
<td>confess</td>
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</tr>
<tr>
<td>j</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>deny</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

- Global utility is maximal if both cooperate (deny)
- But: for each single agent the rational choice is not to cooperate but to testify
- Is cooperation feasible in a society of rational, egoistical agents?