Negociating with bounded rational agents in environments with incomplete information using an automated agent

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Example


Stu's Views
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U
Bob said, "Let's negotiate."
I said, "Over my dead body."

- 2 agents: Alice and Bob
- 2 activities: Basketball game (B) and Movie (M)
- 2 days: Friday (F) and Saturday (S)
- Preferences:

Bob

$B \succ M$
$(B, S) \succ (B, F)$
$(M, F) \succ (M, S)$

Alice

$M \succ B$
$(M, S) \succ (M, F)$
$(B, F) \succ (B, S)$

Question

What to do over the weekend ?

Outline

Introduction

Type of negotiation:

- **Finite horizon:** finite history
- **Bilateral:** 2 agents involved
- **Incomplete information:** uncertainty regarding the preferences of the opponent
- **Multi-issue**
- **Time constraint**

Introduction

Bounded rational agent (Herbert Simon 1957)

The agents behave in a manner that is **nearly** optimal with respect to its goals as its resources will allow.

- They gain or lose utility over time

Introduction

- Create an automated agent for negotiation
- Goals:
  - Train people
  - Assist in e-commerce
  - Modelling negotiation process
  - ....
- Means:
  - Learning mechanism: Bayesian learning algorithm
  - Decision making mechanism: bounded rationality assumption

Outline

Problem description

Notations:

- I set of issues
- $\forall i \in I \quad O_i$ set of values
- O finite set of values $(O_1 \times ... \times O_{|I|})$
- $\overrightarrow{o} \in O$ an offer
- $Time = \{0, ..., dl\}$ set of time period
- Time costs which influence utility as time passes

Problem description

- 2 agents: Alice and Bob
- Question: “What to do over the weekend ?”
- 2 issues: Activity and Night: $I = \{A, N\}$
- $O_{Activity} = \{\text{Movie (M)}, \text{Basketball game (B)}\}$
- $O_{Night} = \{\text{Friday (F)}, \text{Saturday (S)}\}$
- Offers:
  - $\overrightarrow{o_1} = \{M, S\}$
  - $\overrightarrow{o_2} = \{M, F\}$
  - $\overrightarrow{o_3} = \{B, S\}$
  - $\overrightarrow{o_4} = \{B, F\}$

Problem description

Types of agreement

- Partial: agreement over a subset of issues
- Full: agreement over the set of issues

Types of action

- Accept: end of the negotiation
- Reject
- Opt out: end of the negotiation

Problem description

- A default value is assigned to each attribute
- 3 possible ends for a negotiation
  1. Full agreement
  2. One of the agent opt out (*OPT* is the corresponding outcome)
  3. The deadline *dl* is reached
     - Partial agreement (subset of the issues)
     - No agreement: status quo (outcome *SQ*)

Problem description

Utility

$\forall l \in Types, \quad u_l : O \bigcup \{SQ\} \bigcup \{OPT\} \longmapsto \Re$

Reservation price

Minimum value r_l of the utility of an offer under which an agent of type l is unwilling to accept the offer

- Assumptions:
  - The agent knows the finite set of types: $Types = \{1, ..., k\}$
  - The agent doesn't know the exact utility of the opponent
  - The agent has a probabilistic belief of the opponent's type

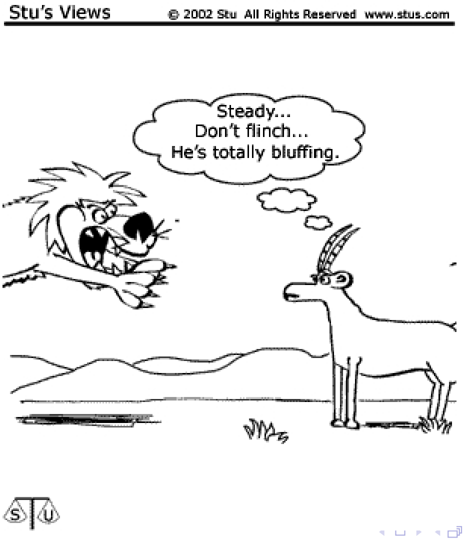
Outline

1. Problem description
2. Agent Design
   - Learning mechanism
     - Bayes formula
     - Luce numbers
     - Example
   - Decision mechanism
     - Generating offers
     - Example
     - Accepting/Rejecting offers
     - Example
3. Experiments
4. Conclusion
5. Discussion & Future work

Agent design

2 mechanisms:

1. Learning mechanism
2. Decision making mechanism


Stu's Views
© 2002 Stu All Rights Reserved www.stus.com
Steady...
Don't flinch...
He's totally bluffing.


Stu's Views
© 2002 Stu All Rights Reserved www.stus.com
Attorneys rarely survive in the wild
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U
"But I came here to negotiate."

Bayes formula

- Goal: to allow an agent to update its belief regarding the opponent's type

Bayes Formula

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

where:
$P(A|B)$ conditional probability of A given B
$P(A), P(B)$ prior probability of A and B respectively

Bayes formula

- k different types for the opponent
- $\forall i \in Types \quad P(type^i_{t=0}) = \frac{1}{k}$

Bayes Formula with agents' types

For each period of time:

$$\forall i \in Types \quad \forall \overrightarrow{o_t} \in O \quad P(type^i | \overrightarrow{o_t}) = \frac{P(\overrightarrow{o_t} | type^i_t) P(type^i_t)}{P(\overrightarrow{o_t})}$$

where: $P(\overrightarrow{o_t}) = \sum_{i=1}^{i=k} P(\overrightarrow{o_t} | type^i_t) P(type^i_t)$

Problem

How to compute $P(\overrightarrow{o_t} / type^i_t)$?

Luce numbers

Luce numbers

$$\forall o \in O \quad lu(\overrightarrow{o_t}) = \frac{u(\overrightarrow{o_t})}{\sum_{\overrightarrow{x} \in O} u(\overrightarrow{x})}$$

Theorem

$$\forall \overrightarrow{x}, \overrightarrow{y} \quad u(\overrightarrow{x}) \geq u(\overrightarrow{y}) \Longleftrightarrow lu(\overrightarrow{x}) \geq lu(\overrightarrow{y})$$

- **Estimation** of the acceptance rate of the opponent's offer

Believed type

Believed type

For each $t \in Times$:

$$BT(t) = arg \max_{i \in Types} P(type^i / \overrightarrow{o_t})$$

Given the fact that:

$$P(\overrightarrow{o_t} / type^i_t) \simeq lu(\overrightarrow{o_t} / type^i_t)$$

Example

- 2 types for Alice (ie 2 types of utility)
  - Type 1 (t_1): $M \succ B$
  - Type 2 (t_2): $(M, F) \succ (B, F)$
- Initially (t=0): $P(t_1) = P(t_2) = \frac{1}{2}$
- Alice's offer (t=1): $\overrightarrow{o_t} = \{B, F\}$

Table 3

Example: Calculating Alice's believed type

		$\vec{o}_1 = \{M, S\}$	$\vec{o}_2 = \{M, F\}$	$\vec{o}_3 = \{B, S\}$	$\vec{o}_4 = \{B, F\}$
1	$u_a(\vec{o}_i)$, type^1	10	9	4	6
2	$u_a(\vec{o}_i)$, type^2	10	7	5	9
3	$lu_a(\vec{o}_i)$, type^1	$10/29 = 0.34$	$9/29 = 0.31$	$4/29 = 0.14$	$6/29 = 0.21$
4	$lu_a(\vec{o}_i)$, type^2	$10/31 = 0.32$	$7/31 = 0.23$	$5/31 = 0.16$	$9/31 = 0.29$

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$$P(t_1|\overrightarrow{o_4}) = \frac{lu_a(\overrightarrow{o_4}|t_1)P(t_1)}{P(\overrightarrow{o})} = \frac{0.21 \times 0.5}{0.21 \times 0.5 + 0.29 \times 0.5} = 0.42$$

$$P(t_2|\overrightarrow{o_4}) = \frac{lu_a(\overrightarrow{o_4}|t_2)P(t_2)}{P(\overrightarrow{o})} = \frac{0.29 \times 0.5}{0.21 \times 0.5 + 0.29 \times 0.5} = 0.58$$

Decision mechanism

- Used for:
  1. Accepting/rejecting offers
  2. Generating offers (only 1 offer for a given period)
- Use of 2 methods:
  1. Maximin method
  2. Ranking of offers
- Take into account:
  - Utility function of the agent
  - Believed type of the opponent

Decision mechanism

Generating offers

- The generating mechanism is based on:
  - The utility of the offer for the agent
  - The probability the opponent accepts it

Notion of *rank* for an offer

$$rank(\overrightarrow{o}) = \frac{order(\overrightarrow{o}, O)}{|O|}$$

where *order* is a ranking of the offer using their normalized utility

- We use the Luce number to estimate the probability of an agent accepting the offer

Generating offers

Notations

Notations:

- $u_{opp}^{BT(t)}$ utility function corresponding to the believed type of the opponent (noted u_{opp})
- $rank_{opp}^{BT(t)}$ rank function corresponding to the believed type of the opponent (noted $rank_{opp}$)
- $lu_{opp}(\overrightarrow{o}\,|\,u_{opp}^{BT(t)}) = lu_{opp}(\overrightarrow{o})$ Luce number corresponding to the believed type
- $lu_{agent}(\overrightarrow{o})$ Luce number corresponding to the agent type

Generating offers

Function Qualitative Offer

Function Qualitative Offer

$$QO(t) = arg \max_{\vec{o} \in O} min\{\alpha, \beta\}$$

where:

$\alpha = rank(\vec{o}).lu_{agent}(\vec{o})$

$\beta = [lu_{opp}(\vec{o}) + lu_{agent}(\vec{o})]rank_{opp}(\vec{o})$

Pessimistic assumption

The offer is accepted based on the agent that favors the offer the least

- Equivalence: $lu_{opp}(\vec{o}) + lu_{agent}(\vec{o}) \sim$ social welfare

Generating offers

Steps

- 3 steps:
  1. Computation of the believed type of the opponent $BT(t)$
  2. Computation of the Luce numbers using u_{opp} and u_{agent}
  3. Choice of the best offer using the Qualitative Offer QO function

Generating offers

Example

- The agent plays the role of Bob.

Assumptions:

- Alice has only one possible type
- The utilities are time independent

Table 1
Example of calculating QO

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5	$rank_b(\vec{o}_i)$	$1/4 = 0.25$	$2/4 = 0.50$	$4/4 = 1.00$	$3/4 = 0.75$
6	$rank_a(\vec{o}_i)$	$4/4 = 1.00$	$3/4 = 0.75$	$1/4 = 0.25$	$2/4 = 0.50$
7	$lu_b(\vec{o}_i) \cdot rank_b(\vec{o}_i)$	0.04	0.11	0.36	0.21
8	$lu_a(\vec{o}_i) \cdot rank_a(\vec{o}_i)$	0.34	0.23	0.03	0.10
9	$[lu_b(\vec{o}_i) + lu_a(\vec{o}_i)] \cdot rank_a(\vec{o}_i)$	0.49	0.39	0.12	0.25
10	$[lu_a(\vec{o}_i) + lu_b(\vec{o}_i)] \cdot rank_b(\vec{o}_i)$	0.12	0.26	0.49	0.37

- $\alpha = rank(\vec{o}).lu_b(\vec{o})$
- $\beta = [lu_a(\vec{o}) + lu_b(\vec{o})]rank_a(\vec{o})$

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Function QO

$$QO(t) = arg \max_{\vec{o} \in O} min\{\alpha, \beta\}$$

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Decision mechanism

Accepting/Rejecting offers

Notations

Notations:

- $a, b \sim$ agent a, b $\sim$ type a,b
- a automated agent
- b opponent
- $\overrightarrow{o_i}$ offer received from agent i
- t current time
- T threshold

Accepting/Rejecting offers

Rules

Rule 1

If $u_a(\overrightarrow{o_b}) \geq u_a(QO(t+1))$ then $\overrightarrow{o_b}$ is accepted

where $QO(t+1)$ is the best offer the agent will be able to do for the next period

Accepting/Rejecting offers

Rules

- Otherwise:

$$u_a(\overrightarrow{o_b}) < u_a(QO(t+1))$$

- Take into account the probability that its counter offer will be accepted by the opponent:

Rule 2

If $|u_b(QO(t+1)) - u_b(\overrightarrow{o_b})| \leq T$ then $\overrightarrow{o_b}$ is rejected

- The two offers are quasi equivalent for the opponent
- BUT: QO(t+1) is more valuable for the agent

Accepting/Rejecting offers

Rules

- Otherwise:

$$u_a(\overrightarrow{o_b}) < u_a(QO(t+1))$$

$$|u_b(QO(t+1)) - u_b(\overrightarrow{o_b})| > T$$

- Take into account its reservation price:

Rule 3

If $u_a(\overrightarrow{o_b}) \geq r_a$ then $\overrightarrow{o_b}$ is rejected with the probability $rank(\overrightarrow{o_b})$

- Alice suggests to Bob: $\overrightarrow{o_2} = (M, F)$
- We suppose that $r_{bob} = 5$ and $T = 0.05$

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Example of calculating QO

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1	$u_b(\vec{o}_i)$	4	6	10	8
2	$u_a(\vec{o}_i)$	10	9	4	6
3	$lu_b(\vec{o}_i)$	$4/28 = 0.14$	$6/28 = 0.21$	$10/28 = 0.36$	$8/28 = 0.29$
4	$lu_a(\vec{o}_i)$	$10/29 = 0.34$	$9/29 = 0.31$	$4/29 = 0.14$	$6/29 = 0.21$
5	$rank_b(\vec{o}_i)$	$1/4 = 0.25$	$2/4 = 0.50$	$4/4 = 1.00$	$3/4 = 0.75$
6	$rank_a(\vec{o}_i)$	$4/4 = 1.00$	$3/4 = 0.75$	$1/4 = 0.25$	$2/4 = 0.50$
7	$lu_b(\vec{o}_i) \cdot rank_b(\vec{o}_i)$	0.04	0.11	0.36	0.21
8	$lu_a(\vec{o}_i) \cdot rank_a(\vec{o}_i)$	0.34	0.23	0.03	0.10
9	$[lu_b(\vec{o}_i) + lu_a(\vec{o}_i)] \cdot rank_a(\vec{o}_i)$	0.49	0.39	0.12	0.25
10	$[lu_a(\vec{o}_i) + lu_b(\vec{o}_i)] \cdot rank_b(\vec{o}_i)$	0.12	0.26	0.49	0.37

- Bob checks his own utility
- Bob knows that $\overrightarrow{o_4}$ is the best offer he can do

Table 1
Example of calculating QO

		$\vec{o}_1 = \{M, S\}$	$\vec{o}_2 = \{M, F\}$	$\vec{o}_3 = \{B, S\}$	$\vec{o}_4 = \{B, F\}$
1	$u_b(\vec{o}_i)$	4	6	10	8
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9	$[lu_b(\vec{o}_i) + lu_a(\vec{o}_i)] \cdot rank_a(\vec{o}_i)$	0.49	0.39	0.12	0.25
10	$[lu_a(\vec{o}_i) + lu_b(\vec{o}_i)] \cdot rank_b(\vec{o}_i)$	0.12	0.26	0.49	0.37

Rule 1

If $u_a(\overrightarrow{o_b}) \geq u_a(QO(t+1))$ then $\overrightarrow{o_b}$ is accepted

- Rule 1 is violated: $u_b(\overrightarrow{o_2}) < u_b(\overrightarrow{o_4})$

Table 1
Example of calculating QO

		$\vec{o}_1 = \{M, S\}$	$\vec{o}_2 = \{M, F\}$	$\vec{o}_3 = \{B, S\}$	$\vec{o}_4 = \{B, F\}$
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3	$lu_b(\vec{o}_i)$	$4/28 = 0.14$	$6/28 = 0.21$	$= 0.36$	$8/28 = 0.29$
4	$lu_a(\vec{o}_i)$	$10/29 = 0.34$	$9/29 = 0.31$	0.14	$6/29 = 0.21$
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Rule 2

If $|u_b(QO(t+1)) - u_b(\overrightarrow{o_b})| \leq T$ then $\overrightarrow{o_b}$ is rejected

- Rule 2 is violated: $|u_a(\overrightarrow{o_4}) - u_a(\overrightarrow{o_2})| > 0.05$

Table 1
Example of calculating QO

		$\vec{o}_1 = \{M, S\}$	$\vec{o}_2 = \{M, F\}$	$\vec{o}_3 = \{B, S\}$	$\vec{o}_4 = \{B, F\}$
1	$u_b(\vec{o}_i)$	4	6	10	8
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7	$lu_b(\vec{o}_i) \cdot rank_b(\vec{o}_i)$	0.04	0.11	0.36	0.21
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10	$[lu_a(\vec{o}_i) + lu_b(\vec{o}_i)] \cdot rank_b(\vec{o}_i)$	0.12	0.26	0.49	0.37

Rule 3

If $u_a(\overrightarrow{o_b}) \geq r_a$ then $\overrightarrow{o_b}$ is rejected with the probability $rank(\overrightarrow{o_b})$

- Rule 3 is enforced: $u_b(\overrightarrow{o_2}) \geq 5$

Decision mechanism

Table 1
Example of calculating QO

		$\vec{o}_1 = \{M, S\}$	$\vec{o}_2 = \{M, F\}$	$\vec{o}_3 = \{B, S\}$	$\vec{o}_4 = \{B, F\}$
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10	$[lu_a(\vec{o}_i) + lu_b(\vec{o}_i)] \cdot rank_b(\vec{o}_i)$	0.12	0.26	0.49	0.37

- Bob accepts Alice's offer with probability $1 - rank_b(\vec{o_2}) = 0.5$

Outline

Experiments

- Scenario 2: a job candidate and an employer
- 5 issues:
  1. Salary
  2. Job description
  3. Social benefits
  4. Promotion possibilities
  5. Working hours
- Number of possible agreements: 1296
- Time constraint: $<$ 28 minutes

Experiments

Domain 2:

- Both agents lose as time advances
- Status quo *SQ* is similar for both agents
- Three possible types
- Assigned utility for each negotiator
- Precise opponent type unknown
- The different possible types are public
- At most 14 time periods of 2 minutes

Experiments

- Protocol:

	Utility range (min-max)	Status Quo outcome
Employer	170-620	240
Job candidate	60-635	-160

- Fixed loss per time period:
  - -6 units for the employer
  - -8 units for the job candidate
- 44 simulations

Summary

In a nutshell:

- Automated Agent (AA) achieves better agreement
- The social welfare increases if an AA is involved

Statistical tests:

- t-test: to compare utility value
- Wilcoxon signed-rank test: to compare discrete samples
- Fisher's exact test: correlation between the type of agreement and the type of negotiator

Automated agent vs human

- Utility value for the AA: Higher
- Sum of the utility: Higher
- Full agreement: 86% instead of 72% (Human vs Human)
- Probability of reaching a full agreement: Higher

But: the results are significantly higher for only one of the two roles (in this case for the job candidate)

Automated agent vs automated agent

Opponents:

- The same automated agent
- A Bayesian Equilibrium Agent (BEA)

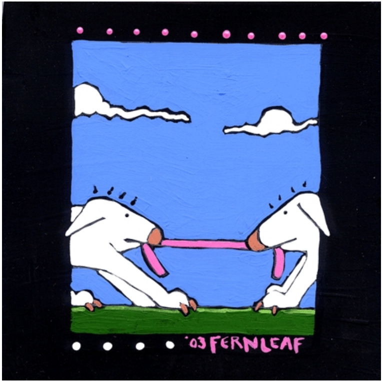
AA vs AA:

- Average and sum of utility: Higher
- Kind of agreement: Better

AA vs BEA:

- QO higher than when humans are involved
- Ended early

Reasons



Reasons

Reasons

How to explain these results ?

- AA is rational: it considers the offers that are good for it **AND reasonable for the opponent**
- AA pays more attention to the gain/lose as time advances

Outline

Conclusion

- Flexibility of the automated agent
- Effective outcomes
- No constraints on the model induced by the domain

Outline

Future work

- Improve the offer generating mechanism: most of the reached agreements are based on human made offers
- Make more than one offer per turn:
  - More interaction with the opponent
  - Use the pressure of time
- Experiments with real negotiators
- Take into account more than one future step
- Introduce the notion of power for the agent
- Use other learning techniques (more flexible): neural networks, genetic algorithms,...

Pros and Cons

Pros:

- Interesting examples
- Agent design

Cons:

- Theoretical justifications
- Related work
- Use of only utility as a measurement of quality
- No clear justification for their experimental choices

Questions

Thank you very much for your attention