Negotiation by Abduction and Relaxation

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Motivation

- In negotiation dialogues, agents generate proposals by reasoning on their own goals.
- In automated negotiation, behavior of agents is usually represented as specific (meta-)knowledge of an agent, or specified as negotiation protocols in particular problems.
- The goal of this research is to develop **general inference rules** for producing proposals and to mechanize a process of exchanging (counter-)proposals in negotiation dialogues.

Contributions

- Introduce methods for generating 3 different types of proposals:
  - **conditional proposals** by **abduction**
  - **neighborhood proposals** by **relaxation**
  - **conditional neighborhood proposals** by abduction and relaxation
- Develop a **negotiation protocol** between two agents.
- Provide a **procedure** for computing proposals.

Problem Setting

- **one-to-one negotiation** between two agents.
- An agent has a knowledge base represented by an **abductive logic program**.
- Negotiation proceeds in a series of **rounds** and each agent makes a proposal at every round.
- An agent that received a proposal responds in two ways: accept/reject the proposal or building a **counter-proposal**.

Logic Programming (or Answer Set Programming)

A logic program considered here contains **disjunction** (**;**), **explicit negation** (¬), and **default negation** (**not**), which are used for representing incomplete information. The meaning of a program is given by **answer sets.**

<u>*Example* (A scholar in Hawaii)</u>

swimming **;** *shopping* ← ¬ *study*,

¬ *study* ← ***not*** *study*.

The program has two answer sets:

{ *swimming* , ¬ *study* } and

{ *shopping*, ¬ *study* }.

Extended Abduction

- An **abductive program** is a pair <P,H> where P is a logic program and H is a set of literals representing **hypotheses** (called **abducibles**).
- Given an **observation** G as a conjunction
  $L_1, \ldots, L_m, \textbf{\textit{not}}\ L_{m+1}, \ldots, \textbf{\textit{not}}\ L_n$, ($L_i$: literal)
  a pair (E, F) is an **explanation** of G if
  1. $(P \setminus F) \cup E$ has an answer set satisfying G,
  2. $(P \setminus F) \cup E$ is consistent,
  3. E and F are sets of ground literals s.t.
     $E \subseteq H \setminus P$ and $F \subseteq H \cap P$.
- A set S is a **belief set** of <P,H> satisfying G if S is an answer set of $(P \setminus F) \cup E$ satisfying 1-3 above.
- An explanation (E, F) is **minimal** if
  $E \subseteq E'$ and $F \subseteq F'$ for any explanation (E', F').

Proposal

- A **proposal** G is a conjunction

  $L_1, \ldots, L_m,$ ***not*** $L_{m+1}, \ldots,$ ***not*** $L_n,$ (L_i : literal)

  where every variable in G is existentially quantified and range-restricted.
- A proposal G is called a **critique** if G=*accept* or G=*reject*.
- A proposal G is **accepted** in an abductive program <P,H> if P has an answer set satisfying G.

Conditional Proposal by Abduction

Given an abductive program <P,H> and a proposal G, if (E,F) is a minimal explanation of $G\theta$ for some substitution θ, the conjunction

$$G\theta, E, \text{not } F$$

is called a **conditional proposal**, where E, **not** F represents $A_1,\ldots,A_k$, **not** $A_{k+1},\ldots,$ **not** A_l for $E=\{A_1,\ldots,A_k\}$ and $F=\{A_{k+1},\ldots,A_l\}$.

∗ A conditional proposal represents a minimal requirement for accepting G.

Example

An agent seeks a position of a research assistant at the computer department of a university with the condition that the salary is *at least 50K USD* per year.

Then, he makes his request as

$G = assist(comp\_dept), salary(x), x \geqq 50K .$

Exxample

The university has the abductive program <P,H>:

P: salary(40K) ← assist(comp_dept), ***not*** *hasPhD,*

salary(60K) ← assist(comp_dept), hasPhD,

salary(50K) ← assist(math_dept),

salary(55K) ← sys_admin(comp_dept),

employee(x) ← assist(x),

employee(x) ← sys_admin(x),

assist(comp_dept) ***;*** *assist(math_dept)* ***;*** *sys_admin(comp_dept) ←,*

H: hasPhD .

Exxxample

- First, P has no answer set satisfying G, so G is not accepted as it is.
- Next, (E,F)=({ *hasPhD* },{ }) becomes the minimal explanation of

  $G\theta$ =*assist(comp_dept), salary(60K)*

  with θ ={ x / 60K }.

  Then, the conditional proposal made by the university becomes

  assist(comp_dept), salary(60K), hasPhD .

Relaxation

- **Relaxation** is a technique of **cooperative query answering** in databases.
- When an original query fails in a DB, relaxation *expands* the scope of the query by relaxing constraints in the query.
- This allows the DB to return **neighborhood answers** which are related to the original query.

Methods for Relaxation

Given an abductive program <P,H> and a proposal G, G is relaxed to G' in the following three ways:

- **Anti-instantiation**: Construct G' s.t. $G'\theta = G$ for some substitution θ.
- **Dropping conditions**: Construct G' s.t. $G' \subset G$.
- **Goal replacement**: When G is a conjunction G_1, G_2 and there is a rule $L \leftarrow G_1'$ in P s.t. $G_1'\theta = G_1$, build G' as $L\theta, G_2$.

Neighborhood Proposals by Relaxtion

- Let G’ be a proposal by anti-instantiation or dropping conditions. If P has an answer set satisfying G’θ, G’θ is called a neighborhood proposal by anti-instantiation/dropping conditions.
- Let G’ be a proposal by goal replacement. For a replaced literal $L \in G'$ and a rule $H \leftarrow B$ in P s.t. $L = H\sigma$ for some substitution σ, put $G'' = (G' \setminus \{L\}) \cup B\sigma$. If P has an answer set satisfying G”θ, G”θ is called a neighborhood proposal by goal replacement.

Example, cont.

Given the initial proposal

G = assist(comp_dept), salary(x), $x \geqq 50K$,

produce

G_1 *= assist(w), salary(x), $x \geqq 50K$*

by substituting *comp_dept* with a variable *w.*

As $G_1 \theta_1$ *= assist(math_dept), salary(50K)*

with $\theta_1 = \{ w / math\_dept \}$ is satisfied by an answer set of P, $G_1 \theta_1$ becomes a neighborhood proposal by anti-instantiation.

Exxample

Given the initial proposal

$G = assist(comp\_dept), salary(x), x \geqq 50K$,

produce

$G_2 = assist(comp\_dept), salary(x),$

by dropping the salary condition.

As $G_2\theta_2 = assist(comp\_dept), salary(40K)$

with $\theta_2 = \{ x / 40K \}$ is satisfied by an answer set of P, $G_2\theta_2$ becomes a neighborhood proposal by dropping conditions.

Exxxample

Given the initial proposal

$G = assist(comp\_dept), salary(x), x \geqq 50K$,

produce

$G_3 = employee(comp\_dept), salary(x), x \geqq 50K$

by replacing *assist(comp_dept)* with *employee(comp_dept)* using the rule $employee(x) \leftarrow assist(x)$ in P.

By G_3 and the rule $employee(x) \leftarrow sys\_admin(x)$ in P,

$G_3' = sys\_admin(comp\_dept), salary(x), x \geqq 50K$

is produced. As

$G_3'\theta_3 = sys\_admin(comp\_dept), salary(55K)$

with $\theta_3 = \{ x / 55K \}$ is satisfied by an answer set of P, $G_3\theta_3$ is a neighborhood proposal by goal replacement.

Negotiation Protocol: Overview

- Negotiation starts by a proposal of one agent Ag_1.
- Another agent Ag_2 either accepts it, rejects it, or builds a counter-proposal. In case of acceptance, negotiation ends in success. In case of rejection, Ag_2 informs Ag_1 of a reason for rejection.
- In response to rejection, Ag_1 tries to change its initial proposal. In response to a counter-proposal made by Ag_2, Ag_1 evaluates it.
- The process iterates until negotiation ends in success or failure. A negotiation fails when every counter-proposal made by one agent is rejected by another agent.

Negotiation Protocol: Tips

- Possible (counter-)proposals are accumulated in a **negotiation set** of each agent at every round.
- Rejected proposals are accumulated in a **failed proposal set** to avoid proposing once rejected proposals.
- Reasons for rejection of proposals by one agent are accumulated in a **critique set** of another agent. An agent takes care of its critique set for building new proposals.

Properties

Theorem: Let Ag_1 and Ag_2 be two agents having abductive programs $<P_1, H_1>$ and $<P_2, H_2>$, respectively.

- If $<P_1, H_1>$ and $<P_2, H_2>$ are function-free (i.e., both P_i and H_i contains no function symbol), every negotiation terminates.
- If a negotiation terminates with agreement on a proposal G, both $<P_1, H_1>$ and $<P_2, H_2>$ have belief sets satisfying G.

Example – Negotiation Dialogue

A seller has the abductive program $\langle P_s, H_s \rangle$:

P_s: $pc(b_1,1G,512M,80G)$ **;** $pc(b_2,1G,512M,80G) \leftarrow$,

% *pc(brand, CPU, Memory, HDD)*

dvd-rw **;** *cd-rw* $\leftarrow$,

normal_price(1300) $\leftarrow$ $pc(b_1,1G,512M,80G)$, *dvd-rw*,

normal_price(1200) $\leftarrow$ $pc(b_1,1G,512M,80G)$, *cd-rw*,

normal_price(1200) $\leftarrow$ $pc(b_2,1G,512M,80G)$, *dvd-rw*,

price(x) $\leftarrow$ *normal_price(x), add_point(x)*,

*price(x*0.9)* $\leftarrow$ *normal_price(x), pay_cash,* ***not*** *add_point(x)*,

add_point $\leftarrow$.

H_s: *add_point, pay_cash.*

Exxample

A buyer has the abductive program <P_b, H_b>:

P_b: *drive* ← *dvd-rw,*

drive ← *cd-rw,*

price(x) ←*,*

pc(b$_1$*,1G,512M,80G)* ←*,*

dvd-rw ←*,*

cd-rw ← ***not*** *dvd-rw,*

% if dvd-rw is not available, buy cd-rw.

← *pay_cash,* *% do not pay by cash*

← *price(x), x > 1200,* *% price must not exceed 1200*

H_b: *dvd-rw*

Exxxample

(1^{st} round) First, the buyer proposes:

G_b^1: *pc(b_1,1G,512M,80G), dvd-rw, price(x), x≤1200*.

P_s has no answer set satisfying G_b^1, then the seller does not accept it. The seller abduces the minimal explanation (E,F)=({ *pay_cash* }, { *add_point* }) which explains $G_b^1 \theta_1$ with θ_1 = { x/1170 }.

The seller constructs the conditional proposal:

G_s^1: *pc(b_1,1G,512M,80G), dvd-rw, price(1170), pay_cash, **not** add_point*

and offers it to the buyer.

Exxxxample

(2nd round) The buyer does not accept G_s^1 because she cannot pay it by cash. The buyer returns the critique

G_b^2: *reject*

to the seller.

As no other conditional proposal exists, the seller next produces neighborhood proposals. He relaxes G_b^1 by dropping $x \leq 1200$ in the condition and produces

pc(b_1*,1G,512M,80G), dvd-rw, price(x).*

As P_s has an answer set satisfying

G_s^2: *pc(*b_1*,1G,512M,80G), dvd-rw, price(1300),*

the seller offers it as a new proposal.

Exxxxample

(3rd round) The buyer does not accept G_s^2 because she cannot pay more than 1200. The buyer again returns the critique

G_b^3: *reject*

to the seller.

The seller then considers another proposal by replacing the brand b_1 with a variable w, G_b^1 now becomes *pc(w,1G,512M,80G), dvd-rw, price(x),* $x \leq 1200$.

As P_s has an answer set satisfying

G_s^3: *pc(*b_2*,1G,512M,80G), dvd-rw, price(1200),*

the seller offers it as a new proposal.

Exxxxxample

(4th round) The buyer does not accept G_s^3 because P_b has no answer set satisfying it. The buyer then changes her original goal. She relaxes G_b^1 by goal replacement using the rule drive ← dvd-rw in P_b and produces

pc(b$_1$,1G,512M,80G), drive, price(x), x≤1200.

Next, using the rule drive ← cd-rw in P_b she produces

pc(b$_1$,1G,512M,80G), cd-rw, price(x), x≤1200.

As the minimal explanation (E,F)=({},{*dvd-rw*}) explains the above, the buyer proposes the conditional neighborhood proposal

G_b^4: *pc(b$_1$,1G,512M,80G), cd-rw, **not** dvd-rw, price(x), x≤1200*

to the seller. Since P_s also has an answer set satisfying G_b^4, the seller accepts it and sends the message G_s^4 =accept to the buyer. Thus, the negotiation ends in success.

Computation

Given a proposal G and an abductive program <P,H>;

- a **conditional proposal** is computed using extended abduction by computing a minimal explanation of G.
- a **neighborhood proposal** is computed by first building a relaxed/neighborhood goal G' then computing an answer set satisfying $G'\theta$.
- a **conditional neighborhood proposal** is computed by combining the above two steps.

These computation is realized on top of the existing answer set solvers.