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**.

*Example* (A scholar in Hawaii)

\[
\text{swimming ; shopping} \leftarrow \neg \text{study}, \\
\neg \text{study} \leftarrow \text{not} \text{ study}.
\]

The program has two answer sets:

\[
\{ \text{swimming , } \neg \text{study} \} \text{ and } \\
\{ \text{shopping, } \neg \text{study} \}.
\]
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 \(L_1, ..., L_m, \text{not } L_{m+1}, ..., \text{not } L_n, (L_i: \text{literal})\)
  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 $G=\text{accept}$ or $G=\text{reject}$.

• 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 \(\theta\), the conjunction

\[ G\theta, E, \text{not } F \]

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

* 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

\[ G = \text{assist(comp\_dept), salary}(x), x \geq 50K \].
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`.
Example

• First, \( P \) has no answer set satisfying \( G \), so \( G \) is not accepted as it is.
• Next, \((E, F) = (\{ \text{hasPhD} \}, \{\})\) becomes the minimal explanation of
  \[ G \theta = \text{assist(comp_dept), salary(60K)} \]
  with \( \theta = \{ x / 60K \} \).

Then, the conditional proposal made by the university becomes

\[ \text{assist(comp_dept), salary(60K), hasPhD} \]
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 \( \theta \).

• **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 $G' \theta$, $G' \theta$ 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 $\sigma$, put $G'' = (G' \setminus \{L\}) \cup B \sigma$. If $P$ has an answer set satisfying $G'' \theta$, $G'' \theta$ is called a neighborhood proposal by goal replacement.
Example, cont.

Given the initial proposal

\[ G = \text{assist}(\text{comp\_dept}), \text{salary}(x), x \geq 50K, \]

produce

\[ G_1 = \text{assist}(w), \text{salary}(x), x \geq 50K \]

by substituting \textit{comp\_dept} with a variable \textit{w}.

As \[ G_1 \theta_1 = \text{assist}(\text{math\_dept}), \text{salary}(50K) \]

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

\[ G = \text{assist(comp_dept), salary}(x), x \geq 50K, \]

produce

\[ G_2 = \text{assist(comp_dept), salary}(x), \]

by dropping the salary condition.

As \( G_2 \theta_2 = \text{assist(comp_dept), salary}(40K) \)

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

Given the initial proposal

\[ G = assist(comp\_dept), \text{salary}(x), x \geq 50K, \]

produce

\[ G_3 = employee(comp\_dept), \text{salary}(x), x \geq 50K \]

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 \( P \),

\[ G_3' = sys\_admin(comp\_dept), \text{salary}(x), x \geq 50K \]

is produced. As

\[ G_3' \theta_3 = sys\_admin(comp\_dept), \text{salary}(55K) \]

with \( \theta_3 = \{ x \mapsto 55K \} \) 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 $\text{Ag}_1$ and $\text{Ag}_2$ 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 \(<P_s, H_s>:\)

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

\(\% \quad pc(brand, CPU, Memory, HDD)\)

\(dvd-rw \ ; \ cd-rw \leftarrow, \)

\(normal\_price(1300) \leftarrow pc(b_1, 1G, 512M, 80G), dvd-rw,\)

\(normal\_price(1200) \leftarrow pc(b_1, 1G, 512M, 80G), cd-rw,\)

\(normal\_price(1200) \leftarrow pc(b_2, 1G, 512M, 80G), dvd-rw,\)

\(price(x) \leftarrow normal\_price(x), add\_point(x),\)

\(price(x*0.9) \leftarrow normal\_price(x), pay\_cash, not \ add\_point(x),\)

\(add\_point \leftarrow.\)

\(H_s: \quad add\_point, \ pay\_cash.\)
A buyer has the abductive program $<P_b, H_b>$:

$P_b$:  
\[
\begin{align*}
  &\text{drive } \leftarrow \text{dvd-rw}, \\
  &\text{drive } \leftarrow \text{cd-rw}, \\
  &\text{price}(x) \leftarrow, \\
  &\text{pc}(b_1, 1\text{G}, 512\text{M}, 80\text{G}) \leftarrow, \\
  &\text{dvd-rw} \leftarrow, \\
  &\text{cd-rw} \leftarrow \text{not dvd-rw}, \\
  &\quad \quad \% \text{if dvd-rw is not available, buy cd-rw.} \\
  &\quad \leftarrow \text{pay\_cash}, \quad \% \text{do not pay by cash} \\
  &\quad \leftarrow \text{price}(x), \ x > 1200, \quad \% \text{price must not exceed 1200} \\
\end{align*}
\]

$H_b$:  
\text{dvd-rw}
(1\textsuperscript{st} round) First, the buyer proposes:

\[ G_{b_1}: \text{pc}(b_1,1G,512M,80G), \text{dvd-rw}, \text{price}(x), \ x \leq 1200. \]

If \( P_s \) has no answer set satisfying \( G_{b_1} \), then the seller does not accept it. The seller abduces the minimal explanation \((E,F)=( \{ \text{pay\_cash} \}, \{ \text{add\_point} \})\) which explains \( G_{b_1} \theta_1 \) with \( \theta_1 = \{ x/1170 \} \).

The seller constructs the conditional proposal:

\[ G_{s_1}: \text{pc}(b_1,1G,512M,80G), \text{dvd-rw}, \text{price}(1170), \text{pay\_cash}, \text{not add\_point} \]

and offers it to the buyer.
(2\textsuperscript{nd} 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 $pc(b_1,1G,512M,80G), dvd-rw, \text{price}(x)$.

As $P_s$ has an answer set satisfying $G_s^2$: $pc(b_1,1G,512M,80G), dvd-rw, \text{price}(1300)$, the seller offers it as a new proposal.
Example

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

$$G_b^3: \text{reject}$$

to the seller.

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

As $P_s$ has an answer set satisfying

$$G_s^3: pc(b_2, 1G, 512M, 80G), \text{dvd-rw, price}(1200),$$

the seller offers it as a new proposal.
Example

(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

$dvd-rw \leftarrow drive$ in $P_b$ and produces

$$pc(b_1,1G,512M,80G), \ drive, \ price(x), \ x \leq 1200.$$ 

Next, using the rule $drive \leftarrow cd-rw$ in $P_b$ she produces

$$pc(b_1,1G,512M,80G), \ cd-rw, \ price(x), \ x \leq 1200.$$ 

As the minimal explanation $(E,F)=(${}$,\{dvd-rw\})$ explains the above, the buyer proposes the conditional neighborhood proposal $G_b^4$: $pc(b_1,1G,512M,80G), \ cd-rw, \ not \ dvd-rw, \ price(x), \ x \leq 1200$ 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.