Negotiation by Induction

(Short Paper)

Chiaki Sakama
Dept. Computer and Communication Sciences
Wakayama University
Sakaedani, Wakayama 640 8510, Japan
sakama@sys.wakayama-u.ac.jp

ABSTRACT

This paper presents a logical framework for automated negotiation. An agent accepts a proposal if it is proved by its knowledge base. If this is not the case, an agent seeks conditions to accept a proposal or may give up some of its current belief to reach an agreement. These attitudes of agents are characterized using *induction* and *default reasoning.*

Categories and Subject Descriptors

F.4.1 [**Mathematical Logic**]: Logic and constraint programming;; I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Theory

Keywords

default logic, induction, negotiation

1. INTRODUCTION

Negotiation is a process of reaching agreement between different agents. In a typical one-to-one negotiation, an agent makes a proposal on his/her request and the opponent agent decides whether it is acceptable or not. If it is unacceptable, the opponent tries to make a counter-proposal. Negotiation proceeds in a series of rounds and each agent makes a proposal at every round until it reaches a (dis)agreement. Our primary interest of this paper is a process of evaluation and construction of proposals. A proposal is acceptable if it does not conflict with the interest of an agent. When a proposal is unacceptable for an agent, he/she seeks conditions to accept it. Those conditions would be found by updating his/her current beliefs: in one way, by introducing new beliefs, and in another way, by giving up some of his/her current belief.

Consider the following dialogue between a buyer B and a seller S (subscripts represent rounds in negotiation).

B_1: "I want an external HDD with 200GB".

S_1: "It costs 120USD".

B_2: "I want to get it at 100USD."

S_2: "We can provide it at the discount price if you pay by cash."

B_3: "I don't want to pay by cash".

S_3: "We can provide an external HDD with 180GB at 100USD".

B_4: "OK, I accept it".

In this dialogue, the buyer does not accept the initial offer S_1 made by the seller. Then, the buyer made a new proposal B_2 for a discount price. In response to this, the seller provides a condition to meet the request (S_2). The buyer does not accept it (B_3), and the seller proposes downgrade of the product (S_3). The buyer accepts it, and negotiation ends.

In the second round, the seller seeks conditions to accept B_2. The process of finding a condition to accept a proposal is logically characterized as follows. Suppose a knowledge base K represented by a first-order theory, and a proposal G represented by a formula. Then, K could accept G under the condition H if the next relation holds:

$$K \cup H \models G\,.$$

Here, H is a set of formulas and bridges the gap between the current belief K of an agent and the request G made by another agent. At this point, there are structural similarities between the problem presented above and the problem of *induction*, a method of machine learning in artificial intelligence. In fact, viewing G as an observed evidence, the problem of finding H is considered a process of building a *hypothesis* to explain G under K. Induction is an ampliative reasoning and extends the original theory to explain observed new phenomena. In negotiation, an agent also extends his/her original belief to accommodate another agent's request. Back to the negotiation dialogue, in response to the proposal S_3, the buyer concedes to accept it. This is done by withdrawing her original request. The process of concession is also formulated as follows. Given a knowledge base K of an agent and a proposal G by another agent, K could conditionally accept G by concession if the next relation holds:

$$(K \setminus J) \cup H \models G\,.$$

Here, J is a part of belief included in K, which could be given up to accept G.

Cite as: Negotiation by Induction (Short Paper), Chiaki Sakama, *Proc. of 7th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2008)*, Padgham, Parkes, Müller and Parsons (eds.), May, 12-16., 2008, Estoril, Portugal, pp. 1459-1462.

In this paper, we provide a logical framework of negotiating agents who have capabilities of evaluating and building proposals. We first consider an agent who has a knowledge base represented by first-order logic and characterize a process of making proposals using induction. We show that different types of proposals are built in terms of induction. Next, we formulate a process of making a concession in negotiation. We show that concession is done by inference from a default theory. Due to the lack of space, we omit all proofs of technical results in this paper. They are found in the longer version of this paper [7].

2. NEGOTIATION BY INDUCTION

2.1 Induction

A *first-order theory* is a set of formulas defined over the first-order language. The definition of the first-order language is the standard one in the literature. A first-order theory T *entails* a formula F (written as $T \models F$) if F is *true* in every model of T. A first-order theory T is *consistent* if it has a model; otherwise, T is *inconsistent*.

Induction in first-order logic is defined as follows. Given a *background knowledge base* K as a consistent first-order theory and a formula G as an *observation*, *induction* produces a set H of formulas as a *hypothesis* satisfying the condition:

$$K \cup H \models G \tag{1}$$

where $K \cup H$ is consistent. When H satisfies the above condition, we say that a hypothesis H *covers* (or *explains*) G with respect to K. This type of induction is used in the context of *inductive logic programming* [4].

EXAMPLE 2.1. Suppose the knowledge base K and the observation G:[1]

$$K: \quad swan(a) \wedge swan(b),$$
$$G: \quad white(a) \wedge white(b).$$

Then,

$$H: \ \forall x\,(swan(x) \rightarrow white(x))$$

covers G with respect to K.

2.2 Building Proposal

We consider an agent who has a knowledge base K represented by a consistent first-order theory.

DEFINITION 2.1. (proposal) A *proposal* G is a formula. In particular, G is called a *critique* if $G = accept$ or $G = reject$ where *accept* and *reject* are the reserved propositions.

A critique is a response as to whether or not a given proposal is accepted. It is decided by evaluating a proposal in a knowledge base of an agent.

DEFINITION 2.2. (acceptability) Given a knowledge base K and a proposal G,

- G is *accepted* in K if $K \models G$.
- G is *acceptable* in K if $K \cup \{G\}$ is consistent.
- G is *unacceptable* (or *rejected*) in K if $K \cup \{G\}$ is inconsistent.

If a proposal G made by an agent Ag_1 is accepted/rejected by another agent Ag_2, Ag_2 returns the critique *accept/reject* to Ag_1. On the other hand, if a proposal is acceptable, an agent seeks conditions to accept it.

DEFINITION 2.3. (conditional acceptance) Given a knowledge base K and a proposal G, G is *conditionally accepted* (with H) in K if

$$K \cup H \models G \tag{2}$$

holds for a set H of formulas such that $K \cup H$ is consistent. A set H of formulas is called an *accepting set of conditions* (with respect to K and G). In particular, H is called a *minimal* accepting set of conditions if H is a minimal set (under set inclusion) satisfying (2).

By the definition, it is easily seen that G is conditionally accepted in K if and only if it is acceptable in K. The notion of acceptance in Definition 2.2 is a special case of conditional acceptance with $H = \emptyset$. By Definition 2.3, we can see that the problem of finding a condition H for accepting a proposal G is identical to the problem of finding inductive hypothesis in (1). That is, by viewing a proposal G as an observation, an accepting set H of conditions is considered a hypothesis which covers G with respect to a background knowledge base K. This correspondence is not only in the definition of formulas, but also in the ground of their usage. In induction, when an agent observes a new evidence that cannot be explained in its current knowledge base, the agent induces a hypothesis which well accounts for the evidence and updates the knowledge base if necessary. In negotiation, on the other hand, an agent also observes a new proposal that is not entailed by its current knowledge base. Then, the agent constructs a hypothesis which well accounts for the proposal. Among accepting sets of conditions, we are interested in minimal accepting sets of conditions which represent minimal requirements for accepting a proposal. For this reason, we hereafter consider minimal accepting sets of conditions unless stated otherwise.

There are different types of accepting sets of conditions satisfying the relation (2). We provide some typical types of proposals in negotiation based on this definition. Suppose that an agent Ag_1 makes a proposal G and another agent Ag_2 who has a knowledge base K builds a counter-proposal in response to G.

Consent : When $H = \{G\}$, it holds that $K \cup H \models G$. In this case, Ag_2 accepts a proposal G if it is acceptable. Then, Ag_2 returns the critique $G' = accept$ to Ag_1.

Constraint : When $H = \{\, G \wedge C \,\}$, it holds that $K \cup H \models G$. In this case, Ag_2 accepts a proposal G with a constraint C. Then, Ag_2 returns the counter-proposal $G \wedge C$ to Ag_1. For example, given $G = go(restaurant)$, $C = on(Saturday)$ represents a constraint for accepting G.

Generalization : When $H = \{\, G' \,\}$ such that $G'\theta = G$ for some substitution θ, it holds that $K \cup H \models G$. In this case, Ag_2 returns the counter-proposal G' which is more general than G. For example, given $G = show\_product(TV, b)$ with some specific brand-name b,

[1] Throughout the paper, we shall omit braces { } in examples to represent the sets K and H of formulas, but the meaning is clear from the context.

$G' = show\_product(TV, x)$ with a variable x represents TV of any brand.

Subsumption : When H is a concept which subsumes G and K contains subsumption knowledge between H and G, it holds that $K \cup H \models G$. In this case, Ag_2 returns a counter-proposal H to Ag_1. For example, let $G = go(bookstore)$ and K contains $go(shopping\text{-}mall) \rightarrow go(bookstore)$, then $go(shopping\text{-}mall)$ becomes a counter-proposal.

Implication : When $H = \{ F \rightarrow G \}$ and $K \cup H \models G$, F represents a condition to accept G. In this case, Ag_2 returns the counter-proposal F to Ag_1. For example, let $G = want(chocolate)$ and K contains $want(biscuit)$, then $H = \{ want(biscuit) \rightarrow want(chocolate) \}$ represents exchange of sweets and $want(biscuit)$ becomes a counter-proposal.

In the above, *Consent* characterizes very generous attitude of an agent. *Constraint* and *Generalization* are considered special cases of *Implication* as both $G \wedge C \rightarrow G$ and $G' \rightarrow G'\theta$ hold. *Subsumption* is also a special case of *Implication* such that K contains a dependence relation between F and G. In case of subsumption, *abduction* [2] is used for the purpose instead of induction. Abduction is also hypothetical reasoning satisfying the relation (1). In contrast to induction which constructs a rule $F \rightarrow G$ from K and G, abduction extracts a fact F from G and a rule $F \rightarrow G$ which is derived from K.

2.3 Concession

An agent rejects a proposal if it is unacceptable. On the other hand, an agent can take an action of *concession* if he/she wants to reach an agreement in negotiation. To characterize agents who may concede in negotiation, we suppose agents who have two different types of knowledge: the one is strong belief and the other is weak belief. Strong belief is persistent belief or strong desire that cannot be abandoned. By contrast, weak belief can be given up depending on situation. Formally, a first-order theory K is divided into two disjoint sets:

$$K = \Sigma \cup \Gamma$$

where Σ represents *strong belief* and Γ represents *weak belief*. We assume that an agent gives up weak belief but not strong one when he/she makes a concession.

DEFINITION 2.4. (acceptable by concession) Let K be a knowledge base such that $K = \Sigma \cup \Gamma$ as above. Then, a proposal G is *acceptable by concession* in K if there is a set J of formulas such that $J \subseteq \Gamma$ and $(K \setminus J) \cup \{G\}$ is consistent.

DEFINITION 2.5. (conditional acceptance by concession) Let K be a knowledge base such that $K = \Sigma \cup \Gamma$. Then, a proposal G is *conditionally accepted by concession* (with H) in K if

$$(K \setminus J) \cup H \models G \qquad (3)$$

holds for some sets H and J of formulas such that $J \subseteq \Gamma$ and $(K \setminus J) \cup H$ is consistent. A set J of formulas is called an *accepting set of concessions* (with respect to K and G). In particular, J is called a *minimal* accepting set of concessions if J is a minimal set (under set inclusion) satisfying (3).

PROPOSITION 2.1. *A proposal G is conditionally accepted by concession in K iff G is acceptable by concession in K.*

Comparing Definition 2.5 with Definition 2.3, concession may give up (a part of) the current belief of an agent for accepting proposals. In particular, the relation (3) reduces to (2) when $J = \emptyset$. We assume that an agent wants to give up his/her current belief as little as possible, so we hereafter consider minimal accepting sets of concessions as well as minimal accepting sets of conditions.

EXAMPLE 2.2. Suppose that an agent Ag_1 has the knowledge base K:

f_1 : $have(mirror) \wedge have(nail) \rightarrow hang(mirror)$,
f_2 : $have(mirror) \wedge have(screw) \rightarrow hang(mirror)$,
f_3 : $give(nail) \rightarrow \neg have(nail)$,
f_4 : $have(screw) \rightarrow give(nail)$,
f_5 : $\forall x\, get(x) \rightarrow have(x)$,
f_6 : $have(mirror)$,
f_7 : $have(nail)$,

where the strong belief Σ consists of f_1–f_6 and the weak belief Γ consists of f_7. The meaning of each formula is: f_1 and f_2 represent conditions to hang a mirror. If Ag_1 gives a nail, he/she does no longer have the nail (f_3). If Ag_1 has a screw, he/she can give a nail (f_4). If one gets an object, one has the object (f_5). Ag_1 has both a mirror (f_6) and a nail (f_7). Suppose that Ag_1 has the intention of hanging a mirror. Consider that another agent Ag_2 makes the request

$$G : \ give(nail).$$

This proposal is not acceptable in K because $K \cup \{G\}$ is inconsistent. The agent Ag_1 may reject G with this reason, but he/she could look for conditions for concession. Ag_1 finds the solution

$$J : \ have(nail)$$

and

$$H : \ get(screw)$$

which satisfy the relation $(K \setminus J) \cup H \models G$. Then, Ag_1 offers a counter-proposal H to Ag_2.

Our next question is how to distinguish different types of belief in both syntactically and semantically. For this purpose, we use *default logic* [5] for representing a knowledge base. Default logic distinguishes two types of knowledge as first-order formulas and default rules. Formally, a *default theory* is defined as a pair $\Delta = (D, W)$ where D is a set of default rules and W is a set of first-order formulas. A default rule (or simply *default*) is of the form:

$$\frac{\alpha : \beta_1, \ldots, \beta_n}{\gamma}$$

where $\alpha, \beta_1, \ldots, \beta_n$ and γ are quantifier-free formulas and respectively called the *prerequisite*, the *justifications* and the *consequent*. A default is *ground* if it contains no variable. Any default with variables represents the set of its ground instances over the language of Δ. As defaults and first-order formulas are syntactically distinguishable, we often put a default theory $\Delta = W \cup D$ for convenience. A set S of formulas is *deductively closed* if $S = Th(S)$ where Th is the deductive closure operator as usual. A set E of formulas is an *extension* of (D, W) if it coincides with a minimal deductively closed set E' of formulas satisfying the conditions: (i) $W \subseteq E'$, and (ii) for any ground default $\alpha : \beta_1, \ldots, \beta_n / \gamma$ from D, $\alpha \in E'$ and $\neg\beta_i \notin E$ $(i = 1, \ldots, n)$ imply $\gamma \in E'$. An extension E is *consistent* if E is a consistent set of formulas. A default theory may have none, one or multiple extensions in general.

To represent weak belief of an agent, we use default rules of the form:

$$\frac{:\gamma}{\gamma}. \qquad (4)$$

This type of rule is called *super-normal* and a *super-normal default theory* is a default theory in which every default has the form (4). The rule (4) is read as "if it is consistent to assume γ, then believe γ". We represent weak belief of an agent by super-normal defaults in D, and distinguish them from strong belief represented by first-order formulas in W.

DEFINITION 2.6. (default representation) Let K be a first-order theory such that $K = \Sigma \cup \Gamma$. Then, a *default representation* of K is defined as a super-normal default theory $\Delta_K = (D, W)$ such that $D = \{\, \frac{:\gamma}{\gamma} \mid \gamma \in \Gamma \,\}$ and $W = \Sigma$.

Concession is characterized in a default theory as follows.

THEOREM 2.2. *Let K be a first-order theory such that $K = \Sigma \cup \Gamma$.*

(i) A proposal G is acceptable by concession in K iff $\Delta_K \cup \{G\}$ has a consistent extension.

(ii) A proposal G is conditionally accepted by concession with H in K iff $\Delta_K \cup H$ has a consistent extension E such that $G \in E$.

Theorem 2.2 represents that conditional acceptance by concession is characterized in terms of default inference of G from $\Delta_K \cup H$.

EXAMPLE 2.3. (cont. Example 2.2) The knowledge base is represented by the default theory $\Delta_K = (D, W)$ where

$$\begin{aligned}
W:\quad & have(mirror) \wedge have(nail) \rightarrow hang(mirror),\\
& have(mirror) \wedge have(screw) \rightarrow hang(mirror),\\
& give(nail) \rightarrow \neg\, have(nail),\\
& have(screw) \rightarrow give(nail),\\
& \forall x\; get(x) \rightarrow have(x),\\
& have(mirror),\\
D:\quad & \frac{:have(nail)}{have(nail)}.
\end{aligned}$$

Given the request $G = give(nail)$, G is included in a default extension of $\Delta_K \cup \{\, get(screw) \,\}$.

3. DISCUSSION

Several studies use logic-based *abduction* or *abductive logic programming* [2] as a representation language of negotiating agents. Sakama and Inoue [6] propose methods for building new proposals by *extended abduction* and *relaxation*. Extended abduction is an extension of abduction proposed by Inoue and Sakama [1], which can not only introduce hypotheses to a knowledge base but remove hypotheses from it to explain an observation. Relaxation is a technique of weakening constraints in database queries. They use extended abduction to compute *conditional proposals* and use relaxation to compute *neighborhood proposals*. An essential difference from our present work is that they use (extended) abduction for computing conditions of accepting a proposal, while we use induction for that purpose.

Formally, extended abduction is defined as follows. An *abductive framework* is a pair $\langle K, \Gamma \rangle$ in which both K and Γ are first-order theories. Given an observation G as a formula, a pair (E, F) is an *explanation* of G (with respect to $\langle K, \Gamma \rangle$) if (1) $(K \setminus F) \cup E \models G$, (2) $(K \setminus F) \cup E$ is consistent, and (3) both E and F consist of instances of elements from Γ. They also introduce the notion of *anti-explanations* to *un*explain negative observations. The above definition appears similar to the notion of "conditional acceptance by concession" which is defined as the relation $(K \setminus J) \cup H \models G$ in Definition 2.5 of this paper. However, there is an important difference between two definitions. In extended abduction, a hypothesis space Γ is given in advance. An explanation (E, F) is selected from the direct product $\Gamma \times \Gamma$. In our Definition 2.5, a set J is selected as a subset of weak belief Γ in a knowledge base K, while a hypothesis H is *newly* built by a knowledge base K and an observation G. This difference comes from the inherent characteristics of abduction and induction. In (extended) abduction, the goal is to compute causes of some observed events using a background knowledge base. In this case, possible causes are extracted from information in the knowledge base. In induction, on the other hand, the goal is to discover unknown general rules that would lie between observed events and the current belief in a knowledge base. We make use of this style of inference in the context of negotiation. A proposal given by another agent is not always explained using information included in a knowledge base only. In this case, an agent tries to bridge the gap between the proposal and its current belief. To the best of our knowledge, no study characterizes the process of making proposals in terms of induction. In the longer version of this paper [7], we develop a method of computing proposals using *answer set programming* [3].

4. REFERENCES

[1] K. Inoue and C. Sakama. Abductive framework for nonmonotonic theory change. In: *Proc. IJCAI-95*, pp. 204–210, Morgan Kaufmann, 1995.

[2] A. C. Kakas, R. A. Kowalski, and F. Toni. The role of abduction in logic programming. In: *Handbook of Logic in AI and Logic Programming*, D. M. Gabbay, et al. (eds), vol. 5, pp. 235–324, Oxford University Press, 1998.

[3] V. Lifschitz. Answer set programming and plan generation. *Artificial Intelligence* 138:39–54, 2002.

[4] S.-H. Nienhuys-Cheng and R. De Wolf. *Foundations of inductive logic programming.* Lecture Notes in Artificial Intelligence 1228, Springer, 1997.

[5] R. Reiter. A logic for default reasoning. *Artificial Intelligence* 13:81–132, 1980.

[6] C. Sakama and K. Inoue. Negotiation by abduction and relaxation. In: *Proc. AAMAS'07*, pp. 1018–1025, ACM Press, 2007.

[7] C. Sakama. Inductive negotiation in answer set programming. Submitted for publication, 2008.