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Assimilating Ontological Additions in Convergent Negotiation Protocols

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ABSTRACT

We consider negotiation protocols in which each offer contains a price and a description from some given ontology. If the opposing negotiation agents do not share the same version of this ontology, for instance because not all have been made aware of the latest changes, then a fixed communication protocol may be expected to fail when one opponent is faced with an offer including a concept novel to it. However, the communication may proceed if the agent is allowed to ask for, receive and assimilate the missing information. This information may come from the other partner, a trusted source, or the human that the agent is serving. We propose a method whereby assimilation is accomplished dynamically so that existing conversations do not need to be abandoned. Our setting employs negotiation protocols that are required to be convergent, i.e. to make progress by exploring a finite negotiation space and thus terminate, either with a mutually acceptable offer or with an indication that no such offer exists. We show that existing convergent negotiation protocols, when applied in a setting that allows assimilation of monotonic additions, retain the property of convergence despite the permissibility of messages that do not meet the condition of making progress. We motivate the work within an e-marketplace where negotiation is over product features and can lead the conversation deeper into specific features, about which some fact may not be mutually known until more information is shared.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous

General Terms

Algorithms

Keywords

Negotiating Agents, Assimilation, Convergent Negotiation, Ontologies, Negotiation Protocols

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1. INTRODUCTION

Consider the following conversation:

Buyer: "How much for the bike?"

Seller: "$4000 for the basic model. $6000 if you want the titanium frame."

Buyer: "What's a titanium frame?"

It is easy for people to imagine that the seller then discusses something about the titanium frame and the conversation follows. Perhaps the buyer feels that the titanium frame is not worth the extra money, and makes a counteroffer for the titanium model for, say $5000. The point here is that new information is assimilated into the conversation. The seller would be surprised if the buyer again asked for the price for the basic bicycle.

When negotiations of this type are undertaken by mechanized agents, we expect that the agents will share a common ontology of the products. In cases where new features and other information are rapidly emerging, it may happen that one negotiating party does not enter the conversation with all of the facts known to the other, or that each contains a subset. This will be revealed when one agent mentions a concept that the other agent has not heard of. At this point that second agent will ask for information around that new concept, either of the first agent or a trusted third party responsible for maintaining the ontology. After that information is added, the second agent will likely need some more information that helps him evaluate the usefulness of that item to him, i.e., his utility for that item. Then he is able respond to the first agent without having to end and restart the conversation. This dynamic assimilation of ontology additions will be necessary in any real world negotiation situation since agents cannot know *a priori* every detail about every item they will negotiate.

Consider also this conversation:

Buyer: "How much for a cell phone with MP3Player but no camera?"

Seller: "The phone with the MP3 player only comes with the camera."

In this conversation the buyer is told new information of a different kind. He has just learned that the model he wants is not available. In this paper we consider the first conversation where the agent learns about new items in the ontology. We do not focus on the problem of agents having different, conflicting information, which is a special case of the belief revision problem[1]. We only consider adding new information monotonically to the store of existing believed information.

We consider convergent negotiation protocols, which make progress exploring a finite space of offers, so that agents will terminate their conversations, either with an mutually acceptable offer or an indication that so such offer exists. In a convergent protocol, an agent is not allowed to repeat an offer to his opponent, or make an offer which, when compared to previous offers he has made, he knows to be worse for his opponent. We assume this is governed by a mutually-known partial order on offers. The protocol uses this ordering to control what offers can be made in the future. For instance a seller is not allowed to make an offer that differs from a previous offer only in that it has a higher price; nor is the buyer allowed to ask for an item with a longer warrantee for the same price as he previously bid for it. Other common mutual knowledge is that more features are better for the buyer so the buyer would be seen as bargaining in bad faith if he asks for a superset of features at the same or a lower price compared to one of his previous offers. Thus the space of open offers can be seen as monotonically decreasing as the negotiation proceeds; new offers eliminate some portions of the space that would be less interesting to the opponent.

This paper addresses the following question: The convergent negotiation process monotonically decreases the space of offers while the assimilation process monotonically increases it; which one wins? As may be expected, when assimilation is completed, convergent negotiation will eventually force the parties find a mutually agreeable offer, or determine none exists.

This paper investigates negotiation protocols, i.e. allowable offers, but does not discuss or propose any negotiation strategy.

In the following sections we cover the basics of description logic and protocols for negotiation over multiple attributes, including convergent protocols, and discuss how items can be evaluated. We then illustrate how in the assimilation setting convergent protocol appear to allow cycling, following which we show in the case of finitely many monotonic additions, convergence is preserved.

2. BACKGROUND

Description logic statements express information about individuals, the classes they belong to and the properties or roles associated with those classes. Formulas are partitioned into two sets: the T-Box for class or concept information (i.e. types or terminology) and the A-Box for assertions about individuals and their roles which are binary relations over individuals.

Different description logics are categorized according to the syntactic constructors. We will consider the description logic $\mathcal{ALC}$[2], which contains negation, conjunction and disjunctions on classes, and exists and value restriction on roles. The syntax allows atomic concepts written as $A, B, ...$ or words (and phrases) starting in upper case such as $DogLover$, negations, conjunctions and disjunctions of concepts written as $\neg A$,$A \sqcap B$,and $A \sqcup B$, respectively. Respectively these represent classes, complements, intersection and unions of classes. $\top$ and $\bot$ are also classes, interpreted as the universe of discourse and the empty set, respectively. Classes are interpreted according to the standard set theoretic semantics. The syntax also includes a set of constants a, b, c, representing individuals in the domain of discourse and roles $R, S, ...$ or words (and phrases) starting in upper case such as $PetOf$, representing binary relations over individuals. Thus $< a, b >$: R states that b plays the R role for a, or simply that a is related to b through R.

$A \doteq D$ states that A is the name of the class described by the class-valued formula D. If we want to assert that a new class is a subclass, we can assert $A \sqsubseteq D$, which is equivalent to $A \doteq D \sqcap D_1$ for some D_1.

Classes can also be written using universal and existential restrictions. The value restriction $\forall R.C$ expresses the class of individuals all of whose R roles are filled by elements of C. The exists restriction $\exists R.C$ expressed the class of individuals where at least one of the R roles is filled by an element of C. For instance, we can define a dog lover as someone whose pets are all dogs, $DogLover \doteq \forall PetOf.Dog$, while a dog liker is someone whose has a dog for a pet but may have other types of pets $DogLiker \doteq \exists PetOf.Dog$.

2.1 Negotiation

We consider multi-attribute negotiations in a simple form, where each partner can express the exchange they would be willing to perform, consisting of a price or a range of prices, and a description of an item to be exchanged. Suppose someone is asking to buy a table made of wood described at about \$100, as $< Table \sqcap Wooden, \$100 >$. A counter offer might use a different price and/or a different description. A pedestal table has a single pedestal support, rather than having legs, and is a special type of table: $PedestalTable \sqsubseteq Table$. If a negotiator receives a counteroffer $< PedestalTable \sqcap Wooden, \$150 >$ but does not know about pedestal tables, he is free to ask for a definition of this new set, and to enter into a conversation where he continues to ask questions until he has enough information to estimate his value for the pedestal table: $< PedestalTable \sqcap Wooden, \$125 >$. Either agent is also free to offer a range of prices, so if the seller has a number of tables in the range of \$100 to \$1000, he can offer $< Table, \$100 - \$1000 >$. Typically negotiation would end when both sides agreed on a single price.

2.2 Convergent Negotiation

In some negotiation protocols, the agents are free to make offers that repeat or are known to be of lower utility to the other party, and thus waste time. We consider the setting of *convergent* protocols that restrict these messages, and therefore force the parties to make progress[6]. Even though the agents are forced to make progress, there may still be a large space of offers to explore. But for convergent negotiation protocols, the agents are guaranteed to find an offer acceptable to both if such an offer exists, and otherwise to terminate with an indication that no such offer exists. In convergent negotiation protocols, all offers remain "on the table" in that any offer can be accepted by the opponent at any future time.

For a given negotiation over an item with multiple attributes, where each attribute has several values, there is a combinatorially large set of possible configurations of those attributes. The convergent negotiation protocols will restrict the partners from making repeat offers. Thus they are required to progress at least through an enumeration of the space. In fact any protocol can become a convergent one simply by eliminating duplicate offers, forcing an enumeration of all possible offers.

The CONNEG protocol[6] will do better than enumeration in two respects: for attributes that are set-valued, the protocol will often be able to eliminate subsets or supersets

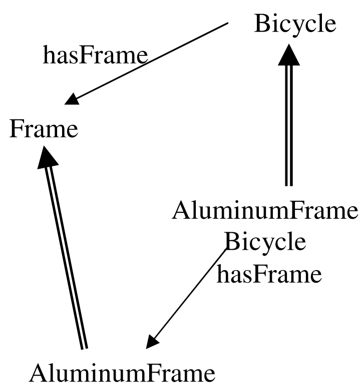

Figure 1: Bicycle Example Ontology

of previous offers, and for attributes whose values are scalars from a partial order, the protocol will eliminate some values. In both cases there must be a mutually known partial order of preferences. For instance it is usual that the buyer will prefer to buy more features for the same price than less. So if the feature set is a set-valued attribute, then the seller is disallowed from making an offer that is identical to a some previous offer except that it contains fewer features. Likewise for scalar-valued attributes, such as number of years of warranty; the seller is not allowed to offer fewer years of warranty. For set-valued attributes where supersets are better than subsets for the buyer, the subset relation induces a partial order on offers. A partial order on the preference over some attribute induces a partial order on offers. When these partial orders are mutually known, that agent's opponent is not allowed to make an offer that is less favorable to the given agent in these partial orders.

Experiments with a convergent protocol for privacy shows that negotiation agents can be built that often achieve convergence with a number of offers that is linear in the number of choices in space, rather than exponential in that number[4].

3. NEGOTIATION FRAMEWORK AND ASSIMILATION

In our framework, negotiation is over a description of an item. For example, consider the shared ontology in Figure 1. It is the graphical representation of the following ontology in $\mathcal{ALC}$:

$$\begin{aligned}&Bicycle \sqsubseteq \exists hasFrame.Frame\\&AluminumFrame \sqsubseteq Frame\\&AluminumFrameBicycle \sqsubseteq Bicycle\\&AluminumFrameBicycle \sqsubseteq\\&\quad \exists hasFrame.AluminumFrame\end{aligned}$$

These lines state that bicycles have frames, that aluminum frames are frames, that aluminum-framed bicycles are bicycles, and that aluminum-framed bicycles have aluminum frames.

Consider the following negotiation between the buyer B and the seller S:

$$S :< Bicycle, \$1000 - \$8000 > \quad (1)$$
$$B :< Bicycle, \$3000 - \$5000 > \quad (2)$$
$$S :< AluminumFrameBicycle, \$4000 > \quad (3)$$
$$B :< AluminumFrameBicycle, \$3000 > \quad (4)$$
$$S :< TitaniumFrameBicycle, \$5000 > \quad (5)$$

In line 1, the seller offers a bicycle for anywhere from \$1000 to \$8000 as the seller has a range prices for bicycles. The buyer in line 2 narrows the range of interest to between \$3000 and \$5000. The seller selects the aluminum-framed bicycle, and prices it at \$4000. The buyer seems to value the aluminum-framed bicycle rather lower, and offers \$3000 in line 4. Recognizing the seller's low value of aluminum, the seller offers a titanium-framed bicycle for \$5000.

The condition of convergence requires the parties to make progress toward an eventual deal, and thus prevent them from making offers that do not make progress. For instance, the seller could not offer \$9000 in line 3 for the $AluminumFrameBicycle$, since this is outside of the range of prices for bicycles, previously set at $\$1000 - \$8000$. Likewise, the buyer at any time after line 4 cannot offer to buy an aluminum-framed bicycle for \$3000 or any lower price, since this would waste time and may lead to endless negotiations.

Assimilation: At this point the buyer is not able to proceed since he has no knowledge of titanium-framed bicycles. He asks for and receives this information from a trusted party, which may be the seller. This gives rise to the new shared ontology, shown in Figure 2.

$$\begin{aligned}&TitaniumFrameBicycle \sqsubseteq Bicycle\\&TitaniumFrameBicycle \sqsubseteq \exists hasFrame.TitaniumFrame\\&TitaniumFrame \sqsubseteq Frame\end{aligned}$$

He also asks for and receives information about the value of a titanium frame.[1] Suppose the seller determined that a titanium frame is indeed worth \$5000. He accepts the seller's last offer and the negotiation is completed.

Now suppose instead that the buyer does not know that titanium-framed bicycles are generally accepted to be more valuable, and the buyer offers a price of \$3000 for the titanium-framed bicycle, which is lower than his previous offer for the aluminum-framed bicycle. To the seller, this seems to be wasting time, as the negotiation is considering offers that would have been eliminated if the buyer had shared this ordering information. In this case, we see that the assimilation of new information seems to be undermining the convergent negotiation progress.

Moreover, any time new information is added, it takes time for the agents to investigate the consequences of that new information, and this naturally extends the time needed to reach convergence.

4. EVALUATION OF OFFERS

We propose to exchange descriptions of items coming from a description logic, so the evaluation of offers must deal with

[1] Since the seller is an opponent in the negotiation, he may want to receive information on the worth of a titanium frame from some other source.

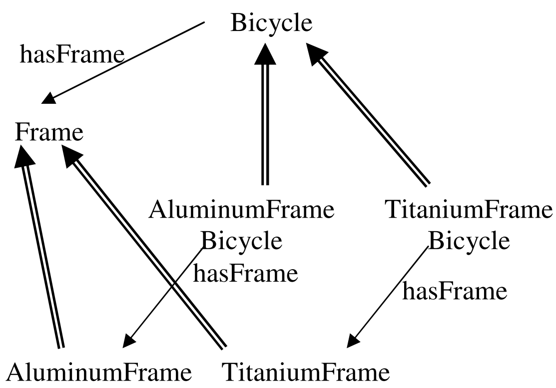

Figure 2: Second Bicycle Example Ontology

the inherent ambiguity of these descriptions, i.e. they are not forced to be fully described items, only to belong to the extension of the description. Thus we allow the evaluation to return a range of values. This means finding the lowest and highest valued items in the class defined by the description. We give some general idea of how this can be done without paying attention to efficiency. In this paper we do not specify how to assign a value to an object, but it is common to use standard utility theory to do so[7, 5].

Given an ontology and a description, generating one item that adheres to the description is merely a operation of constructing a canonical instance from a set. This is guaranteed to exist and to be finite, by the finite tree model property of $\mathcal{ALC}$[3].

The canonical object construction procedure can be pictured as follows: for simplicity assume that the description is simply a class in the ontology. From this starting point, we manufacture an object to be a candidate instance in this class, and incrementally add information about it. Two classes are said to be *compatible* if they transitively abstract the same class. Construct a set of classes compatible with the given description in two steps: (1) nondeterministically select any chain of abstraction links below, following them in the reverse direction back to a most specific class, and (2) construct the transitive closure of abstraction links above, following them in the forward direction. The set of compatible classes is constructed as the union of these two steps. From each element of the set, follow all existential quantification links in the forward direction to find all of the objects that are entailed to fill roles for that object. For each of these classes, recursively construct a set of compatible classes and again find all of the objects entailed to fill roles. Alternate in this manner until a complete tree is build for each object.

Because the above procedure is nondeterministic, it is capable of generating a variety of candidate objects. Not all of those objects necessarily exist, as there are constraints should be applied. For instance. it is commonly assumed that classes that are not compatible are therefore disjoint, a form of the closed world assumption. Thus if the same role is filled by two different types of objects that are not compatible, that candidate is eliminated. Other constraints are imposed by the universal quantification links, which require that roles to filled by objects be of a fixed class. If this fixed class is not be compatible with the class already proposed by the construction procedure, the candidate object is eliminated.

For example, given Figure 1, and starting from *Bicycle*, the only other compatible class is $AluminumFrameBicycle$. The role of $hasFrame$ is filled by a $Frame$ (looking from *Bicycle*) and by an $AluminumFrame$ (looking from *AluminumFrameBicycle*. Both types of frames are compatible and there is no conflict. Thus the only object that can be constructed is an aluminum-framed bicycle.

For another example, given Figure 2, again starting from *Bicycle* we can construct an object of class *Bicycle* and $AluminumnFrameBicycle$ for which the role of $hasFrame$ is filled by a $Frame$ (looking from *Bicycle*) and by an *AluminumFrame* (looking from $AluminumFrameBicycle$). But if we choose to specialize $Frame$ by following the abstraction link to $TitaniumFrame$, we find that the $hasFrame$ role is filled by an object with two incompatible classes: *TitaniumFrame* and *AluminumFrame*. Thus this candidate is eliminated. The nondeterministic construction procedure is capable of generating four candidates, of which only two are consistent, so in the end, there are only two canonical objects: the aluminum-framed bicycle and the titanium-framed one.

Once all of the items that match a description have been constructed, each is evaluated for utility for the agent, and the lowest and highest values are used in the counteroffer.

For the purposes of convergent negotiation, we also allow ranges to shrink, and consider this still to be making progress. For example, an offer by the buyer for an item in the range $10-$20 could be followed by an offer in the range $10-$15. While this second offer is worse for the seller, it does represent progress on the part of the buy as he is specializing the range of items to be considered. However, we do not allow the buyer to then make an offer for the same item if the range includes numbers less than $10.

5. PRESERVING CONVERGENCE DURING ASSIMILATION

As outlined in Section 3, this paper addresses a problem that arises when two processes are undertaken that seem to conflict with each other. On the one hand, in convergent negotiation protocols, as the negotiation proceeds the space that is left to be explored by negotiation monotonically decreases. On the other hand, as both either or both agents increase their ontologies, the space to be negotiated increases. The question this paper sets out to answer is under what conditions does the protocol retain the property of convergence.

When one agent is given new information in the ontology, but not given information that is widely known about the relative values of the new items being considered, that agent can enter into time-wasting offers. While these may prevent the negotiation from proceeding as quickly as it would be forced to had the agent been given relative values, the convergent negotiation protocol will retain it convergence just on the basis of disallowing repeat offers.

Given the previous discussion, it is now a straightforward observation that if the set of information to be assimilated is finite, then after all assimilation is done, the convergent negotiation will have no opponent, and will enforce convergence. We expect this to be the case, since new information is not expected to be infinite. Thus we are assured that convergence is preserved.

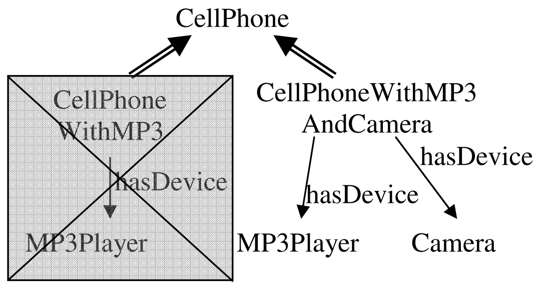

Figure 3: Cellphone Example

6. RELATED WORK

Beyond our work on CONNEG, there is closely related work on convergent protocols[11, 8, 9]. All proposals share the fundamental idea to demonstrate termination by enumerating offers within a finite space.

Previous work on ontologies of negotiations makes a different use of ontologies, proposing to adapt negotiating agents to different negotiation situations, such as various types of auctions. The negotiation conditions state what offers are allowed at what time and what constitutes an agreement. Different choices give rise to different protocols. [10] describe an ontology of such choices, and an agent that can adapt to these choices. On the other hand we negotiate by exchanging ontological descriptions, rather than fully constructed objects.

7. CONCLUSIONS AND FUTURE WORK

This paper investigates questions about two-party negotiation protocols: Can a protocol allow dynamic integration of novel information? Can a convergent protocol allow this assimilation and preserve convergence? We observe that both of these are answered yes, when the additions are monotonic.

We focus on negotiating protocol and do not make any contribution to negotiation strategies. However, we note that the CONNEG protocol makes only a few reasonable restrictions, and so interferes little, if at all, with strategies.

In this paper we have focused on two-party negotiation and in the future we will consider assimilation of new information in multiparty negotiations, including auctions.

We have also focused on monotonic additions to the protocol. Consider again the example from the introduction:

Buyer: "How much for a cell phone with MP3Player but no camera?"

Seller: "The phone with the MP3 player only comes with the camera."

The agent's initial belief can be expressed in the formula in Figure 3, and in these clauses:

$$CellPhoneWithMP3 \sqsubseteq CellPhone \sqcap \exists hasDevice.MP3Player$$

$$CellPhoneWithMP3AndCamera \sqsubseteq CellPhone \sqcap \exists hasDevice.MP3Player \sqcap \exists hasDevice.Camera$$

As the buyer finds out there is no device *CellPhoneWithMP3*, the first formula above needs to be eliminated from the buyer's ontology. While simply deleting information from an ontology may not be difficult to deal with, the buyer may not always be able to update his ontology so simply. For instance if the buyer is told that some combination of features is not available, it may mean that some of his beliefs are not true, and it is not clear which beliefs need to be removed. Consider the Figure 4, where the agent is told that the intersection $A \sqcap B$ is empty. It may be that $C \not\sqsubseteq A$ or $C \not\sqsubseteq B$ or some other problem, but the agent has no way to tell which.

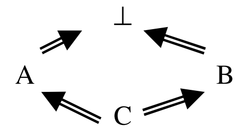

Figure 4: Negative Update Example

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