REASONING WITH INFORMATION SOURCES ORDERED BY TOPICS

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Abstract

This paper presents a logic for reasoning with information provided by several information sources. The main problem is that even if these sources are independently consistent, they might be contradictory. We introduce the notion of topic of information in order to gather information which concern the same subject. The logic defined here is a modal logic whose modalities allows us to express information about the relative reliability of the different sources, topic by topic. We show that when the orders of reliability are topic-compatible, then, our logic does not collapse even if the sources are contradictory.

1 Introduction

The main problem addressed in our paper is the problem of merging several information sources and more specifically, merging information sources which are contradictory. These sources may be databases which have been independently developped and which have to be federated[10] . They also may be belief sets of several agents which one wants to gather. For instance, this is the case when a police inspector queries different witnesses about a crime : he has to collect and to reason with the different accounts in order to find the clue. We assume that the different information sources share the same language, a propositional language, and reason in the same logic : the classical propositional logic. The main problem that may happen, even if each different source is consistent, is that they may be contradictory one each other. This problem has been studied under different names and different approaches. In[1,2] the authors address the problem of combination from a syntactical point of view, defining the combining on sets of formulas : two representations of the same theory that are syntactically different may behave in two different ways. In[8,4,5] the authors address the problem of "multi-source reasoning". The first paper describes the use of possibilistic logic and the last two papers adopt a model-based approach. From a theoretical point of view all these works try to find a solution to the problem of dealing with inconsistent information. Removing inconsistency requires to make choices, and they use extra-information and specific logics for that purpose. Notice that theses different approaches (formula-based, model-based ..) can be found in two related domains: database updates and belief revision[11,17,13,16,14,12] . A comparison between the problem of merging and the problem of updating will be given in the last section.

The main idea of our previous work[4,5] was to express the fact that, when merging different information sources, one often has an extra-information about the relative reliability of the sources. For instance, when federating databases, one may know that such a database is more reliable than such other, because it has been updated more recently. Ordering the different information sources according to their relative reliability allows to solve that problem of contradictions. We have defined two logics for reasoning with information provided by ordered sources corresponding to two different attitudes and are called "suspicious logic" and "trusting logic".

The purpose of this paper is to refine this previous work : indeed, until now, it has been supposed that there was only one order. The user, when merging the information sources, assumed that they were ordered according to their reliability. Here, we want to show that in fact, according to the topics of the data, the user may want to express several orders on the sources, which are then topics-dependent orders. The use of the notion of topics in combining knowledge-bases constitue the core of our paper. We focus on the extension of the trusting attitude. (An illustration of the trusting merging will be given in the next section).

Assumptions :
In this paper, we assume that the n information sources to be merged (we will also call them agents, knowledge bases, databases or more generaly bases) are satisfiable but not necessarily complete sets of literals of a propositional language L. We also will consider total orders on bases. Extensions of these assumptions are discussed in the last section.

2 Trusting merging with only one order : an example

The trusting attitude for combining ordered knowledge-bases consists in suspecting only the very information provided by a base which contradicts a more reliable base.

Let us take the exemple of a police inspector who gathers the accounts of two witnesses. Assume that the first witness, say Bill, said that he saw a black car, while the second, say John, said that he saw two men in a white car. Considering an order may reflect the fact that the inspector himself has some convinction (which can not be denied) or possesses some information which are true : for instance, he went to the meteorological station and he knows that the crime was committed on a foggy day. So he can assume that John is less reliable than Bill, since the latter was standing too far from the crime place and because of the fog, he could not see well. In this case, the inspector will consider that : inspector > Bill > John. The trusting attitude will lead the inspector to consider that the car was black and to reject the fact that it was white because this information contradicts an information provided by a more reliable agent. However, being trustful, the inspector will conclude that there were two men in this car, because this information does contradict nothing.

3 Topic-dependent orders

In this paper we aim to prove that considering only one order on the bases to be merged, is too restrictive. The following example will show that, in fact, one assumes as many orders as topics of data.

3.1 A motivating example

Let us come back to the example of the police inspector. Assume now that the two witnesses questionned by the inspector are a woman and a man. They both provide information about what they have seen. The woman says that she saw a girl, wearing a Chanel suit, jumping into a sport Wolkswagen car. The man says that he saw a girl wearing a dress. He assumed that she jumped into a car that he did not see but he heard that it was a diesel. The two accounts are contradictory : Did the girl wear a dress or a suit ? Was the car a sport car or not ? For solving these contradictions, the inspector may use the fact that, when speaking clothes, women are generally more expert than men ; and when speaking mechanics, men are generally more expert than women. This leads the inspector to assume two orders, depending on the two topics "clothes" and "mechanics" : the woman is more reliable than the man as regard to "clothes" and the man is more reliable than the woman as regard to "mechanics". Adopting a trusting attitude, the inspector will conclude that there was a girl, wearing a Chanel suit, jumping into a diesel car which was a Wolkswagen make.

3.2 Topics

The notion of topic has been investigated to characterize sets of sentences from the point of view of their meaning, independently of their truth values. For example, in the context of Cooperative Answering, topics can be used to extend an answer to other facts related to the same topic[7,3] . In the context of Knowledge Representation[15] , topics are used to represent all an agent believes about a given topic. It has also been used in the domain of updates[6] . In other works[18,9] the formal definition of the notion of "aboutness" is investigated in general. The purpose of this paper is not to define a logic for reasoning about the links between a sentence and a topic in general, but to define a logic that is based on source orders which depend on topics.

We assume that the underlying propositional language is associated to a finite number of topics which are sets of literals which agree on the following postulates :

- each literal of L belongs to a topic.
- topics may intersect.
- let l be a literal of L, let t be a topic: $(l \in t) \iff (\neg l \in t)$.

3.3 Compatibility between orders and topics

The inspector example shows that it is useful to associate an order on the bases with any topic. The following definition defines a notion of compatibility between the topics and the associated orders.

Definition :

Let $t_1 \ldots t_m$ be the topics of L. Let $O_1 \ldots O_m$ be total orders on the bases, associated with the topics $t_1 \ldots t_m$. $O_1 \ldots O_m$ are $(t_1 \ldots t_m)$-compatible iff
$\forall\, k = 1 \ldots m\ ,\ \forall\, r = 1 \ldots m \quad t_k \cap t_r \neq \emptyset \quad \Longrightarrow O_k = O_r$.

Intuitively, this definition characterizes orders which, in some sense, "agree on" the structure of the topics. According to topic-compatible orders, if a source is more reliable than another one, as regard to a topic, then it is also more reliable to this one, as regard to any sub-topic and any super-topic.

For instance, consider two topics "classical-music" and "baroque-music". The latter is included in the former. Consider two persons P1 and P2, providing you with information about baroque music and more generally about classical music. It is not realistic to assume that P1 is more reliable than P2 as regard to classical and that P2 is more reliable than P1 as regard to baroque. Indeed, if P1 is more reliable than P2 about classical music, he is also more reliable than P2 about baroque since any information which is about baroque music is also about classical music.

4 A trusting logic for reasoning on topic ordered sources

Notations :

Let us consider n databases to be merged. Let us note L the underlying propositional language and let $t_1 \ldots t_m$ be the topics on L.

If O denotes the total order $i_1 > i_2 > \ldots > i_p$, on some databases $i_1, i_2, \ldots, i_p$, and if i is another database, then $O > i$ will denote the order $i_1 > i_2 > \ldots > i_p > i$.

When associating an order with a topic, we will index this order by the topic 's index. So, O_k will be an order associated with the topic t_k.

O_Ω will denote a set of orders, $(O_1, \ldots, O_m)$, each of them being associated with a topic.

If O_Ω denotes a set of orders $(O_1, \ldots, O_m)$, then $O_{\Omega_k > i}$ will denote a set of orders $(O'_1, \ldots, O'_{k-1}, O_k > i, O'_{k+1}, \ldots, O'_m)$, where for any p different of k, O'_p is any order which extends the order O_p with database i. In other terms, i is considered as least reliable according to topic t_k, but i is inserted at any place in the order O_p, if p is different of k.

Let m be an interpretation of L, and t a topic of L, m | t will denote the set $\{l : l \in m \text{ and } l \in t\}$, i.e. m | t is the projection of m on topic t. Let us notice that, because topics are not necessarily disjoint, the set of m | t 's is not a partition of m.

Let E be a set of interpretations of L, and t be a topic of L, E | t will denote $\{ m \mid t : m \in E \}$.

4.1 The language of FT

The language L' of the logic FT we are going to define, is obtained from L by adding a finite number of modalities :

- B_{O_Ω}, where $O_\Omega = (O_1 \ldots O_m)$ such that the O_i's are total orders on subsets of $\{1 \ldots n\}$ which are $(t_1 \ldots t_m)$-compatibles.

Let $O_\Omega = (O_1 \ldots O_m)$ a set of total orders on k databases, which are topic-compatible. Then, $B_{O_\Omega} F$ will mean that F is true in the database obtained from merging the k databases according to the orders O_i.

Remark :
Let us notice that this general form of modalities allows us to represent the particular case where k=1. In this case, there is only one database, say i, to be merged. Thus, $O_1 = \ldots = O_m = \{i\}$. In this case, B_{O_Ω} will be noted B_i.

4.2 Semantics of the trusting merging with topic dependent orders

We first need to introduce the following definition : we will say that a set of interpretations of L "represents a database" iff E is the set of all the models of a given set of literals. More formally :

Definition :
Let E be a set of interpretations of L. Let PVAR be the set of the propositional variables of L. We define :
$dbE = \{ l : \forall w \ (w \in E \Longrightarrow w \models l) \}$.
$PVAR(dbE) = \{ p : (p \in PVAR) \text{ and } (p \in dbE \text{ or } \neg p \in dbE) \}$.
$\{p1 \ldots pm\} = PVAR \setminus PVAR(dbE)$.
$\overline{dbE} = \{ l_1 \ldots l_m : \forall i = 1 \ldots m, li = pi \text{ or } li = \neg pi \}$.
Then E "represents a database" iff $\forall l_1 \ldots l_m \in \overline{dbE}, \exists w \in E : w \models (l_1 \wedge \ldots \wedge l_m)$.

Definition :
An interpretation of FT, is a pair : I = (W, r), where :

- W is the finite set of all the interpretations of the underlying propositional language L.
- r = is a finite set of W subsets associated with the modalities B_{O_Ω} defined by :
  - if B_{O_Ω} is a modality of the form B_i, it is associated to a set noted M_i which is a non empty subset of W which "represents a database".
  - in any other case, if $O_\Omega = (O_1 \ldots O_m)$, the modality B_{O_Ω} is associated to M_{O_Ω} such that $M_{O_\Omega} = \{ s : s = s_1 \cup s_2 \cup \ldots \cup s_m$ and $s_1 \in M_1(O_1)$ and ... and $s_m \in M_m(O_m) \}$ where :

    $M_k(O > i) = f_{k,i}(M_O)$ and
    $f_{k,i}(E) = \{ w : w \in E \mid t_k$ and $w \models L_{i,k,E} \}$ and
    $L_{i,k,E} = \{ l : l$ literal of topic t_k such that :
    $(\forall v\ (v \in M_i \mid t_k \implies v \models l))$ and $(\exists u\ (u \in E \mid t_k$ and $u \models l)) \}$

Result 1 :
Let us notice here that, since the considered orders are topic-compatible, if a literal belongs to an interpretation of one $M_i(O_i)$, then its negation cannot belong to an interpretation of another $M_j(O_j)$. This result is important because it guarantees that the sets of literals which are obtained by $\{ s : s = s_1 \cup s_2 \cup \ldots \cup s_m$ and $s_1 \in M_1(O_1)$ and ... and $s_m \in M_m(O_m) \}$ are interpretations of L.

Result 2 :
We can also notice that, for any modality B_{O_Ω}, the set M_{O_Ω} is never empty. This guarantees that the database obtained by our trusting merging is not contradictory.

Result 3 :
For any modality B_{O_Ω}, we can prove that the associated set M_{O_Ω} "represents a database". This result ensures us that, when applying our trusting merging method to bases which are sets of literals, we obtain a base which is a set of literals.

Definition : Satisfaction of formulas :
Let F be a formula of L. Let F1 and F2 be formulas of L'. Let O_Ω be a set of total orders on a subset of {1..n} which are topic-dependent. Let M = (W,r) be an interpretation of FT and let $w \in W$.

$r,w \models_{FT} F$	iff	$w \models F$
$r,w \models_{FT} B_{O_\Omega}F$	iff	$\forall w'\ (w' \in M_{O_\Omega} \implies w' \models F)$
$r,w \models_{FT} \neg F1$	iff	$r,w \not\models_{FT} F1)$
$r,w \models_{FT} F1 \wedge F2$	iff	$r,w \models_{FT} F1$ and $r,w \models_{FT} F2$

Definition : Valid formulas in FT.
Let F be a formula of L'.
F is a valid formula in FT iff $\forall$ M = (W,r), $\forall$ w $\in$ W, r,w $\models_{FT}$ F

4.3 Axiomatics

Axioms of FT are :

- (A0) Axioms of the propositional logic.
- (A1) $B_{O_\Omega} \neg F \rightarrow \neg B_{O_\Omega} F$
- (A2) $B_{O_\Omega} F \wedge B_{O_\Omega}(F \rightarrow G) \rightarrow B_{O_\Omega} G$
- (A3) $B_{O_\Omega} l \rightarrow B_{O_{\Omega_k > i}}\ l$ if l is a literal which belongs to topic k.
- (A4) $B_i l \wedge \neg B_{O_\Omega} \neg l \rightarrow B_{O_{\Omega_k > i}}\ l$ if l is a literal which belongs to topic t_k.
- (A5) $\neg B_{O_\Omega} l \wedge \neg B_i l \rightarrow \neg B_{O_{\Omega_k > i}}\ l$ if l is a literal which belongs to topic t_k.
- (A6) $B_{O_\Omega}(l1 \vee \ldots \vee lp) \rightarrow B_{O_\Omega} l1 \vee \ldots \vee B_{O_\Omega} lp$ where li's are non complementary literals.

Inferences rules of FT are :

- (Nec) $\vdash_{FT} F \Longrightarrow \vdash_{FT} B_{O_\Omega} F$ (if F is a propositional formula)
- (MP) $\vdash_{FT} F$ and $\vdash_{FT} (F \rightarrow G) \Longrightarrow \vdash_{FT} G$

(A3), (A4) and (A5) express the trusting attitude. They mean that :
- if a literal l, belonging to topic t_k, is true in the base obtained by merging some databases ordered with some orders, then it remains true if we merge a new database i considered as least reliable on topic t_k.
- if it is the case that a literal, belonging to topic t_k, is true in the database i and if its negation is not true in the base obtained by merging several database with orders O_Ω , then it remains true if we merge the new database i considered as least reliable on topic t_k.
- if l is a literal of a given topic t_k, which is true in a base obtained by merging several bases with another base i, considered as least reliable on topic t_k, then either l is true in the merging of these bases or l is true in database i.

(A6) expresses that when merging sets of literals, one gets sets of literals.

4.4 Propositions

Let us recall that the logic FT is introduced to modelize the trusting merging of databases which are sets of literals.

Let us note $\psi = \bigwedge_{i=1}^{n}(\bigwedge_{l \in bdi} B_i l \wedge \bigwedge_{bdi \not\vdash c} \neg B_i c)$, where l is a literal and c a clause.

ψ expresses, for each database, the literals it believes and the clauses it does not believe. In other terms, ψ lists what each database "only believes" .
We are interested in finding valid formulas of the form : $\psi \rightarrow B_{O_\Omega} F$, i.e finding formulas F which are true in the database obtained by merging several databases ordered by topic dependent orders O_Ω .

Result 4 :
Let F be a formula of L, and let O_Ω be a set of topic compatible orders on a subset of $\{1 .. n\}$. Then : $\models_{FT} (\psi \rightarrow B_{O_\Omega} F) \iff \vdash_{FT} (\psi \rightarrow B_{O_\Omega} F)$.

Sketch of proof :

This proof is based on the one we had made in the case when there was no topic and thus only one order on the sources.

We show the ($\Rightarrow$) condition by showing that, for any formula F of L' we have : $\models_{FT} F \implies \vdash_{FT} F$. We first show this implication for all the axioms of FT. Then we show that the inference rules preserve that property.

We show the ($\Leftarrow$) condition by induction on the length of the orders.

When the length is one, this means that there is only one base which is considered. Then, $B_{O_\Omega} = [\{i\} .. \{i\}]$. So $\models_{FT} (\psi \rightarrow B_{O_\Omega} F)$ implies that F is deducible from the base i. Thus, $(\psi \rightarrow B_{O_\Omega} F)$ is a theorem of FT.

When the length is greater than one, we make an induction on the form of F. First, we prove this condition for literals, then for disjunctions of literals, and finally, for conjunctions of disjunctions of literals.

Result 5 :
With the same assumptions : $\vdash_{FT} (\psi \rightarrow B_{O_\Omega} F)$ or $\vdash_{FT} (\psi \rightarrow \neg B_{O_\Omega} F)$.

Sketch of proof :
We prove it by induction of the form of F. In the case of literals, we make an induction on the length of the orders. Then we consider disjunctions of literals, then conjunctions of disjunctions of literals.

Result 6 :
In the particular case where there is only one topic, then :
$\vdash_{FT} (\psi \rightarrow B_O F)$ iff $\vdash_F (\psi \rightarrow B_O F)$
(where $\vdash_F$ was the symbol of deduction in the trusting logic with only one topic)

(The proof is obvious)

In other terms, the logic studied here is an extension of the logic previously defined.

4.5 An example

Let us come back to the police inspector example and define the language L whose propositions are : Chanel, suit, dress, sport, Wolkswagen, diesel (meanings are obvious). Two disjoint topics may be considered :
clothes = {Chanel, suit, dress } and mechanics = {sport, Wolkswagen, diesel } .

The two knowledge bases are :
woman = {Chanel, suit, ¬ dress, sport, Wolkswagen } and
man = {dress, ¬ suit, diesel, ¬ sport }

Let us consider ψ as before. Here are some deductions that the inspector can make (for readibility, the order indexes, representing topics, are forgotten : the first orders will concern the "clothes" topic and the second ones will concern the "mechanics" topic).

- $\vdash_{FT} (\psi \rightarrow B_{(\text{woman} \quad \text{woman})}$ (Chanel $\wedge$ suit)

  In other terms, when listening only to the woman, the inspector can deduce that the girl was wearing a Chanel suit.

- $\vdash_{FT} (\psi \rightarrow B_{(\text{woman}>\text{man} \quad \text{man}>\text{woman})}$ (Chanel $\wedge$ suit $\wedge$ ¬ dress $\wedge$ diesel $\wedge$ ¬ sport $\wedge$ Wolkswagen)

  In other terms, when considering that the woman is more reliable than the man when speaking clothes and that the man is more reliable than the woman when speaking mechanics, the inspector believes that there was a girl, wearing a Chanel suit (and not a dress) jumping into a diesel car (and not a sport-car) which was a Wolkswagen make.

- $\vdash_{FT} (\psi \rightarrow B_{(\text{man}>\text{woman} \quad \text{man}>\text{woman})}$ (dress $\wedge$ diesel $\wedge$ Wolkswagen)

  In other terms, if the inspector considers that the man is more reliable than the woman on every topic, then he believes that the girl who jumped into a diesel car Wolkswagen make was wearing a dress.

- $\vdash_{FT} (\psi \rightarrow (B_{(\text{woman}>\text{man} \quad \text{man}>\text{woman})}$ (suit) $\wedge$ $(B_{(\text{man}>\text{woman} \quad \text{man}>\text{woman})}$ (dress)

  In other terms, the inspector can deduce that the girl who was jumping into the car, was wearing a suit or a dress, depending on whether the woman is more reliable than the man on clothes or not.

5 Open questions

The work we have presented provides a contribution to three different kind of problems : reasoning about agents that "only believes" sets of literals, merging several information sources that have different levels of reliability, and refining levels of reliability by topics. However, there are still several open questions that are listed below :

- The first question one can ask concerns the fact that we have here considered total orders. Indeed, sometimes, one can not order the bases with total (topic dependent) orders but only with partial orders. We have recently shown a solution for the trusting logic with one order in the case of partial order. This solution consists in considering that a formula is true in the base obtained by merging several bases with a partial order if, by definition, it is true in any base obtained by merging these bases with any total order which extends the partial one. Such a solution can easily be applied in the present case of topic dependent orders.

- Few comments may be done on the notion of compatibility between orders and topics. The definition we give in section 3.3, does not take into account the content of the bases. It expresses that when two topics are not disjoint, the associated orders may be the same. However, this condition is not necessary if the bases do not provide us with literals which belong to the intersection of topics. This shows a way for refining the definition.

- As said in the introduction, two attitudes were defined for merging ordered sources. In this paper, we have focused on one of them, the trusting one, but the modification of this semantics to the suspicious merging with several orders is obvious. It leads, of course, to different merged base which express the fact that in each topic, the merging is supicious. For instance, if the inspector was suspicious, when considering that the man is more reliable than the woman about mechanics, it would not trust her when she says that the car was a Wolswagen make.

- Let us notice that the definition of interpretations of FT is based on a function $f_{k,i}$ which restricts a set of interpretations, $M(O_k)$, to the interpretations which satisfy all the literals of topic k which belong to any model of database i and which belong to almost one interpretation in $M(O_\Omega)$. We have shown that this function could be defined by : $f_{k,i}(E) = \bigcup_{m \in R(i)|t_k} Min(E \mid t_k, \leq_m)$, where $\leq_m$ is defined in[14] . So the link between information sources merging and updates is established : when there is only one topic, merging several databases ordered by $i_1 > ... > i_n$ according to the trusting attitude, comes to update the database i_n by the result of the update of database $i_{(n-1)}$ by ... i_1.

  In other terms, updating database i by database j comes to trustfully merge database i and j, assuming that i is more reliable than j. The extension of merging to several topic dependent orders, gives an idea of how one could refine the definition of updates when there are several topics : indeed, when updating, the new information is generally considered as more reliable than the old one (except in the classical approach to database updates where the base is considered as more reliable than the new information). We could be more precise by considering topics and express that, according to such a topic, the new information is more reliable than the old one, but according to such other, it is less reliable.

- Finally, let us say that we are working on the extension of this work in the case where the bases are sets of clauses. We suggest to modify the semantics in two directions : the condition of sets which "represent a database" must be discarded, since it was introduced for our particular case of sets of literals. Furthermore, the definition of $f_{k,i}$ could be replaced by : $f_{k,i}(E) = \bigcup_{m \in R(i)|t_k} Min(E \mid t_k, \leq_m)$. Defined in this way, trusting merging is still an extension of updating. For this extension, the axiomatics has to be modified and we could take inspiration of the work by Lakemayer[15] to represent the "only believes about" aspect of the problem.

Finally, let us say that a theorem prover is under development. It has been specified as a meta program. And it is implemented at the meta level of a PROLOG-like language. It is an extension of the theorem prover which we had defined previously in the case when there was no topic[5] .

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