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BELIEF REVISION IN SNePS

by

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ABSTRACT

SNePS is a powerful knowledge representation system which allows multiple beliefs (beliefs from multiple agents, contradictory beliefs, hypothetical beliefs) to be simultaneously represented, and performs both forward and backward reasoning within sets of these beliefs. SNeB, described in this paper, is a belief revision system available in SNePS. SNeB relies on a logic developed to support belief revision systems, the SWM system, and its implementation relies on the manipulation of assumptions, rather than justifications, as is common in other belief revision systems. The first aspect guarantees, among other things, that every proposition in SNeB is associated with those (and only those) hypotheses from which it was derived. The second aspect enables it to effectively switch reasoning contexts and to avoid having to "mark" every proposition which should not be considered by the knowledge base retrieval operation.

INTRODUCTION

SNePS (Semantic Network Processing System), Shapiro 79a is a powerful knowledge representation system which allows multiple beliefs (beliefs from multiple agents, contradictory beliefs, hypothetical beliefs) to be simultaneously represented, and performs both forward and backward reasoning within sets of these beliefs. In this paper, we discuss SNeB (SNePS Belief Revision), a belief revision system available in SNePS. Belief revision systems are AI programs that can detect and recover from contradictions. Belief revision systems have been implemented by several researchers (e.g., Doyle 79; Martin 83; McElister 80; Steel 81). It has been argued that a belief revision system relying on the manipulation of assumptions is associated with each proposition in the hypotheses (non-derived propositions) that underlie it, has multiple advantages over one relying in the manipulation of justifications. These systems associate each proposition with the propositions that directly originated it. Martin 83, Martin and Shapiro 83; de Kleer 84. A difficulty associated with assumption-based belief revision systems is that it must be possible to compute exactly which assumptions underlie a given proposition. SNeB relies on the manipulation of assumptions, and is based on a logic, the SWM system, which guarantees that every proposition is associated with exactly every hypothesis used in its derivation SWM guarantees much more than just this, see [Martin 83]. In this paper we briefly introduce SNeB and its underlying systems, SWM, and show an example obtained using SNeB. SNeB is fully implemented in Franz Lisp, running on VAX-11 Systems.

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The SWM System - Theoretical Foundations

The SWM system [Martin 83] is the logical system that provides the theoretical foundations for SNeB. It is loosely based on the relevance logic systems of [Anderson and Belnap 75] and [Shapiro and Wand 76]. Distinguishing features of SWM include recording dependencies of wfs, not allowing irrelevances to be introduced, and providing for dealing with contradictions. SWM deals with objects called supported wfs. Supported wfs are of the form $F \mid r, a$, in which $F$ is a wfs (well-formed formula), $r$ (the origin tag) is an element of the set $(	ext{hyp}, 	ext{der}, 	ext{ext})$, $a$ (the origin set) is a set of hypotheses, and $r$ (the restriction set) is a set of sets of hypotheses. The origin set contains all the hypotheses which were actually used in the derivation of $F$. The origin tag tells whether $F$ is an hypothesis $(r = \text{hyp})$, a normally derived wfs $(r = \text{der})$, or a wfs with an extended origin set $(r = \text{ext})$. The restriction set contains sets of hypotheses, each of which when unions with the hypotheses in the origin set forms a set which is known to be inconsistent. The rules of inference of the SWM system (see, for example Martin and Shapiro 844), guarantee that:

1. The origin set of a supported wfs contains every hypothesis that was used in its derivation.
2. The origin set of a supported wfs contains only the hypotheses that were used in its derivation.
3. The restriction set of a supported wfs records every set known to be inconsistent with the wfs origin set.
4. The application of rules of inference is blocked if the resulting wfs would have an origin set known to be inconsistent.

Contexts and Belief Spaces

SNeB relies on the notions of context and belief space. A context is a set of hypotheses. A context determines a Belief Space (BS) which is the set of all the hypotheses defining the context and all the propositions which were derived from them. Within SWM, the propositions in a given BS are characterized by having an origin set which is contained in the context. Any query to the network is associated with a context. When answering the query SNeB only considers the propositions in the network which belong to the BS defined by that context.

Non-Standard Connectives

SNePS has a powerful set of non-standard connectives (79a, 79b; Martin and Shapiro, forthcoming). The disadvantage in using the standard connectives ($\land$, $\lor$, $\rightarrow$) relates to the fact that all the connectives,

1 After Shapiro, Wand and Martin.
2 The latter case will not be discussed in this paper and can be found in Martin 83 and Martin and Shapiro 84.
exception, are binary and therefore expressing sentence about sets of propositions becomes cumbersome. For example, we can express the fact that exactly one of X, Y, and Z is true. A simple way to do this is to use logical connectives in a formula. Here, we use \( A \lor B \land C \lor D \) to express that exactly one of the propositions \( A, B, C, \) or \( D \) is true. However, a more explicit way to express that exactly one of \( a_1, a_2, \ldots, a_n \) is true is to use the formula \( \bigwedge_{1 \leq i \leq n} (a_i \land (\neg \bigwedge_{j \neq i} a_j)) \). This formula states that each \( a_i \) is true and all the others are false.

The standard logical connectives are the AND, OR, NOT, and the implication. The AND connective is denoted by \( \land \), the OR by \( \lor \), the NOT by \( \neg \), and the implication by \( \rightarrow \).

The inference system is the part of the network that performs the inferences. The inference system consists of both the problem-solving model and the decision-making model. The problem-solving model is responsible for generating the problem-solving strategies, and the decision-making model is responsible for selecting the best strategy. The inference system uses a set of inference rules to determine the next step in the problem-solving process.

The inference rules can be divided into two categories: the deduction rules and the forward chaining rules. The deduction rules are used to derive new propositions from the existing ones. The forward chaining rules are used to select the next step in the problem-solving process.

The inference system is modular and can be extended to include new inference rules. The inference rules are implemented as a set of procedures that can be called from the knowledge base. The procedures are structured in a hierarchical manner, with the top-level procedures calling the lower-level procedures.

The inference system is also extensible. New inference rules can be added to the system without changing the existing code. This is done by writing new procedures that can be called from the existing procedures.

The inference system is also flexible. It can be used to solve a wide range of problems, from simple logical problems to complex real-world problems. The inference system can be used to solve problems in areas such as artificial intelligence, expert systems, and decision support systems.

The inference system is also efficient. The inference rules are designed to be executed quickly, and the inference system can be optimized for speed. The inference system can be used to solve problems in real-time, and it can be used to solve problems that are too large to be solved by other methods.

The inference system is also robust. It can handle errors and exceptions gracefully. The inference system can be used to solve problems that are inherently uncertain, and it can be used to solve problems that are subject to change.

The inference system is also scalable. It can be extended to solve larger problems by adding more procedures and inference rules. The inference system can be used to solve problems that are too large to be solved by other methods.

The inference system is also modular. It can be used to solve problems in a modular manner, with each module solving a specific problem. The inference system can be used to solve problems in a distributed manner, with each module solving a specific problem on a separate computer.
Suppose we ask who Freeman will marry under the BS defined by the context \{w15, w12, w13, w11, w14, w16\}. In this BS there is no evidence about who Freeman will marry, but a KB may enable its deduction.

NeBR sets up two sub-goals: finding who is over 30, and finding who is a teacher (Figure 3).

I wonder if marry(Freeman, who) holds within the BS defined by the context \{w12, w13, w11, w14, w16\}. Let me try to use the rule \{1\} (w12, w13, marry(Freeman, z), z, w14, age(z, 30), worker(z, teacher))

I wonder if age(z, 30) holds within the BS defined by the context \{w12, w13, w14, w15, w16\}. I know age(Cyd, 30)

I know age(Ada, 30)

I wonder if worker(z, teacher) holds within the BS defined by the context \{w12, w13, w14, w15, w16\}. I know worker(Ada, teacher)

I wonder if Ada = teacher holds within the BS defined by the context \{w12, w13, w14, w15, w16\}. I know worker(Ada, teacher) and age(Ada, 30) if marry(Freeman, Ada)

Figure 3: Ada and Cyd are over 30. Ada and Deb are teachers. Freeman will marry Ada

Figure 3 shows NeBR's deduction that Freeman will marry Ada. The inference does not stop here, however, since there are several processes still waiting for answers and NeBR needs to infer some additional information as shown in Figure 4.

Since age(Ada, 30) and age(Cyd, 30) hold within the BS defined by the context \{w12, w13, w14, w15, w16\} if marry(Freeman, Ada) holds within the BS defined by the context \{w12, w13, w14, w15, w16\}, we infer age(Ada, 30)

Figure 4: Ada and Cyd are over 30. Deb is over 30.

After the deduction of the information shown in Figure 4, a contradiction is detected (Figure 5). A contradiction will be detected by NeBR when one of the following conditions occurs: (1) Nodes representing contradictory facts are built into the BS under consideration; (2) Information gathered by a connective elimination process shows that a rule is invalidated by the data in the BS.

In our example the latter case occurs: there exists one process to deduce information using the rule \{1\} (age(Ada, 30), age(Ba, 30), age(Cyd, 30), age(Ada, 30)) which gathers that there are three women who are over 30 (Ada, Cyd, and Deb).

WARNING:

Contradiction detected in the following subcontext \{w15, w16, w13, w12, w11\} age(Ada, 30), age(Ba, 30), age(Ada, 30)

More true arguments than max

Do you want to continue anyway? y

Do you want to re-start the request in a new context? y

Figure 5: A contradiction is detected.
Upon detecting the contradiction SNeBR gives the options of continuing the reasoning within the inconsistent BS, modifying the current context in order to obtain a consistent BS or giving up the result. In our example, we decided to restore consistency causing the interaction shown in Figures 6 and 7. 13

Figure 6 shows the inspection of the hypotheses that are responsible for the contradiction. Although the context under consideration is the set \{wif9, wif13, wif28, wif21, wif89\} only the hypotheses represented by wif13, wif13 and wif89 were used in the derivation of the contradiction and thus they are the only ones whose change will restore consistency. The SW31 system guarantees that removing exactly one of them will generate

In order to make the context consistent you must delete some hypotheses from the set (wif13 wif15 wif89). You are now entering a package that will enable you to delete some hypotheses from this set.

Do you want to take a look at wif13 ?

\[ \Rightarrow \rightarrow n \]

There are 5 propositions depending on wif13 : (wif97 wif16 wif23 wif91 wif90)

Do you want to look at [all of them], [some of them], or [none]?

\[ \Rightarrow \rightarrow a \]

\[ \Rightarrow \rightarrow \{(\text{married(Freeman, Eve)})\} \text{ ext.} (wif13, wif28, wif89), \{(wif15)\} \]

What do you want to do with wif13 ?

[discard from the context, keep in the context, undecided, quit this package]

\[ \Rightarrow \rightarrow d \]

Do you want to take a look at wif15 ?

\[ \Rightarrow \rightarrow y \]

age(Cyd, o30) \text{ hyp. (wif13), \{(wif13, wif89)\} }

There are 2 propositions depending on wif15 : (wif16 wif94)

Do you want to look at [all of them], [some of them], or [none]?

\[ \Rightarrow \rightarrow n \]

What do you want to do with wif15 ?

[discard from the context, keep in the context, undecided, quit this package]

\[ \Rightarrow \rightarrow d \]

Do you want to take a look at wif89 ?

\[ \Rightarrow \rightarrow y \]

wif97 wif16 wif94 wif3 wif92 wif91 wif90

Do you want to look at [all of them], [some of them], or [none]?

\[ \Rightarrow \rightarrow n \]

What do you want to do with wif89 ?

[discard from the context, keep in the context, undecided, quit this package]

\[ \Rightarrow \rightarrow k \]

Figure 6: Inspecting the inconsistent hypotheses

A context which is not known to be inconsistent. We keep the hypothesis concerning the statement of the puzzle (wif90) and discard the hypotheses concerning the women's ages (wif13 and wif15). We also enter new hypotheses concerning the women's ages (Figure 7).

After resolving the contradiction the inference resumes (Figure 8). In this case there is no further contradiction detected and SNeBR reports that Freeman will marry Deb and will not marry Ada, Bea, Cyd nor Eve.

The following (not known to be inconsistent) set of hypotheses was a part of the context where the contradiction was derived: (wif13 wif28 wif89) Do you want to inspect or discard some of them?

\[ \Rightarrow \rightarrow n \]

Do you want to add some new hypotheses?

\[ \Rightarrow \rightarrow y \]

Enter an hypothesis using SNePSLOG

\[ \Rightarrow \rightarrow \text{ age(Bea, o30)} \]

Do you want to enter another hypothesis?

\[ \Rightarrow \rightarrow y \]

Enter an hypothesis using SNePSLOG

\[ \Rightarrow \rightarrow \text{ age(Deb, o30)} \]

Do you want to enter another hypothesis?

\[ \Rightarrow \rightarrow n \]

Figure 7: Adding new hypotheses

I wonder if marry(Freeman, Eve) holds within the BS defined by the context (wif14 wif16 wif28 wif31 wif89)

1 know age(Deb, o30)

1 know age(Bea, o30)

1 know worker(Deb, teacher)

1 know worker(Ada, teacher)

since \[ \text{age(Deb, o30)}, \text{worker(Deb, teacher)} \]

1 infer marry(Freeman, Deb)

since age(Ada, o30) and age(Deb, o30)

1 infer \[ \text{age(Eve, o30)} \]

\[ \text{age(Ada, o30)} \]

since not age(Ada, o30)

1 infer \[ \text{age(Eve, o30)} \]

1 infer \[ \text{age(Freeman, Eve)} \]

Figure 8: Freeman will marry Deb Eve, Cyd and Ada are not over 30

CONCLUDING REMARKS

We discussed SNeBR, the belief revision system used by SNePS, briefly described some of the concepts of the logic that underlies SNeBR, and showed an example. The example presented was obtained from an actual run just by slightly changing the syntax of the propositions.

SNeBR is implemented in SNePS, a powerful knowledge representation system. A distinguishing characteristic of SNeBR is that it is based on a logic designed with the goal of supporting belief revision systems. SWM associates each proposition with all the hypotheses used in its derivation and with all the hypotheses with which it is known to be incompatible. The SWM formalism guarantees that (1) The origin set of a supported wff contains every proposition that was used in its derivation. (2) The origin set of a supported wff only contains the hypotheses that were used in its derivation. (3) The restriction set of a supported wff records every set known to be inconsistent with the wff's origin set. (4) The application of the rules of inference is blocked if the resulting wff would have an origin set known to be inconsistent.

In SNeBR, propositions are represented by SNePS network nodes and are indexed by (linked with) the hypotheses in their origin set and the sets in their restriction set.

The queries to SNeBR are associated with a context, the network retrieval function only considers the propositions in the BS defined by that context. When a contradiction is detected, after selecting one hypothesis (or several hypotheses) as the culprit for the contradiction, the "removal" from the network of all the propositions depending on such hypothesis (hypotheses) is done just by dropping it (them) from the context being considered. Afterwards these propositions will no longer be in the BS under consideration and thus will not be considered by SNeBR.

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11In SNeBR this is not dangerous since it is based on relevance logic in which the paradoxes of implication [e.g., from a contradiction anything can be derived] do not arise.

12Note that the restriction set of this extended wff has the set (wif15), meaning that wif15, wif28, wif89, wif15 is a set known to be inconsistent.
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