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Preface

This volume contains the papers accepted for presentation at ECSQARU-93, the European Conference on Symbolic and Quantitative Approaches to Reasoning and Uncertainty, held at the University of Granada, Spain, from November 8 to 10, 1993.

In recent years it has become apparent that an important part of the theory of Artificial Intelligence is concerned with reasoning on the basis of uncertain, incomplete, or inconsistent information. Classical logic and probability theory are only partially adequate for this and a variety of other formalisms both symbolic and numerical have been developed, some of the most familiar being non-monotonic logic, fuzzy sets, possibility theory, belief functions, and dynamic models of reasoning such as belief revision and Bayesian networks.

These are new and active areas of research with many practical applications and many interesting theoretical problems as yet unresolved. Several European research projects and working groups have been formed and it soon became apparent that there was a need for a regular European forum where work in this area could be presented and discussed by specialists. The first conference was held at Marseille in 1991 (LNCS 548). This, the second of a regular biennial series, has again been sponsored by the major European research project in this area, DRUMS (Defeasible Reasoning and Uncertainty Management Systems, ESPRIT BRA 6156), involving 21 European partners and by the newly-formed European Society for Automated Practical Reasoning and Argumentation (ESAPRA).

The executive Scientific Committee for the conference consisted of Philippe Besnard (IRISA, Rennes), Rudolf Kruse (University of Braunschweig), Henri Prade (IRIT, Toulouse) and Michael Clarke (QMW, University of London). We gratefully acknowledge the contribution of the many referees, too many to list individually, who were involved in the reviewing process. Finally we would like to thank the University of Granada for providing all the necessary facilities and Serafín Moral of the University of Granada who was responsible for the local organisation.

August 1993 Michael Clarke, Chairman

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$\mathcal{RES}$: A formalism for reasoning with relative-strength defaults

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Areas: Common Sense Reasoning, Knowledge Representation, Probabilistic Reasoning.

Abstract

$\mathcal{RES}$ is a system for reasoning about evidential support relationships between statements[1, 2]. In $\mathcal{RES}$, the preferences of these supports are represented symbolically, by directly comparing them, instead of by numerical degrees. Z^+ is a formalism for reasoning with variable-strength defaults[5] which provides a mechanism to compute a minimum admissible ranking for models (subject to the consistency condition) from the given integer strengths of defaults.

In this paper, we combine the two systems. We show that the same consistency condition of Z^+ can be applied to $\mathcal{RES}$ even though the preferences of rules are represented as a relation in $\mathcal{RES}$. A similar procedure is devised which can produce the admissible relative strengths (a relation) and can produce the relation on models with respect to the strengths of the rules they violate. A consequence relation is defined and a procedure to answer queries concerning it is devised. The resulting system, also called $\mathcal{RES}$, is then compared to Z^+. We show that, while $\mathcal{RES}$ is very similar to $Z^+$and displays comparable reasoning processes most of the time, they are not the same and $\mathcal{RES}$ is more in agreement with common sense in some situations. Comparing $\mathcal{RES}$ to the stratified ranking system [6] shows that $\mathcal{RES}$, as presented, also shares some limitations with Z^+.

1 Introduction

It has been widely acknowledged that all defaults are not created equal [5, 11] and that defaults differ in many aspects such as in their importance and their firmness. It has been widely agreed also that a language or a mechanism must be devised for expressing this valuable knowledge. The only problem remaining is what aspects about this knowledge should be represented and how.

The general way of representing this knowledge is by the strengths of defaults. Thus it will be very desirable if we can have a standard measurement of such strengths. As a matter of fact, there are many cases where such a measurement is available. These situations have been studied extensively in the literature. Different measurements have been proposed and both quantitative and qualitative reasoning with those measurements have been investigated[3, 8, 12, 13]. There are cases, however, where a normal measurement is not available or is not suitable. At the same time, there are also cases where the desirable reasoning patterns are amenable to some other representations simpler and more primitive than such measurements.

$\mathcal{RES}$ is a system for reasoning about evidential support relationships between statements, where the preferences of these supports are represented symbolically, by directly comparing these supports, instead of by numerical degrees. That is, we begin with a set of arguments and a relation on this set which reflects the strengths of the arguments. Here, by an argument we mean the relationship between statements e and p, representing that when e is found to be true, there is a justification to conclude that p is true. It has been shown that $\mathcal{RES}$, in a defined sense, can represent all the information in a probability distribution, belief function, or possibility distribution and can reflect many reasoning patterns[1, 2].

The $\mathcal{RES}$ system as presented has a serious problem in that it doesn't have a built-in way to scale up. In $\mathcal{RES}$, the two statements in an argument $\langle e, p \rangle$, *i.e.* e and p, are required to belong to separated first order logics. Conclusions reached cannot be used as evidence to trigger further reasoning. In this paper, we try to remedy this fault of $\mathcal{RES}$ by applying the Z^+ mechanism [5]. The arguments will be treated as rules as in Z^+, but instead of associating integers with rules, preferences among rules will be represented as a relation, called the *base relation*. A procedure will be proposed which can form the relative strengths of the rules given the base relation and can produce a relation on the models of the language with respect to the relative strengths of the rules which are falsified in these models (subject to the same consistency condition). In this way, we extend the reasoning capability of $\mathcal{RES}$.

In the following section, the presentation of Z^+ formalism in [5] is parallelled but in relative terms. We define some important terms and present the two procedures mentioned above. The resulting system will also be denoted as $\mathcal{RES}$. Examples are presented showing that $\mathcal{RES}$ can display similar reasoning processes as Z^+ in many cases. In section 3, $\mathcal{RES}$ is compared to Z^+ showing that they are not completely the same and in some situations $\mathcal{RES}$ can display reasoning processes more defensible than these displayed by Z^+. $\mathcal{RES}$ is also compared to the stratified ranking system, showing that $\mathcal{RES}$ shares some limitations with Z^+. In the last section, the conclusions are summarized.

2 Relative Rule Strength and Plausible Conclusions

As with Z^+, we consider a set of rules $\Delta = \psi_i \rightarrow \phi_i$ where ψ_i and ϕ_i are propositional formulas over a finite alphabet of literals, "$\rightarrow$" denotes a new connective. But different from Z^+, the preferences of such rules are represented as a relation. That is, we have a relation S over Δ (denoted as "$\preceq$"). These relations are required to be reflexive and transitive and are called *base relations*.

Following the terms with Z^+, we will call a truth valuation of the literals in the language *a model*. For a formula ψ of the language, M is said to be *a model for* ψ, denoted as $M \models \psi$, iff ψ is true in M. A model M is said to *verify* a rule $\psi \rightarrow \phi$ if $M \models \psi \wedge \phi$, to *falsify* $\psi \rightarrow \phi$ if $M \models \psi \wedge \neg\phi$, and to *satisfy* $\psi \rightarrow \phi$ if $M \models \psi \supset \phi$. A rule $\psi \rightarrow \phi$ is *tolerated* by Δ iff there exists a model M such that M verifies $\psi \rightarrow \phi$ and satisfies all the rules in Δ.

With these terms, the formalism Z^+ can be presented using relative terms. One should notice the parallel between the following presentation with that of Z^+ in [5].

Definition **1** *A relation R on the models of the language is called* a priority relation *if it is reflexive and transitive.*

Such a relation is supposed to have the same role as that of the ranking in Z^+. That is, $M_1 \preceq M_2$ is to be read as M_1 is no more abnormal than M_2[1].

[1] The reverse of the relation, representing normality, might be more intuitive and more consistent with the term priority relation[4]. We use this direction so the following presentation can be in parallel with that of Z^+.

In the following, we will also use $M_1 \prec M_2$ to denote $(M_1 \preceq M_2) \wedge (M_2 \not\preceq M_1)$ and other notations conventionally.

Definition **2** *A model M^+ for ψ is said to be* a minimal model for ψ *under priority relation R^+ iff there is no model M for ψ such that $M \prec M^+$.*

A priority relation R on models of the language is said to be admissible with regard to a default set Δ *iff for every rule $\psi_i \rightarrow \phi_i$, if M^+_+ is a minimal model for $\psi_i \wedge \phi_i$ and M^+_- is a minimal model for $\psi_i \wedge \neg\phi_i$, then $M^+_+ \prec M^+_-$.*

The minimal priority relation admissible to Δ will be denoted as R^+_0.
Notice that the base relation, which carries the preference information among the rules, is not used in the definition above. In fact, the minimal priority relation defined above is composed of the preference relationships which are derivable from the specificity considerations on the rules[10].

From the definition, we can define a set of defaults to be *consistent* if it admits at least one priority relation. A theorem similar to **Theorem 1** in [5] can be reached. This is actually very easily seen, as **Theorem 1** in [5] has established that whether a set of default rules is consistent is completely independent of the strengths of the rules.

But we need to incorporate a base relation S into a priority relation when S is not empty. To do this, we need to define the relative strengths of rules first.

Definition **3** *Let R^+_0 be the minimal admissible priority relation of Δ and let S be a base relation on Δ. A relation S^+ on Δ is called* the relative strengths derived from Δ and S *provided that for any two rules r_i and r_j, $r_i \geq r_j \in S^+$ (meaning r_j is no stronger than r_i) iff*

1. *for every minimal model M_2 falsifying r_j, and every model M_1 falsifying r_i, $M_2 < M_1$; or*
2. *we can have neither $r_i \geq r_j \in S^+$ nor $r_j \geq r_i \in S^+$ from the step above and $r_i \geq r_j \in S$.*

The definition specifies that the relative strength is reached by first adding the relationships which are derivable from the specificity considerations. After that, relationships from the base relation are added if the two rules in those relationships are not comparable so far. If these two rules have become comparable already from specificity considerations, their relationships from S, if existing, will be blocked and not be reflected in S^+.

A priority relation on models reflecting both Δ and S can be defined as follows:

Definition **4** The priority relation R^+ *of Δ and S, denoted as "$\preceq$", is a relation on models in which $M_1 \preceq M_2$ iff*

- *M_1 doesn't falsify any rule; or*
- *for any rule r_i which is falsified by M_1, there exists a rule r_j which is falsified by M_2 such that $r_j \geq r_i \in S^+$. That is, for any rule falsified by M_1, there exists a stronger rule which is falsified by M_2.*

Obviously, $R^+ \supseteq R^+_0$. We can also define a consequence relation using R^+.

Definition **5** *A formula ϕ is called* a plausible conclusion of ψ, *denoted as $\psi \vdash \phi$, iff ϕ is true in all minimal models for ψ.*

The similarity between absolute strength and relative strength doesn't stop here. Similar procedures can be devised for constructing the priority relation and for testing whether a pair of formulae belongs to the consequence relation with regard to a set of default rules and a base relation. These procedures are presented below:

Procedure RS

Input: A consistent set Δ of default rules. A base relation S on Δ.

Output: The priority relation on models and the relative strength relation S^+ on Δ.

Part I

1. Let RZ^+ be an empty set, Δ_1 be Δ, and S_0^+ be an empty relation on Δ.
2. While $RZ^+ \neq \Delta$ do:
   (a) Let Δ_0 be the set of rules tolerated by Δ_1 and $RZ^+ = RZ^+ \cup \Delta_0$.
   (b) $S_0^+ := S_0^+ \cup \{r_i > r_j | r_i \in \Delta_0, r_j \in RZ^+$, there exists at least one model M which verifies r_i and falsifies r_j, and there doesn't exist any other model M' which verifies r_i and falsifies only part of those rules falsified by $M.\}$.
   (c) $\Delta_1 := \Delta_1 - \Delta_0$.
3. Let S_t^+ be the transitive closure of S_0^+.

Part II

1. S^+ is a relation on Δ such that for any rules $r_i, r_j \in \Delta$, $r_i \geq r_j \in S$ iff
   - $r_i \geq r_j \in S_t^+$; or
   - $r_i \geq r_j \notin S_t^+, r_j \geq r_i \notin S_t^+$, and $r_i \geq r_j \in S$.
2. R^+ can be calculated as shown in Definition 4.

Procedure PC

Input: A consistent set Δ, the relation R^+ from Δ, and a pair of consistent formulas ψ and ϕ.

Output: Answer YES/NO/AMBIGUOUS depending on whether $\psi \vdash \phi$, $\psi \vdash \neg\phi$, or neither.

1. If Δ is empty, then RETURN(AMBIGUOUS)[2].
2. TEST1 whether there is a model M such that $M \models \psi \wedge \phi$ and M satisfies Δ.
3. TEST2 whether there is a model M such that $M \models \psi \wedge \neg\phi$ and M satisfies Δ.
4. CASES on the results of TEST1 and TEST2:
   - IF TEST1=Yes and TEST2=No then RETURN($\psi \vdash \phi$).
   - IF TEST1=No and TEST2=Yes then RETURN($\psi \vdash \neg\phi$).
   - IF TEST1=Yes and TEST2=Yes then RETURN(AMBIGUOUS).
   - IF TEST1=No and TEST2=No then let MIN be the set of all minimal rules with respect to R^+. Set Δ to be $\Delta - MIN$ and go back to step 1.

Example 1 *Flying birds.*

Let $\Delta = \{b \rightarrow f, p \rightarrow \neg f, p \rightarrow b\}$ and S be an arbitrary relation on Δ. The rules in Δ stands for the "birds fly", "penguins don't", and "penguins are birds" respectively.

As $b \rightarrow f$ is tolerated by Δ but $p \rightarrow b$ and $p \rightarrow \neg f$ are tolerated only by $\Delta - (b \rightarrow f)$, from part I of the RS procedure we reach that $S_t^+ = \{p \rightarrow \neg f > b \rightarrow f, p \rightarrow b > b \rightarrow f\}$.

When we are asked whether $p \vdash f$ or $p \vdash \neg f$ is in the consequence relation, the first round of the PC procedure will produce "No" answers for both tests. This will lead to the removing of rule $b \rightarrow f$ as it is the weakest. The second round will then

[2] This test is actually necessary even for Z^+.

return with the answer $p \vdash \neg f$. It should be noticed that the answer $p \wedge b \vdash \neg f$ could be reached in the same manner.

It should be noticed also that it is the specificity considerations embodied in the RS procedure which renders minimal models falsifying the rule $b \rightarrow f$ to be preferred to minimal models falsifying rule $p \rightarrow b$ and/or $p \rightarrow \neg f$. In this example, the base relation S can be anything (including the empty relation) and the result would not change as the relationships in S will be blocked anyway.

In the following, an example is presented in which the base relation matters.

Example 2 *The Nixon diamond.*

Let $\Delta = \{q \rightarrow p, r \rightarrow \neg p\}$ where the rules are read as "Quakers are pacifists" and "Republicans are not pacifists". The part I of the procedure RS will find that both rules are tolerated by Δ and will produce an empty relation for S_t^+. Part II of the procedure will then make S^+ to be the same as S, the base relation which is the input.

If we know an individual to be either a Republican or a Quakers but not both, the result is obvious. In the case of the "Nixon-diamond" where Nixon is both a Republican and a Quakers, what conclusion should we make?

Now the base relation S can be one of the four cases depending on which rule is preferred.

1. $S = \phi$. That is, we have no knowledge as to which rule is stronger (which might be an honest representation of somebody's knowledge of this matter.) For the first round, the PC procedure will produce "No" answers for both tests and make Δ empty as both rules are minimal. After that, the answer "AMBIQUOUS" will be returned.
2. $S = \{r \rightarrow p \geq q \rightarrow \neg p\}$. This time, models violating $r \rightarrow p$ is preferred to those violating $q \rightarrow \neg p$ which makes $r \wedge q \vdash p$ the returned answer.
3. $S = \{q \rightarrow \neg p \geq r \rightarrow p\}$. The relationship is reversed from the above case, so is the answer.
4. $S = \{r \rightarrow p \geq q \rightarrow \neg p, q \rightarrow \neg p \geq r \rightarrow p\}$. The relationships in both directions are presented. This is a verbose way to say that the two rules are of the same strength. The process of the first case is then repeated which produces the answer "AMBIGUOUS".

4 Relative vs. Absolute

The difference between the relative method and the method using integers is that, for the relative method, the resulting relation on both rules and models can be partial. The integer method always displays a universal relation. That is, using integers will render every pair of rules or models comparable.

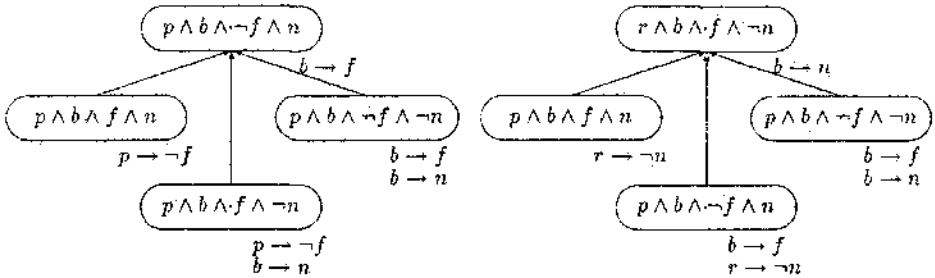
This might not always be an advantage. For a simple example, case 1 of example 2 cannot be represented honestly, even though the result and the reasoning process of case 1 is identical to those of case 4.

There are situations where adhering to numbers will cause some problems which are more serious. In Example 3, we show that the Z^+ranking will change the relationship between rules in an undesirable way. In Example 4, we show that the fact that integers are comparable universally will block some intuitive reasoning.

Example 3 *English speaking.*

Let $\Delta = \{r_1 : c \rightarrow e, r_2 : q \rightarrow \neg e, r_3 : q \rightarrow c, r_4 : le \rightarrow e\}$ be the set of default rules and let the integer strengths of these rules be $\delta_1, \delta_2, \delta_3, \delta_4$ respectively, where δ_i are non negative integers. Rules in Δ stand for "Canadians speak English", "Quebecois don't speak English", "Quebecois are Canadians", and "People who learnt English speak English" respectively. It can be noticed that this default set is isomophic to the "Flying Birds" problem except for the last rule.

Figure 1: Relationships of relevant models



Suppose that we are querying a person who is a Quebacois and who learnt English. What should be our conclusion? The Z^+ ranking of the rules will be computed to be $\delta_1, \delta_1 + \delta_2 + 1, \delta_1 + \delta_3 + 1$ and δ_4 respectively. As $q \wedge le \wedge c \wedge e$ will violate r_2 and $q \wedge le \wedge c \wedge \neg e$ will violate r_4, the result will be dependent on whether $\delta_1 + \delta_2 + 1$ is larger than, smaller than, or equal to δ_4. For example, if we set $\delta_3 = \delta_4 = 2$ and $\delta_1 = \delta_2 = 1$ (for good reasons), the answer will be that this person does not speak English.

However, this conclusion can hardly be justified. Recall that it is the specificity considerations which have increased the ranks of r_2 and r_3 and this specificity should, obviously, have nothing to do with r_4. But now the conclusion is reached by overruling r_4 with those considerations, even though we are told that r_4 is firmer than r_2 at the outset. This is surprising as removing rule r_1 will reverse the answer!

It should be noticed that this kind of reasoning is not justifiable by referring back to probabilistic reasoning on which the Z^+ system is based. In fact, no matter what δ_i is, this set of rules embodies a conflict in probabilistic assertions. Asserting infinitesimal probabilities to all the rules will lead to the conclusion that $q \wedge le$ is impossible.

Using $\mathcal{RES}$, the procedure will not affect the relationship between r_2 and r_4 and thus the result will be decided depending on the input relationship between r_2 and r_4. We can justify conclusions like this very simply as follows: Because there are minimal models which violate only one of these rules, the conclusion should be made by considering which rule is preferred.

This line of reasoning is reflected faithfully in the RS procedure. Here, part I enforces the specificity by changing only the relationships between r_1 and r_2, r_3 and keeps the relationship between r_2 and r_4 untouched.

Example 4 *Flying birds and nesting ones.*

Let $\Delta = \{b \rightarrow f, p \rightarrow \neg f, p \rightarrow b, b \rightarrow n, r \rightarrow \neg n, r \rightarrow b\}$ and S be an empty relation.

In this example, another set of rules asserting a bird property and its exception is added to the rules of Example 1. The additional rules stand for "Birds nest", "Robins don't" and "Robins are birds".

This doubling of rules shows a good feature of the relative strength system. It will produce the relationships between models as shown in Figure 1. In those models, either $p \wedge b$ or $r \wedge b$ is true. In the figure, an arrow will lead from one model to another if the later model is more normal than the former and the rules below a model are those violated in the model.

These relationships are suitable for the relative strength system to display desirable reasoning processes. For example, we have $f \wedge n$ given b, $\neg f \wedge n$ given $p \wedge b$, $f \wedge \neg n$ given $r \wedge b$, and $\neg f \wedge \neg n$ given $p \wedge r \wedge b$.

This extended set of rules, as already noticed in [5], will cause problems for the Z^+ formalism of default strengths. By arranging the integers assigned to those rules carefully, we can have either "penguins nest" or "robins fly". But no matter what integers are assigned to those rules, we cannot have both at the same time.

To see how this happens, we need to consider the two dashed links in Figure 1. To have "penguins nest" we need the dashed link on the left part. The only way to do this with integer strengths is to make the integer assigned to $b \rightarrow n$ greater than that to $b \rightarrow f$.

Symmetrically, to have that "robins fly" will need to assign a bigger integer to $b \rightarrow n$ than to $b \rightarrow f$.

We can do neither (make them equal), either (one bigger than another), but not both.

The analysis has made it obvious that this problem is caused by the fact that all integers are comparable universally. This fact will make the model which violates both $b \rightarrow f$ and $b \rightarrow n$ to be equally minimal as it is one model which violates only one of these two rules. Using relative strengths of rules overcomes this problem. Models violating both rules are set to be more abnormal than models violating only one of these rules, no matter which rule it is. This is done by keeping the two rules *not* comparable.

In the following example, we show that $\mathcal{RES}$ also shares some limitations with Z^+.

Example 5 *(Dead battery) [6])*

The rule set is $\Delta = \{tk \rightarrow cs, tk \wedge bd \rightarrow \neg cs, lo \rightarrow bd\}$ encodes the information that "Typically if I turn the ignition key the car starts", "Typically if I turn the ignition key and the battery is dead the car will not start", and "Typically if I leave the head lights on all night the battery is dead". The relation on the defaults is empty. That is, there is no knowledge concerning the strength of the rules.

For this example, $\mathcal{RES}$ system falls short just as Z^+ does. The problem is that the desirable conclusion "$lo \wedge tk \vdash \neg cs$" cannot be reached. This is because both the Z^+ ranking procedure and the RS procedure embody only the specificity considerations, and there are no reasons from specificity considerations to prefer $lo \rightarrow bd$ to $tk \rightarrow cs$.

To reach the desired conclusion, other considerations are needed. In [6], another kind of ranking, called stratified ranking, is described. Stratified ranking, among other things, embodies the considerations of the direction of causal relationships. Using stratified ranking, the situation presented in this example can be elegantly handled.

Stratified ranking, on the other hand, has problems of its own. As it adheres to the probabilistic ϵ-semantics more closely than Z^+, it cannot incorporate some rule preferences.

5 Conclusions

In this paper, we have shown that the same consistency condition of defaults in Z^+can be applied to the $\mathcal{RES}$ system where preferences among rules are represented as a relation among those rules. Similar procedures have been devised so that the relation representing the relative strengths of rules and the priority relation on models can be computed and queries concerning the consequence relation can be answered, as with system Z^+.

However, $\mathcal{RES}$ is not completely the same as Z^+ and can display some good features which are lacking in Z^+. We have shown that there are problems with Z^+: Ranks are calculated which might change relationships between rules in an undesirable way; The fact that integers are universally comparable might exclude some desirable reasoning processes. Both problems are solved very simply in $\mathcal{RES}$.

$\mathcal{RES}$ also shares some limitations with Z^+. It falls short in some common sense reasoning situations such as those where the direction of causal relationships is important.

It will be interesting to see how other common sense reasoning considerations can be incorporated with relative strengths. For example,

- Comparing $\mathcal{RES}$ to studies on preferential relations and reasoning based on them[7, 9];
- Extending the concept of argument in $\mathcal{RES}$ to be composed of a set of rules instead of only one. As an argument is directed by definition, this might provide a way to incorporate the causal relation considerations.

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References

[1] Z. An, D. Bell, and J. Hughes. $\mathcal{RES}$—a relation based method for evidential reasoning. In *Proc. 8th Conf. on Uncertainty in AI*, pages 1–8, 1992.

[2] Z. An, D. Bell, and J. Hughes. Relation based evidential reasoning. *Int. J. on Approximate Reasoning*, accepted, in preparation.

[3] P. P. Bonissone et al. Uncertainty and incompleteness: Breaking the symmetry of defeasible reasoning. In M.Henrion, R.D.Shachter, L.N.Kanal, and J.F.Lemmer, editors, *Uncertainty in Artificial Intelligence*, volume 5, pages 67–85. 1990.

[4] C. Boutilier. What is a default priority? In *Proc. CCAI 1992*, pages 140–147, 1992.

[5] M. Goldszmidt and J. Pearl. System-Z^+: A formalism for reasoning with variable-strength defaults. In *Proc. AAAI-91*, 1991.

[6] M. Goldszmidt and J. Pearl. Rank-based systems: A simple approach to belief revision, belief update, and reasoning about evidence and actions. In *Proc. Conf. Knowledge Representation*, 1992.

[7] B. Grosof. Generalizing prioritization. In J. Allen, J. Fikes, and E. Sandewall, editors, *Principles of Knowledge Representation: Proc. of the 2nd. Int. Conf.* Morgan-Kauffmann, 1991.

[8] J. Y. Halpern and M. O. Rabin. A logic to reason about likelihood. *Artificial Intelligence*, 32:379–405, 1987.

[9] S. Kraus, D. Lehmann, and M. Magidor. Nonmonotonic reasoning, preferential models and cumulative logics. *Artificial Intelligence*, 44:167–207, 1990.

[10] H. Kyburg Jr. The reference class. *Philosophy of Science*, pages 374–97, 1983.

[11] V. Lifschitz. Circumscriptive theories: a logic-based framework for knowledge representation. *Journal of Philosophical Logic*, 17:391–441, 1988.

[12] J. Pearl. *Probabilistic Reasoning in Intelligent Systems: Networks for Plausible Inference*. Kaufman, 1988.

[13] G. Shafer. *A Mathematical Theory of Evidence*. Princeton University Press, 1976.