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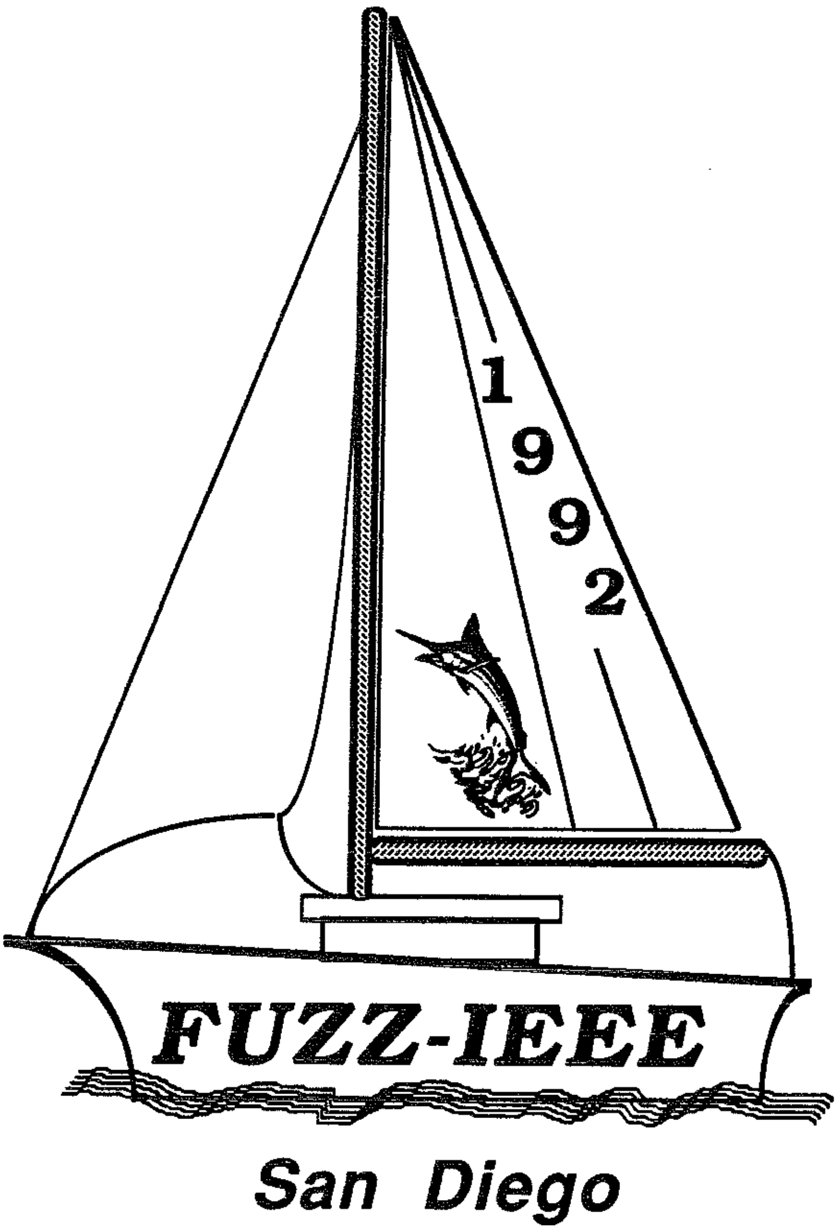

MANAGING LOCAL FUZZY LOGICS IN MILORD-II*

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ABSTRACT

MILORD (Sierra, 1989) is a currently working expert system shell oriented to classification tasks. Its most relevant features are (i) its multi-level architecture and (ii) the management of linguistically expressed uncertainty based on fuzzy logic. In this paper we describe a modular extension of the MILORD system. This modular extension, called MILORD-II, addresses two main characteristics of human problem solving: the adequation of general knowledge to particular problems, and the dependence of the kind of management of uncertainty on the particular subtasks. In this paper we mainly focus on the two important roles uncertainty play in this modular system: (i) as part of local deductive mechanisms, and (ii) as a control feature in the process of selecting and combining Knowledge Base (KB) units or modules.

1. MODULARITY AS KNOWLEDGE ADEQUATION

The use of modularization techniques in expert system design (Agustí-Cullel et al., 1989) is due to the need of adequating the general and spread knowledge in a KB to specific subtasks. Specific subtasks generally make use only of a subset of the whole KB. For instance, the suspicion of a bacterian disease will rule out all knowledge referring to virical diseases, or a patient in coma will make useless all the knowledge units that need patient's answers. Moreover, this adequation determines the universe of discourse, and this is made by means of selecting certain units of the KB which should be of a variable granularity depending on the problem. However, in any case, the level of granularity will never be as fine as reducing the universe of discourse to an elementary KB object (a rule) but a subset of them. These considerations lead to define structured KB's.

In MILORD-II (Agustí et al, 1991a) the basic units of KB are modules. These modules may be hierarchically organised, and consist of an encapsulated set of import, export, rule, meta-rule, inference system and submodules declarations. The declarations of submodules do not differ from the declaration of modules. These declaration of submodules inside a module is what structures the hierarchy which reflects the information dependencies among modules. The meaning of the primitive components of a module are:

Import: is the list of non-deducible facts needed in the module to apply the rules. These facts are to be obtained from the user at run time.

Export: is the list of facts deduced or imported inside a module are visible from the rest of the modules that include the module as a submodule.

Rule: are deductive units that relate import and export components within a module

Metarule: is a meta-logical component of the module.

Inference System: defines (i) the set of linguistic certainty terms used in weighting facts, rules and metarule, (ii) a renaming mapping between the term set of the submodules and the term sets of their module (see next section), and (iii) the connective operators used to combine and propagate the linguistic terms when making inference.

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A more complete description can be found in (Sierra and Agustí, 1990; Agustí et al., 1991a). The next figure shows an example of module definitions:

```
Module Global_Gram =
    Begin
        Module D = Respiratory_diagnosis
        Module T = Type_of_infection
        Module R = Radiology_diagnosis
        Module X = Sputum
        Export Pneumococcus, Haemophillus
        Deductive knowledge =
            Rules:
            R001 If X/DCGP and D/Bacterian then
                    conclude Pneumococcus is very_possible
            R002 If X/DCGP and D/Bacterian and T/Common_acquired then
                    conclude Pneumococcus is quite_possible
            R003 If X/CBGN and D/BCRO then
                    conclude Haemophillus is very_possible
            R004 If X/CBGN and D/BCRO and R/Previous then
                    conclude Haemophillus is quite_possible
            R005 If X/BGN and D/BCRO then conclude BGN is little_possible
            R006 if R/Cavitation then Pneumococcus is possible
            Inference system:
                Truth values = (impossible, little_possible, possible,
                        quite-possible, very_possible, sure)
                Renaming = ; see figure 2
                Connectives :
                    Conjunction = T
                    Disjunction = S
      End deductive
  End

Module Sputum =
    Begin
        Import Class_sputum
        Export DCGP, CBGN, BGN
        Deductive knowledge
            Rules:
            R001 If Class_Sputum = DCGP then conclude DCGP is very_possible
            ...
            Inference system:
                Truth values = (impossible, little_possible, possible,
                        quite-possible, very_possible, sure)
                Renaming = ; see figure 2
                Connectives :
                    Conjunction = T
                    Disjunction = S
      End deductive
  End
```

Figure 1: Example of Module definitions in Milord.

Remark: In the figure 1, the notation "A/fact" means that the fact "fact" is exported from the submodule "A".T and S are tabular representations (truth-tables) of conjunction and disjunction operators. In (López de Mántaras et al., 1990) we present a methodology based on constraint satisfaction techniques to elicit these truth-tables from the expert.

2. LOCAL UNCERTAINTY MANAGEMENT

Psychological experiments (Kuipers et al.,1989) show that human problem solvers do not use numbers to deal with uncertainty and that the way they manage it is situation dependent. These requirements were partially satisfied in the MILORD system in the sense that the treatment of uncertainty was based on different operators defined over a set of linguistic terms describing the global verbal scale the expert uses to express degrees of uncertainty (Godo et al., 1989). However, the modular structure of MILORD-II, together with this approach to uncertainty management, allows to define, in a natural way, local uncertainty calculi attached to each module, in such a way that the knowledge adequation process can also be applied to the uncertainty management. The need of having different uncertainty calculi in a KB becomes clearer when expert systems involving several human experts have to be built.

In the last situation, when two or more uncertainty calculi coexist in a same expert system, another question arises: how they communicate each other. Let's consider the following example where two experts cooperate in solving a problem :

A physician diagnosing a pneumonia could ask to a radiologist about the results of a radiological analysis. The simplest and more frequent type of communication is to get an "atomic" answer like

> "it is *likely* that the patient has a cavitation in his left lung."

Then, to use this information in his own reasoning, the physician must only interpret the linguistic expression *likely* used by the radiologist and perhaps to identify it with another term, for example *acceptable*, used by himself. But the communication could have been richer than that "atomic" answer, and consist of a more complex piece of information. For instance, the radiologist could have answered:

> "if from a clinical point of view you are *very confident* that the patient has a bacterian disease and he is also inmunodepressed, then its *nearly sure* he has a cavitation in his left lung."

As in the previous answer, to use the radiologist information, the physician must again "interpret" it. However, this time the translation can not be only a matter of the uncertainty terms (*very confident*, *nearly sure*) being used but also a matter of the way of reasoning, if he wants to make use of this information in other situations (patients) which do not exactly match the one expressed above.

From the point of view of an expert system shell, the first type of communication only requires an order preserving renaming between the linguistic values of the uncertainty calculi attached to different tasks, while the second type of communication requires that the translation should be inference-preserving. Figure 2 below, shows an example of the first type of communication. We have a module called "Global_Gram" whose local logic uses the truth values : impossible, little_possible, possible, quite_possible, very_possible and sure. This module has a submodule called "Radiology_diagnosis" whose local logic uses: false, unlikely, likely and true. Then, in order to correctly interpret in the module the certainty values of the predicate "cavitation" deduced in the submodule, an order preserving renaming of the certainty values is needed as shown in the figure.

```
Module Radiology_diagnosis =
     Begin
          Module Res = Respiratory_diagnosis
          Import Inmunodepressed
          Export cavitation, Inmunodepressed
          Deductive knowledge =
               Rules:
               ...
               R0014 if Res/Bacterian and Inmunodepressed then cavitation is likely
               ...
               Inference system:
                    Truth values = (false, unlikely, likely, true)
                    Renaming =
                    Connectives :
                         Conjunction = T_Rad
                         Disjunction = S_Rad
          End deductive
     end

Module Global_Gram =
     Begin
          Module D = Respiratory_diagnosis
          Module T = Type_of_infection
          Module R = Radiology_diagnosis
          Module X = Sputum
          Export Pneumococcus, Haemophillus
          Deductive knowledge =
               Rules:
               R001 ... R005
               R006 if R/Cavitation then Pneumococcus is possible
               Inference system:
                    Truth values = (impossible, little_possible, possible,
                              quite-possible, very_possible, sure)
                    Renaming =
                              R/false ==> impossible
                              R/unlikely ==> little_possible
                              R/likely ==> very_possible
                              R/true ==> sure
                    Connectives :
                         Conjunction = T_Gram
                         Disjunction = S_Gram
          End deductive
     End
```

Figure 2: Example of a renaming mapping between two modules in Milord

More generally in MILORD-II we have that :

1) Every expert, or subtask, is modelled as a different module with a local specific logic.

2) The communication between tasks and subtasks is modelled as communication between modules.

Looking carefully at how experts communicate their knowledge and at their problem solving procedures, we can find complex communication mechanisms. Sometimes experts can not reduce their interaction only to the communication of certainty values of predicates. For instance, when communicating, experts in medical diagnosis also need:

a) *To condition their answers* :

Suppose that it is not known if a patient is allergic to penicillin. A module deducing the possibility of giving penicillin can answer: *Penicillin is a good treatment from a clinical point of view if there is no allergy to it.* From a logical point of view, the answer could be:

{if no(allergy_penicillin) then Penicillin is very_possible}

b) *To give conclusions that have to be considered with the answer.* :

If in a culture of sputum pneumococcus have been isolated then it is strongly suggested to make an antibiogram to the patient i.e.

{Pneumococcus_isolation is sure, Make_Antibiogram is definite}

c) *To give conditioned conclusions to be considered with the answer.* :

A treatment with ciprofloxacine is not recommended for breast-feeding women. However if a woman is on breast-feeding period then the treatment can be carried if the woman stops breast-feeding i.e.

{Cipro is very_possible, if breast-feeding then stop_breast-feeding is definite}

d) *To give a more general answer.* :

Imagine that Gram positive coccus are detected. An answer to the predicate pneumococcus is at that moment too precise and cannot be given, but at least the morphological classification can be answered, i. e. : {coccus is definite}

To model such communication protocols, we need to extend the ES answering procedure. What we need is to answer to a given question with a set of formulas (rules and facts). To answer the question, the rules considered are those in deductive paths to and from the question. The facts in the answer are those that have been obtained in the application of such rules. The rules in the answer are those which could not be applied because they used unknown knowledge. We only consider the rules in the deduction tree of the question because we assume that when an user makes a question it expects an answer, and eventually all the relevant information associated with it, to that question only.

When there is a simple communication protocol (predicate and certainty value) we have seen that it is only necessary to define an order preserving renaming relation between the linguistic term sets of two experts. This is so because there is no need for one expert to know how the other combines the certainty values. If a complex communication, of the types explained above, is required, then a “morphism” between local logics is necessary, i.e. an inference preserving mapping between them.

In (Agustí et al., 1991a) we have analyzed under which conditions the mappings between finite multiple-valued logics are inference preserving. These conditions can be summarized by saying that for every fact deducible in a module M, its corresponding fact (through the inference preserving mapping) in another module M' will also be deducible and conversely, if a fact is not deducible in M then, its corresponding fact in M' will neither be deducible from the translated knowledge. These conditions might be too strong so we have also studied another possibility, (Agustí et al, 1991b), to translate knowledge between modules, by means of the so called "weak conservative maps" which allow the reasoning in a module M' to be less accurate when dealing with knowledge translated from another module M, but not incorrect , in any case, with respect to the result that would be obtained in M and then translated to M' (i.e. deducing facts in M', using knowledge translated from M, with lower certainty than deducing first in M and then translating their certainty to the logic of M').

3. UNCERTAINTY AS A CONTROL FEATURE

Finally, let us describe how uncertainty is used in the system as a control feature. The system has some introspection capabilities that allow to control the problem solving process. This control is based on the uncertainty degree that predicates have obtained so far and it is used to determine the focus of attention, the set of modules to be used and the problem solving strategy (Lopez de Mántaras et al, 1991).

In MILORD-II, the introspection capabilities are represented by metarules that control the applicability of submodules and rules. That is, it determines which rules and submodules are useful for the current case. This general mechanism is used in different ways. We are going now to see the most important ones.

Evidence increasing

The current uncertainty of facts can be used to control the deduction steps in order to increase the evidence of a given hypothesis. So, for example, if we have an alcoholic patient showing a cavitation in the chest x-ray and there is low evidence for tuberculosis, then the Ziehl-Nielssen test to determine more clearly whether he has a tuberculosis should not be done. But if he also presents a risk factor for AIDS then we shall increase our evidence for tuberculosis and the test will be suggested. This is expressed as follows:

If tuberculosis > moderately_possible **then conclude** Test Ziehl-Nielssen

If risk_factor_for_AIDS **then conclude** tuberculosis **is** possible

If Alcoholic **and** Cavitation **then** tuberculosis **is** almost_impossible

It should be noticed that the first rule is a rule of the meta-logic component of the language whilst the others are rules at the logic level.

Strategy focusing

The uncertainty of facts can determine the set of hypothesis to be followed in the sequel. Example:

If the pneumonia is bacterial with certainty < quite_possible **and**
the pneumonia is atipical with certainty > possible
Then focus on
Mycoplasm, Virus, Clamidia, Tuberculosis, Nocardia, Criptococcus,
Pneumocistis-Carinii
with certainty quite possible

This example means that the modules to be used in order to find a solution to the current case are those indicated in the conclusion of the meta-rule and should be considered in the order specified there.

Strategies have a certainty degree attached to them. This is useful to differentiate the strategies generated by very specific data from those generated by general data. As an example consider the case of a patient with AIDS (a kind of immunodepression). If we know that the patient suffers from AIDS, a more specific strategy (and also more certain) can be generated. But if we just know that the patient has an immunodepression a less certain general strategy would be generated. Since we may have several candidate strategies simultaneously, combining different strategies is a matter of great importance in the control of the system. This is also achieved by looking at the uncertainty of the strategies, as shows the next example:

> If Strategy (X) and Strategy (Y) and Certainty (X) > Certainty (Y) and
> Goals (X) $\cap$ Goals (Y) $\neq \emptyset$
> Then Ockham (X,Y)

where Ockham (X,Y) is a combination of the strategies that gives priority to those modules found in the intersection of both strategies (Goals (X) $\cap$ Goals (Y)), and then resumes with the goals of strategy X and finally those of strategy Y.

Knowledge adequation

As indicated at the begining of the paper a KB is a set knowledge units that have to be adapted to the current case. For example alcoholism is a useful concept when determining a bacterial pneumonia, but it is useless for non-bacterial diseases. Then, a possible use of the uncertainty of the fact bacterianicity is to decide about the use of a given concept in the whole KB, i.e. to adequate the general knowledge to the particular problem. Example:

> If no bacterian disease
> Then do not use alcoholism in finding the solution

Solution acceptance

The degree of uncertainty of a fact can also be used to stop the execution of the system. For example:

> If Pneumocistis-carinii **and** tuberculosis < possible **and** Criptococcus < possible
> **Then stop**

The control tasks we have discussed use uncertainty as a control parameter and are tasks of the meta-logic level. They are represented as a local meta-logic component of each module in what is called the control knowledge component of a module.

4. CONCLUSIONS

The structured definition of KB's helps not only in the definition of safe and maintainable KB's but also gives some new features that where impossible to achieve in the previous generation of systems. Among them the most important is the possibility of defining a local meta-logical component for each one of the modules.

The definition of strategies (ordered set of elementary steps to solve a problem) in the MILORD system was made globally. Only one strategy could be active at any moment. Presently, as many strategies as nodes in the modules graph structure can be active. This flexibility is linked with the fact that each module can have a different treatment of uncertainty. So, uncertainty plays a different role as a control feature depending on the association between module and logic.

Furthermore, given the fact that the system consists of a hierarchy of submodules the meta-logical components act ones upon the others in a pyramidal fashion. This allows us to have as many meta-logic levels as necessary in an application. Further research will be pursued along this line. A richer representation of the logic components in the meta-logic will also be investigated and sound semantics from the logic point of view will be defined.

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