Redaktorzy:
A.Straszak
Z.Nahorski
J.Sikorski

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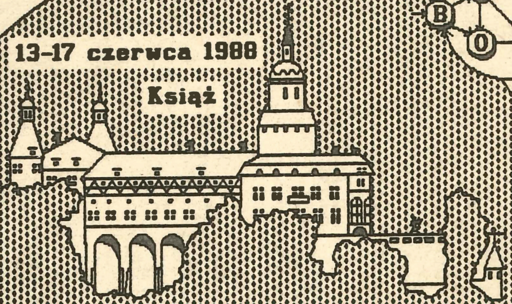

1. Krajowa Konferencja Badań Operacyjnych i Systemowych

TOM 2

BOS'88

POLSKIE TOWARZYSTWO BADAŃ OPERACYJNYCH I SYSTEMOWYCH

INSTYTUT BADAŃ SYSTEMOWYCH POLSKIEJ AKADEMII NAUK

POLSKIE TOWARZYSTWO BADAŃ OPERACYJNYCH I SYSTEMOWYCH

TOM 2

WSPOMAGANIE PODEJMOWANIA DECYZJI
MODELE I SYSTEMY

I KRAJOWA KONFERENCJA

BADAŃ OPERACYJNYCH i SYSTEMOWYCH

Książ, 13 - 17 czerwca 1988

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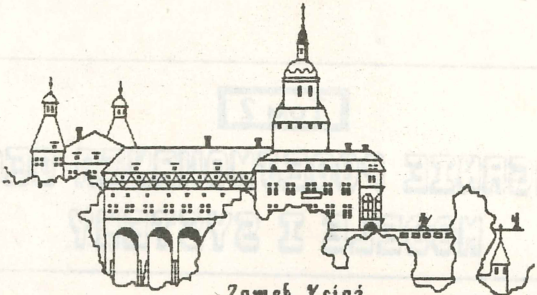

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6. Formalizacja modeli decyzyjnych

6.3

I Krajowa Konferencja
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CONTROL ALGORITHM FOR EXPERT SYSTEMS WITH A KNOWLEDGE BASE INVOLVING UNCERTAINTY.

Cezary Iwanski
Systems Research Institute,
Polish Academy of Sciences
ul. Newelska 6
01-447 Warsaw, Poland

In this paper a control algorithm (forward chaining) for a rule based Expert System in a situation when facts and rules include uncertainty is presented. It is optimal in the sense that every rule is fired only once and no bit of information is lost during the process of derivation.

1. Introduction.

When building a rule based system there arises a problem of constructing a monitor or control algorithm that specifies the execution order for all rules in the rule set. There exist many different control algorithms in a situation without uncertainty. Waterman (1986): "For example the three standard ways of executing rules are sequential, cyclic and random. The sequential monitor executes each rule in sequence and, after executing the last rule, returns.The cyclic monitor also executes the rules in the rule set in sequence; however, rather than returning when it executes the last rule, it reexecutes the first rule, and so on. The random monitor repeatedly executes the rules in the rule set by randomly choosing the next rule to execute". However, a new problem appears in a situation under uncertainty. Firing a rule (i.e. propagating and combining uncertainty as well as deriving new conclusions) is expensive because it consumes a lot of time.If we applied a standard algorithm then either a number of rules (even sequences of rules) would be multiply executed (fired) or part of information included in the Knowledge Base would not be used in the process of derivation. In the former case the execution time for an algorithm would be extended and in the latter the final result would be entirely changed. For instance, when we apply a standard algorithm which executes all fireable rules in the rule set in sequence to an example from Fig. 1, then rules r3 and r4 should be fired twice, because rule r6 "reactivates" rule r3 again. It means that rule r6 contributes to the new degree of certainty of antecedent of r3. Both new and old (i.e. obtained from rule r2) degrees of certainty should be combined and rules r3 and r4 should be fired again. In the classical case without uncertainty or in the case when after firing rule r2 the degree of certainty of antecedent of r3 would be equal to 0 or 1 it would not be necessary to execute rules r5 and r6 and again r3 and so on.

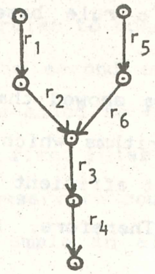


Fig. 1

In a situation under uncertainty different approaches are possible. For example in Flops Buckley et al (1986) and Siler and Tucker (1986) from all fireable rules on a given step that is fired which has the greatest "rule posterior confidence level". In the sequel with aid of command "fire" such a rule can be switched either as "disables" or "fireable". In the former case it might happen that new information significant for the antecedent of that rule would not be considered while in the latter case the execution time could be unnecessarily extended.

We shall present a quite general control algorithm (forward chaining) which chooses only relevant rules at any time and each rule is fired only once. Hence it can reach a conclusion more efficiently. This algorithm uses all information available.

2. Control algorithm for a rule based expert system under uncertainty.

In the introduction we showed that in a situation under uncertainty standard algorithms which specify the execution order for all rules are not efficient because a lot of rules can be multiply fired. Therefore, new methods should be investigated.

At the beginning we described a situation under consideration. Let us assume that the knowledge base consists of two parts: A set of facts F and a set of rules R. There are three kinds of facts "data" F_d, "subgoals" and "goals" F_g. Let F_k denote the set of all known facts i.e. the facts which are known at the beginning (the "data" type) as well as derived during the operation of the algorithm. By R_f we denote a set of fired rules. It should be emphasized that any fired rule can be reactivated and rejected from a set R_f because in order to obtain the final result we want to consider all available information from the knowledge base. Each rule has two parts: antecedent and consequence. They will be accessed through the selectors $\underline{a}(r)$ and $\underline{c}(r)$, respectively. The function $\underline{fire}(r)$ means the whole process of firing, i.e. propagating uncertainty and combining of evidence. We define the set of reactivated rules by rule r as

$$\underline{react}(r) = \{ \bar{r} : \underline{a}(\bar{r}) = \underline{c}(r) \text{ and } \bar{r} \in R_f \}.$$

First, we recall the simple forward chaining algorithm. Its operation can be explained simply as follows: Sell (1985): "Given a list of rules, the forward chainer attempts to draw all possible conclusions. It starts by examining the rule which is given. If it finds no further rules to consider, it exits. If there are more rules to consider, it takes the first one in the list, then the second and so on. If rule r is fired, a new fact c(r) is added to the list of known facts". At that point the list of fired rules R_f is reconstructed. The previous sentence is necessary to complete Sell's explanation because he gave as an example an algorithm for a situation without uncertainty.

1. $F_k := F_d$; $R_f := 0$;
2. for each rule $r \in R-R_f$ do begin

   if $\underline{a}(r) \in F_k$ then begin

   <u>fire</u>(r);

   $F_k := F_k \cup \{\underline{c}(r)\}$;

   $R_f := R_f \cup \{r\}$ - <u>react</u>(r);

   end;

   end;
3. If $R_f = R$ then goto 2;
4. Write $(F_g \cap F_k)$;
5. Stop.

The above algorithm uses all available information. Unfortunately, it has two disadvantages. First, a lot of rules can be fired many times. In the worst case, for example in the situation from Fig. 2, almost 100% rules from a rule list would be fired twice. Second, it is very difficult to find in a rule list a circular reasoning i.e. a sequence of rules such as e.g. $A \rightarrow B$, $B \rightarrow C$, $C \rightarrow A$.

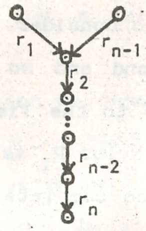


Fig. 2

If we look upon the rules as directed arcs from antecedents to consequences, the rule set can be cast as a directed acyclic graph. Let us connect with each arc (rule) a certain number id(r), the so called indegree number. We can define it simply as $\underline{id}(r) = |\{\bar{r} : \underline{c}(\bar{r}) = \underline{a}(r)\}|$. Those numbers are easy to calculate and it is not necessary to do it every time, but only if the rule set is changed. Now, we can present a new algorithm which operates in the following way: In each iteration only rules with indegree 0 are fired. The indegrees of successive rules are decreased at 1. It terminates when there are no more rules to fire.

1. Rf:=0; for each $r \in R$ calculate $\underline{id}(r)$;
2. for each rule $r \in R-R_f$ do begin

    if $\underline{id}(r) = 0$ then begin

        $\underline{fire}(r)$;

        $R_f := R_f \cup \{r\}$;

        for each $\bar{r} \in \{\bar{r} : \underline{a}(\bar{r}) = \underline{c}(r)\}$ do $\underline{id}(\bar{r}) := \underline{id}(\bar{r}) - 1$;

    end;

end;

3. if R_f=R goto 2;

4. write ($F_g \cap F_k$)

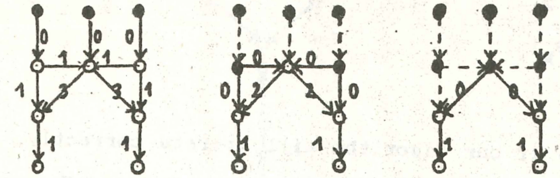
5. stop.

In order to see if our algorithm will operate correctly, let us recall the theorem from Graph Theory (Th. 3.8. in Morary et al (1965)):

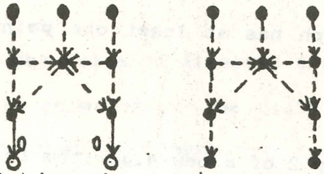
An acyclic directed graph has at least one point of indegree zero.

Roughly speaking in step 2 of a new algorithm the certain arcs are rejected. Thus as a result after each iteration we obtain a directed acyclic graph, too. It means that if our rule set is well defined then in each iteration there must exist rules with id(r)=0. In the first iteration this are all rules which have the antecedent of type "data" i.e. a(r) $\in F_d$. In spite of this, we can easily develop our algorithm and check in step 2 if there really exist rules such that id(r)=0. If not, the algorithm should terminate with a comment that there is a circular reasoning in the rule set. The function react(.) is not necessary because the rule r which is fired can not be reactivated by rules from set R-R_f. There is no rule $\bar{r}$ in the set R-R_f such that a(r)=c($\bar{r}$). Hence, each rule will be fired only once.

Let us see a simple example. The numbers written by arcs are the indegree numbers.The black nodes mean the known facts and the arcs drawn by the broken line mean fired rules in each iteration.



start standpoint 1st iteration 2nd iteration



3rd iteration 4th iteration

3. Summery.

In this paper a control algorithm for rule based Expert Systems under uncertainty is presented. The firing of rules i.e. propagating and aggregating uncertainty requires a lot of time. Applying standard algorithms some rules can be fired many times or the final result can be quite different from the one obtained when using all available information. We proposed an efficient control algorithm (forward chaining) using all available information from knowledge base. It chooses only relevant rules at any time and each rule is fired only once. This algorithm can be easily developed for more complicated cases. For instance, when not all "data" facts are known or when the rules have a more complex form e.g. antecedents are conjunctions of many facts $A_1 \cap A_2 \cap \ldots \cap A_n \rightarrow B$.

Let us notice that in case of backward chaining the above mentioned problem does not appear. When we apply the backtracking in an appropriate way then each rule will be fired only once and the whole information necessary to value a hypothesis will be considered.

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Zarząd
Polskiego Towarzystwa Badań Operacyjnych i Systemowych

Prezes
prof.dr hab.inż. Andrzej Straszak
Instytut Badań Systemowych PAN

Wiceprezes
prof.dr hab.inż. Jan Stasierski
Wojskowa Akademia Techniczna

Wiceprezes
prof.dr hab.inż. Stanisław Piasecki
Instytut Badań Systemowych PAN

Sekretarz generalny
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Instytut Badań Systemowych PAN

Sekretarz
dr inż. Jarosław Sikorski
Instytut Badań Systemowych PAN

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Instytut Informatyki UWr.

Komisja rewizyjna
PRZEWODNICZĄCY

dr Władysław Świtalski
Katedra Cybernetyki i Badań Operacyjnych UW

CZŁONKOWIE

dr inż. Janusz Kacprzyk
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