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Illustrative Examples of EXPERT SYSTEMS

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ABSTRACT

This paper will attempt to illustrate some of the concepts of expert system technology through the use of simplified examples.

OPSOMMING

Hierdie artikel poog om sommige van die konsepte van ekspertstelsels te illustreer deur middel van vereenvoudigde voorbeelde.

"Example is always more efficacious than precept"

Samuel Johnson

1. INTRODUCTION

Problem categories suitable for expert system application may be summarized as follows [1,2] :

* Analyzing, classification and interpreting,
* diagnosing and debugging,
* monitoring and control,
* design, planning and prediction, and
* training and instruction.

Practical expert systems within each of these application areas do exist [1].

The purpose of this paper is primarily to explore and illustrate the concepts and possible application areas of expert system technology, as well as the characteristics and features of some expert system development software, through the use of illustrative examples. The examples were chosen and designed with this purpose in mind and should therefore in no way be seen as fully fledged expert systems with immediate practical application. The first example is a typical classification application while the second example illustrates a diagnostic and repair recommendation application.

2. AN ANIMAL CLASSIFICATION EXPERT SYSTEM USING VP EXPERT

"To err is human, not to, animal"

Robert Frost

This example is a simplified version of one of the classical artificial intelligence classification examples [9]. The purpose of the example is mainly to serve as a vehicle for discussing and illustrating some expert system characteristics and concepts.

The goal of this expert system is to identify (classify) an unknown animal based on a question and answer dialogue between the system and the user. The knowledge domain of the system is such that only four animals may be identified i.e. a Cheetah, Tiger, Giraffe and Zebra. The knowledge base consists of only ten rules and the expertise contained in the system would probably not compare favourable with that of an eighteen month old child. Furthermore, such a child will probably solve the problem using an approach based on pattern matching while the expert system will use a search procedure.

The ten rules of the knowledge base is shown in figure 1 as IF...THEN... rules which were implemented in almost the same format using the VP Expert shell from Paperback Software.

```
RULE 1
      IF animal has hair                          THEN
         specie is mammal

RULE 2
      IF animal gives milk                        THEN
         specie is mammal

RULE 3
      IF animal eats meat                         THEN
         specie is carnivore

RULE 4
      IF animal has pointed teeth AND
                has claws                         AND
                has forward eyes                  THEN
         specie is carnivore

RULE 5
      IF specie is mammal                         AND
         animal has hooves                        THEN
         specie is ungulate

RULE 6
      IF specie is mammal                         AND
         animal chews cud                         THEN
         specie is ungulate

RULE 7
      IF specie is mammal                         AND
                is carnivore                      AND
         animal has tawny colour                  AND
                has dark spots                    THEN
         animal is cheetah

RULE 8
      IF animal has tawny colour                  AND
                has black stripes                 AND
         specie is mammal                         AND
                is carnivore                      THEN
         animal is tiger

RULE 9
      IF animal has dark spots                    AND
                has long neck                     AND
         specie is ungulate                       THEN
         animal is giraffe
RULE 10
      IF animal has black stripes                 AND
         specie is ungulate                       THEN
         animal is zebra
```

Figure 1 IF...THEN... rule base representation

Figure 2 shows very much the same knowledge, from a different perspective, as a semantic network. The knowledge in this semantic network may be implemented using a language such as Prolog. However, this knowledge representation scheme is more suited to determine whether a giraffe is a mammal or to list all the characteristics of a tiger.

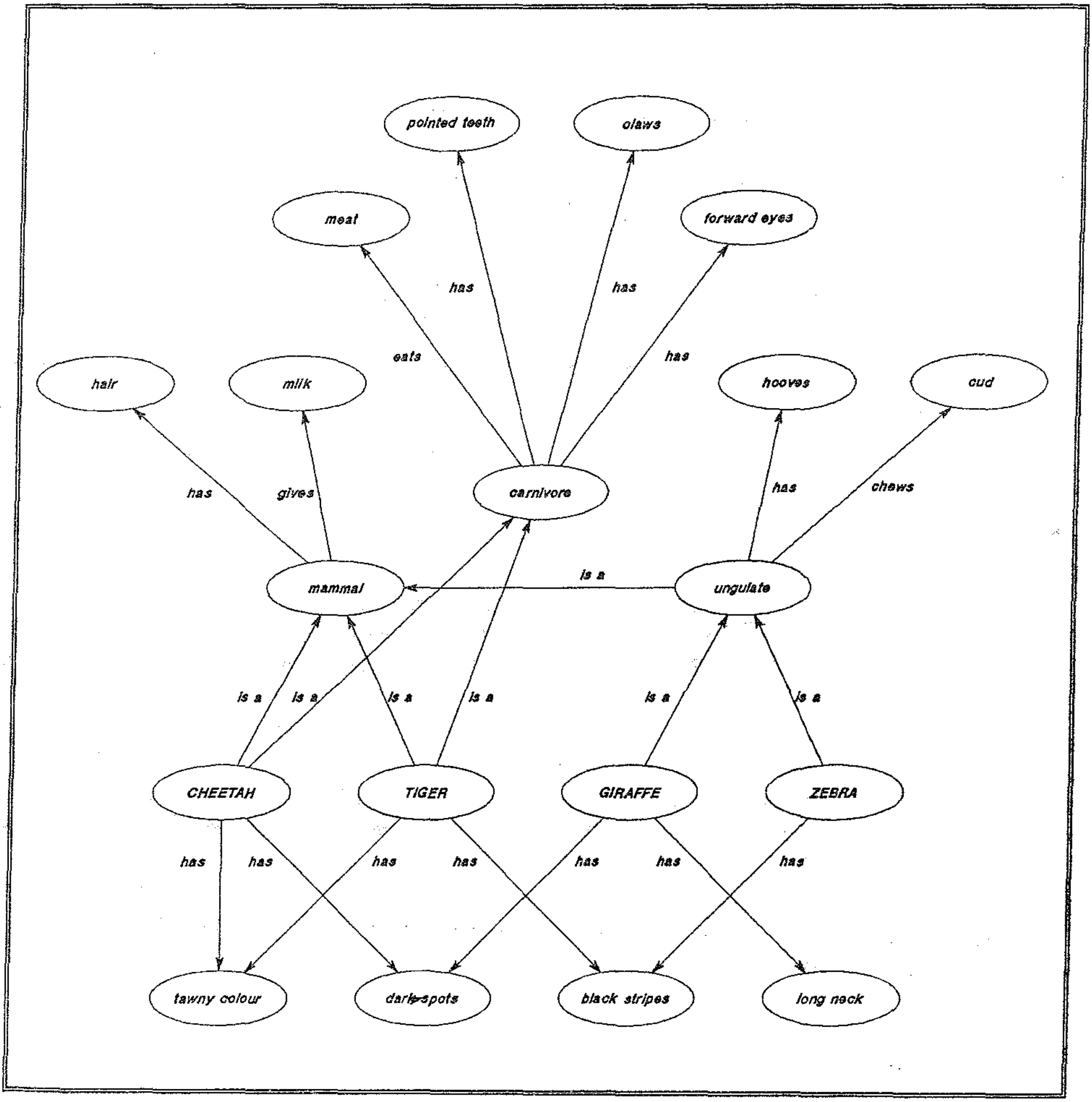


Figure 2 Semantic network knowledge base representation

With reference to the rule base in figure 1, the final goal variable is "animal" with the four possible values already mentioned, but there is also a sub-goal or intermediate goal variable, "specie", with three possible values, i.e. mammal, carnivore and ungulate. Furthermore, there are a total of twelve possible input data values. These values will be solicited from the user as and when needed by the inference engine, which in the case of VP Expert is primarily based on a

The following figures show typical dialogues between a user and the expert system based on the rule base in figure 1. The user's responses are shown in bold print.

```
          Animal Classification Example

       Press any key to start the consultation

Does the animal have hair ?
Yes
Does the animal have a tawny colour ?
              No
Does the animal have dark spots ?
Yes
Does the animal have a long neck ?
Yes
Does the animal have hooves ?
Yes

               Your animal may be a
               Giraffe

             Press any key to continue
```

Figure 3 A typical consultation

With reference to figure 3 the following remarks may be pertinent :

The expert system manages to reach a conclusion or recommendation by soliciting only five of the possible twelve pieces of information.

Superfluous questions such as, "Does the animal give milk ?", after it was already determined that the animal is a mammal, are avoided.

The backward chaining inference engine of VP Expert starts, by default, with the first rule in the rule base, which has as a conclusion one of the possible values of the goal variable. In this instance it is rule 7 with a conclusion "Cheetah". In an attempt to either prove or disprove the hypothesized goal (Cheetah), the inference engine queries the first premise, again by default, of rule 7. Since this premise (specie is mammal) is a sub-goal, the inference engine chains backward to the first rule with "mammal" as a conclusion. This is identified as being rule 1 and the question "Does the animal have hair ?" is asked. Upon receiving an affirmative response to the question, the sub-goal "mammal" is proved as being true and the inference engine goes to the second premise of rule 7. The resultant question "Does the animal have a tawny colour ?" receives a negative response, effectively disproving the goal value "Cheetah" as well as "Tiger". Therefore, the inference engine goes to rule 9, resulting in the question "Does the animal have dark spots ?" being asked. The rest of the inference path may be traced in the same manner.

Once a piece of information has been obtained, or a goal or sub-goal has been proved/disproved, this knowledge is remembered and used automatically in any subsequent situations where it may be relevant.

```
                Your animal may be a
                Giraffe

             Press any key to continue

What if the answer to variable "tawny colour" is
changed ?

Does the animal have a tawny colour ?
Yes

          Animal Classification Example

      Press any key to start the consultation

Does the animal eat meat ?
              No
Does the animal have pointed teeth ?
              No

                Your animal may be a
                Giraffe

             Press any key to continue
```

Figure 4 A "what if" consultation

The structure of a knowledge base often makes it possible to implement the capability to explore "what if" situations. Figure 4 illustrates the consequences of such a "what if" question being asked after the consultation shown in figure 3 was completed. Notice that all the information obtained in the original consultation are considered to be valid still and only the possible consequences of the changed response are evaluated.

Figure 5 illustrates the capability of the expert system to handle "don't know" responses while still being capable to reach a conclusion. This is partly due to a measure of redundancy which exists in the rule base. The reply to the "why ?" response is one type of explanation often provided by expert systems and may be much more elaborate.

Figure 6 demonstrates the expert system's reaction to conflicting information from which no valid conclusion may be reached. It also illustrates the concept of enhancing a specific conclusion with additional advice.

```
          Animal Classification Example

      Press any key to start the consultation

Does the animal have hair ?
Yes
Does the animal have a tawny colour ?
              No
Does the animal have dark spots ?
   Don't know
Does the animal have black stripes ?
Yes
Does the animal have hooves ?
   Don't know
Does the animal chew cud ?
      Why ?
The question is being asked because :
 I am trying to determine if your animal is an
 ungulate and ungulates often chews cud.
Does the animal chew cud ?
Yes

                Your animal may be a
                Zebra
             Press any key to continue
```

Figure 5 A consultation illustrating "don't know" and "why ?" responses

```
          Animal Classification Example

      Press any key to start the consultation

Does the animal have hair ?
              No
Does the animal give milk ?
Yes
Does the animal have a tawny colour ?
Yes
Does the animal have dark spots ?
              No
Does the animal eat meat ?
              No
Does the animal have pointed teeth ?
   Don't know
Does the animal have black stripes ?
              No

Not enough information is available to positively
identify your animal ! It is therefore prudent to
assume that the animal may be dangerous !

                Your animal may be a
                Strange beast
             Press any key to continue
```

Figure 6 An "unsuccessful" consultation

```
          Animal Classification Example

      Press any key to start the consultation

Does the animal have hair ?
Yes 95
Does the animal have a tawny colour ?
Yes 80
Does the animal have dark spots ?
Yes 100
Does the animal eat meat ?
Yes 50
Does the animal have black stripes ?
              No
Does the animal have a long neck ?
Yes 70
Does the animal have hooves ?
   Don't know
Does the animal chew cud ?
Yes 50

                Your animal may be a
                Cheetah CNF 45
                Giraffe CNF 39

             Press any key to continue
```

Figure 7 Confidence factors

The typical utilizing of confidence, or certainty, factors to handle uncertainty is shown in figure 7. Confidence factors may be provided as part of a response but may also be build into the knowledge base as part of the conclusion of a rule. The implied uncertainty results in more than one conclusion being reached. However, the confidence factors are used to rank the conclusions. Notice that the confidence factors assigned to the conclusions do not add up to 100, since these factors are independent measures of confidence and not true probabilities.

The knowledge domain of this classification example is extremely limited, but it should be clear that expanding the rule base is not difficult from a programming point of view. Such an expansion might easily culminate in a domain expertise which may provide useful assistance for practical decision making purposes.

A variety of Industrial Engineering applications exist which may be formulated as classification problems. For example, classification of entities (products, components, etc.) for purposes of group technology, quality assurance, maintenance, etc.

3. A BICYCLE REPAIR EXPERT SYSTEM USING PERSONAL CONSULTANT PLUS

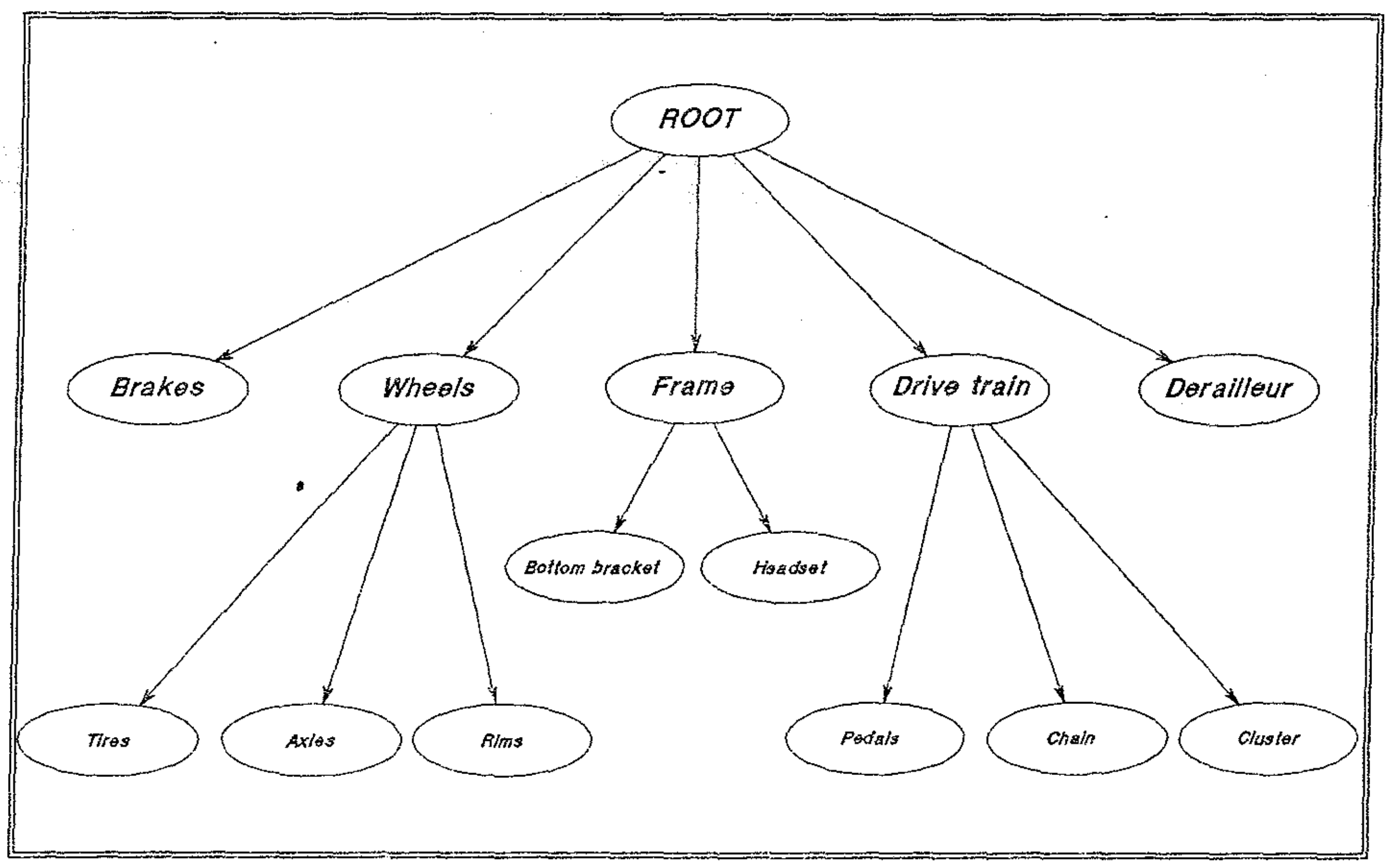
"Be to her virtues very kind;
Be to her faults a little blind;
Let all her ways be unconfin'd;
And clap your padlock - on her mind"

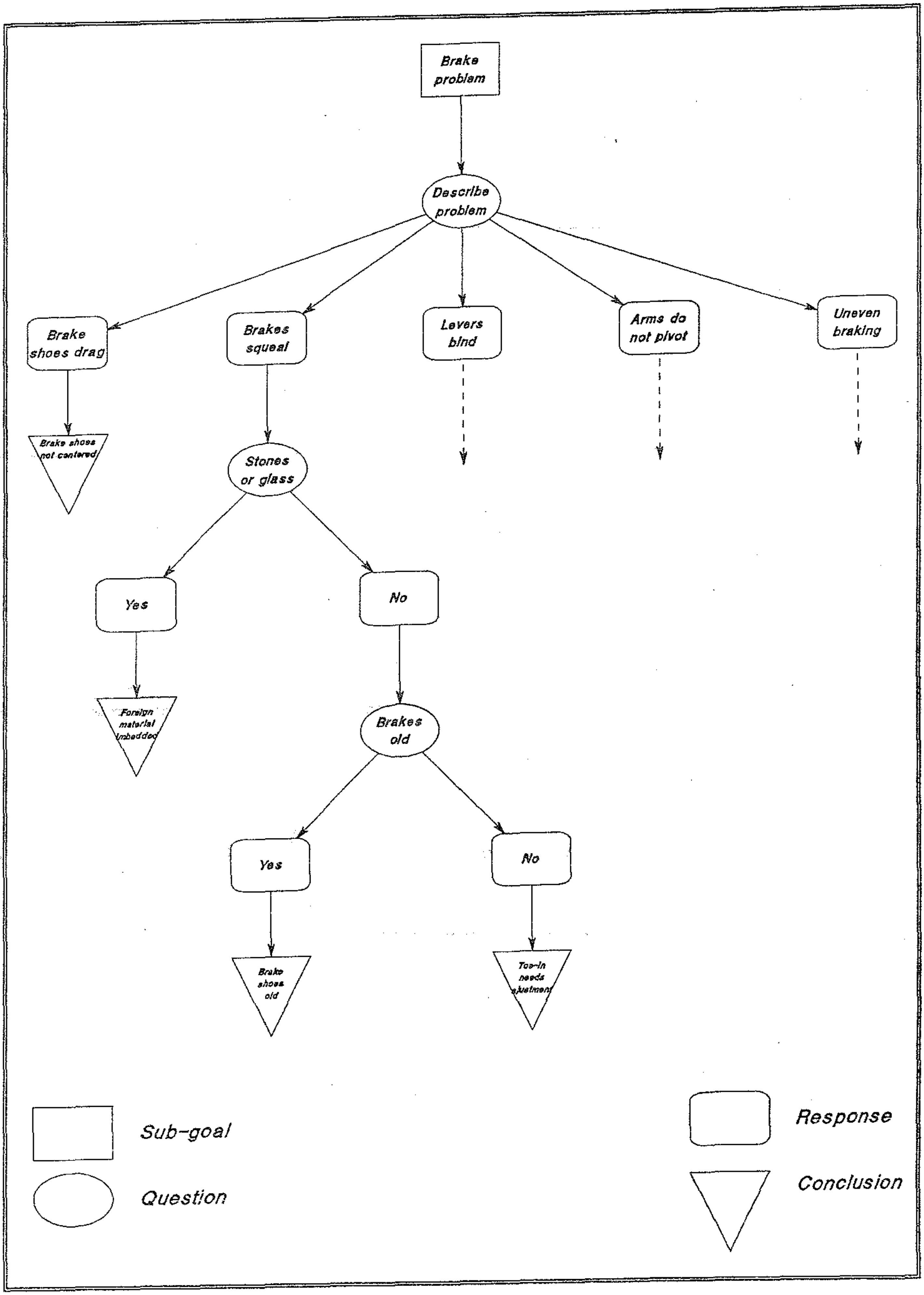
Matthew Prior

The bicycle repair expert system is a typical example of a diagnostics application. Through a question and answer dialogue with the user the system will attempt to determine the particular problem experienced and recommend an appropriate repair action. The system was developed using Personal Consultant Plus (PC Plus) from Texas Instruments and is based on an example provided with the Arity/Expert package from Arity Corporation.

P C Plus is one of the few micro-computer expert system development packages which supports the concept of frames and figure 8 displays the frame hierarchy designed for this expert system. At present only the root, brake and derailleur frames are implemented. Figure 9 shows conceptually a part of the rule set contained in the brake frame. The present system consists of a total of seventy rules organized into three rule sets, each contained in one of the frames. The rules in the root frame is responsible for determining which sub-frame should be instantiated. The rule sets in the brake and derailleur frames will attempt to identify the problem. After the problem has been identified this sub-goal will be used to recommend appropriate repair action.

Figures 10 and 11 shows the results of two typical consultations. The response of the user is shown in bold print.




Brake problem
Describe problem
Brake shoes drag
Brakes squeal
Levers bind
Arms do not pivot
Uneven braking
Brake shoes not centered
Stones or glass
Yes
No
Foreign material imbedded
Brakes old
Yes
No
Brake shoes old
Toe-in needs ajustment
Sub-goal
Question
Response
Conclusion

BICYCLE MAINTENANCE ADVISOR

This programme will attempt to help you identify the cause of problems you may experience with your bicycle.

When a problem has been identified an appropriate repair action will be recommended.

In which sub-system do you experience your problem ?

BRAKES
DERAILLEUR

You have indicated that your problem is related to the brakes of your bicycle. Do you want me to continue with this assumption ?

YES
NO

The brake problem you are experiencing is best described by :

BRAKE_SHOES_DRAG
BRAKES_SQUEAL
BRAKE_LEVERS_BIND
BRAKE_ARMS_DO_NOT_PIVOT
UNEVEN_BRAKING

Does the brake shudder or judder when the brakes are applied ?

YES
NO

Are the rims dented or otherwise out-of-round ?

YES
NO

Why :

Whether Condition of the rims is needed to determine the brake problem

RULE014

If 1) Description of the brake problem is UNEVEN_BRAKING, and
2) Brakes_shudder or judder is not true, and
3) Condition of the rims is not true

Then it is definite (100%) that The brake problem is The head bearing play on the front fork needs to be adjusted

** End - RETURN/ENTER to continue

Help :

Remove the wheel and while holding the wheel with your hands at both sides of the axle, spin the wheel rapidly. Place the side of the wheel next to a fixed object and any dents or buckles should be obvious.

** End - RETURN/ENTER to continue

The brake problem is as follows: The rim is or out-of-round.

The recommended repair action is as follows : Either gently straighten the out-of-round rim mainly by loosening or tightening the appropriate spokes. You will need a special spoke spanner and possibly a special wheel jig to perform this repair. Otherwise request a reputable repair shop to repair or replace the rim. However, if the rim is badly damaged, it may be less expensive to replace the complete wheel.

1. Use the arrow keys or first letter of item to position the cursor
2. Press RETURN/ENTER to continue

Figure 10 A typical dialogue with the Bicycle Maintenance Advisor

BICYCLE MAINTENANCE ADVISOR

This programme will attempt to help you identify the cause of problems you may experience with your bicycle.

When a problem has been identified an appropriate repair action will be recommended.

In which sub-system do you experience your problem ?

BRAKES
DERAILLEUR

You have indicated that your problem is related to the derailleur, i.e. the gear shifting levers, front and back shifting jockeys, etc., of your bicycle. Do you want me to continue with this assumption ?

YES
NO

The derailleur problem you are experiencing is best described by :

GEAR_CHANGES_WHILE_RIDING
CRANK_TURNS_BUT_NOT_WHEEL
GEAR_SHIFTING
CHAIN_PROBLEM

The chain problem you are experiencing is best described by :

CHAIN_RIDES_LARGE_REAR_SPROCKET
CHAIN_RUNS_OFF_SMALL_REAR_SPROCKET
CHAIN_SKIPS_WHILE_PEDALLING
CHAIN_SLIPS_FROM_SMALL_FRONT_CHAINWHEEL
CHAIN_SLIPS_FROM_LARGE_FRONT_CHAINWHEEL
CHAIN_RATTLES_OR_RUBS_AGAINST_JOCKEY

Is the chain too long ?

YES
NO

Are there burrs on the teeth of the freewheel gear cluster ?

YES
NO

Does the chain or gears show excessive wear ?

YES
NO

Has a new chain recently been installed ?

YES
NO

The derailleur problem is as follows : Insufficient chain tension

The recommended derailleur repair action is as follows : The chain tension may be adjusted by tightening the tension spring of the back derailleur tension sprockets. The particular procedure depends on the type of derailleur. Cleaning the back derailleur may alleviate the problem. Shortening the chain may also help but may cause shifting problems

Figure 11 A typical dialogue with the Bicycle Maintenance Advisor

```
Commands :
CONTINUE
HOW
TRACE ON
PRINT CONCLUSIONS
REVIEW
SAVE PLAYBACK FILE
NEW START
QUIT

Determine bike problem class :: (DERAILLEUR 100 RULE002)
Determined to be : DERAILLEUR
 ... by using RULE002

If the bike problem description is DERAILLEUR,
Then 1) It is definite (100%) Determine bike problem class
        is DERAILLEUR, and
     2) Instantiate the frame Determine derailleur related
        problems if appropriate

The derailleur problem :: ("Insufficient chain tension"
                                            100 RULE 035

Determined to be : Insufficient chain tension
 ... by using RULE035

If 1) Description of the derailleur problem is
      CHAIN PROBLEM, and
   2) The chain problem description is
      CHAIN SKIPS WHILE PEDALLING, and
   3) Chain too long is not true, and
   4) Burrs on the teeth of the freewheel gear is not
      true, and
   5) Excessive wear on chain or gears is not true, and
   6) New chain installed is not true,

Then it is definite (100%) that the derailleur problem
is Insufficient chain tension.

The recommended derailleur repair ac .. :: ("The chain tens

Determined to be : The chain tension may be adjusted ....

by using RULE057

If The derailleur problem is Insufficient chain tension.

1. Use the arrow keys or first letter of item to position the cursor
2. Press RETURN/ENTER to continue
```

Figure 11 A typical dialogue with the Bicycle Maintenance Advisor (continued)

With reference to figure 10, it is obvious that an attempt is made very early in the consultation to direct the inference engine to that part of the knowledge base which is most likely to be able to identify the problem. This strategy enhances the effectiveness of the inference engine and is easy to implement if the frame concept is used. Figure 10 also illustrates the "why" and "help" facilities. "Help" facilities may be added to any variable (question) and may include graphics. Figure 11 illustrates the explanation provided after completion of a consultation. The text provided by PC Plus in response to, for example, "why" and "how" requests is automatically synthesized from so called translations provided by the user when defining each variable.

A large number of diagnostic applications may be identified and the structure of such applications will probably be similar to the structure used in the Bicycle Maintenance Advisor.

4. CONCLUSIONS

The examples illustrate, to some extend, only two of the problem categories identified in the introduction. Furthermore, only a fraction of the capabilities of the relevant development software was used. This is especially true for PC Plus which provides a wide variety of sophisticated facilities. Although both examples were developed primarily for illustrative purposes, it should be clear that they may be expanded and enhanced with relative ease to provide practical decision support.

================

REFERENCES

1. FRENZEL L E, 1987, "Understanding Expert Systems", Howard W Sams and Company.
2. FRENZEL L E, 1987, "Crash Course in Artificial Intelligence and Expert Systems", Howard W Sams and Company.
3. Personal Consultant Plus Reference Guide, 1987, Texas Instruments Incorporated.
4. Personal Consultant Getting Started, 1987, Texas Instruments Incorporated.
5. SHEPARD S J, 1988, "Sophisticated Expert", PC Tech Journal, vol 6, no 7, July 1988.
6. The Arity/Expert Development Package, 1986, Arity Corporation.
7. Turbo Prolog Owner's Handbook, 1986, Borland International Incorporated.
8. VP Expert User Manual, 1987, Paperback Software.
9. WINSTON P H, 1977, "Artificial Intelligence" Addison Wesley Publishing Company.