A Comparison of Three Different Methods for Acquiring Knowledge about Virological Hepatitis Tests[1]

Petr Berka[2]

Austrian Research Institute for Artificial Intelligence
Schottengasse 3, A-1010 Vienna, Austria
e-mail: berka@ai.univie.ac.at

Abstract

We present a comparison of Knowledge Seeker, CN2 and Knowledge EXplorer based on a real problem domain, interpretation of virological hepatitis tests. The problem domain can be divided into 6 subdomains, where the knowledge can be acquired separately. Unlike classical machine learning problems the goal classes are not mutually exclusive. The information how to classify contradictory examples was not available for the systems during learning. So the key question was how the systems handle ambiguity in data. Although each system uses different approach, there was no significant difference in the results of testing of acquired rules done for each subdomain separately.

Testing in the whole hepatitis domain was done only for Knowledge EXplorer because only this system can predict multiple classes. The results of testing are poorer then results obtained in the separate subdomains but can be improved by using some additional expert's knowledge.

[1]This work was done in cooperation with the Department of Virology of the University of Vienna, providing the hepatitis database.

[2]Address for correspondence:
Dept. of Information and Knowledge Engineering, Prague University of Economics,
W. Churchill Sq. 4, 130 67 Prague, CR
e-mail: berka@nb.vse.cs

1 Introduction

To evaluate the possibility of automated knowledge acquisition in the virological domain, the problem of hepatitis was selected. This is a good defined problem, where three types of hepatititis, HAV, HB and HCV are evaluated according to six tests: AAK, AGM, CAK, HCK, SAG, SAK. The hepatitis problem domain can even be divided into three independent subdomains:

- HAV depends only on AAK and AGM,
- HB depends only on CAK, SAG and SAK,
- HCV depends only on HCK.

The classes to be learned can be divided into two groups:

- statements about diagnoses,
- statements about further treatments (recommendations of next tests).

So the data can be divided into six subsets schematically shown as follows:

```
       HAV      HB      HCV
  |        |        |        |
--|--------|--------|--------|------
  |        |        |        |
  |        |        |        |   diagnoses
  |        |        |        |
  |        |        |        |
--|--------|--------|--------|------
  |        |        |        |
  |        |        |        |   recommendations
  |        |        |        |
  |        |        |        |
--|--------|--------|--------|------
  |        |        |        |
```

The values of test results of all six tests are given in form of linguistic variables with following meaning:

```
p  positive (5,=,p)
n  negative (2,=,n)
l  extremely negative (2,<,g)
g  extremely positive (5,<,g)
X  not measured
```

The list of all 32 classes is shown in the Appendix A.

The task is to find rules which can be used for consultation about hepatitis A, B and C diagnosis for a new patient. More than one diagnostic statement can be valid for a single case (e.g. *not imun* and *no infection*). This is complicated by the fact, that sometimes the expert is interested in the infection, sometimes in the immunity of an pacient. It depends on the aditional information, the clinical problem solved during the consultation. This information has not been used during learning.

2 Data preprocessing

From the original data set only examples with results for the tests AAK, AGM, CAK, HCK, SAG and SAK were selected. Then we eliminate examples with wrong type of virus and some examples marked by the expert. Thus we obtained 4339 examples which were divided into training set (first 1000 objects) and a testing set (the rest 3339 objects).

Both training and testing set were then divided into 6 subsets according to the subdomain as described above (HAV diagnosis, HAV recommendation, HB diagnosis, HB recommendation, HCV diagnosis, HCV recommendation). In every subset only corresponding input attributes were used. If no diagnostic statement was given for an example within specific subset, this example was assigned to the class *36 (no statement)*. The number of such "unclassified" examples was usually very high:

	HAV_d	HB_d	HCV_d	HAV_r	HB_r	HCV_r
unclassified	336	308	912	998	926	221

Further preprocessing was done to unify the coding of resulting diagnoses and to remove the code of clinical problem.

3 Knowledge acquisition

The systems were running for each of the six subsets separately. We use standard setting of parameters in all three systems, so no aditional background knowledge was used.

We will demostrate the functionality of every system on the HAV diagnosis subset. In this domain only the tests *AAK* and *AGM* are used as input attributes. Relevant diagnoses are:

```
a  1/HAV  Infection A
b  3/HAV  Immune A
c  6/HAV  Not Immune A
d 15/HAV  No Infection A
p   36    No statement
```

3.1 KnowledgeSeeker

KnowledgeSeeker is a TDIDT family system distributed by FirstMark Technologies Ltd. [7]. The algorithm can work with both symbolic and numeric data, it performes non incremental multiple concept learning. The system induces decision tree but allows to transform it into rules either in generic form or in Prolog. The Prolog rules can be used for consultation.

KnowledgeSeeker recursively splits each subset (node) into k new nodes starting with all observations at the initial node. This process continues until no more significant splits can be found. At each node all predictor (input) variables are considered in turn as candidates to split the node. The 'best' k-way split of each variable is found, then the significance of that split is used to rank variables on how well they split the node.

The decision tree for HAV_d domain looks like follows:

```
              Legend
              ------
              diagnosis breakdown    --------
              a                      |  1.0%|
              b                      | 39.8%|
              c                      |  1.1%|
              d                      | 24.5%|
              p                      | 33.6%|
              total                  |1000  |
                                     |------|
                                       AGM
                   |-----------------------------|----------|
                   X                             n          p
                   g                          --------   --------
                --------                      |  0.0%|   |100.0%|
                |  0.0%|                      | 56.6%|   |  0.0%|
                |  2.7%|                      |  0.4%|   |  0.0%|
                |  2.7%|                      | 35.3%|   |  0.0%|
                |  0.7%|                      |  7.7%|   |  0.0%|
                | 94.0%|                      |689   |   |10    |
                |301   |                      |------|   |------|
                |------|                        AAK
                  AAK                  |----------|----------|
         |----------|----------|       g          n          p
         X          n          p       X       --------   --------
     --------   --------   --------   -------- |  0.0%|   |  0.0%|
     |  0.0%|   |  0.0%|   |  0.0%|   |  0.0%| |  0.0%|   | 91.1%|
     |  0.4%|   |  0.0%|   | 70.0%|   |  0.0%| |  1.2%|   |  0.0%|
     |  0.0%|   | 61.5%|   |  0.0%|   |  0.0%| | 91.7%|   |  1.4%|
     |  0.0%|   | 15.4%|   |  0.0%|   | 66.7%| |  7.1%|   |  7.5%|
     | 99.6%|   | 23.1%|   | 30.0%|   | 33.3%| |252   |   |428   |
     |278   |   |13    |   |10    |   |9     | |------|   |------|
     |------|   |------|   |------|   |------|
```

In every node, relative number of examples for every goal class is given. The last number in every node is the number of covered examples. From this tree, Knowledge Seeker creates so called *generic rules* which corresponds to paths from the root to the leaves. In the THEN part of a rule, only goals with nonzero number of covered examples appear. Multiple conclusions in one rule indicate contradictory examples in the training set.

```
RULE_1  IF
         AGM = X or g
         AAK = X
THEN     Diagnosis = b        0.4%
         Diagnosis = p       99.6%
```

```
RULE_2  IF
         AGM = X or g
         AAK = n
THEN     Diagnosis = c      61.5%
         Diagnosis = d      15.4%
         Diagnosis = p      23.1%

RULE_3  IF
         AGM = X or g
         AAK = p
THEN     Diagnosis = b      70.0%
         Diagnosis = p      30.0%

RULE_4  IF
         AGM = n
         AAK = g or X
THEN     Diagnosis = d      66.7%
         Diagnosis = p      33.3%

RULE_5  IF
         AGM = n
         AAK = n
THEN     Diagnosis = c       1.2%
         Diagnosis = d      91.7%
         Diagnosis = p       7.1%

RULE_6  IF
         AGM = n
         AAK = p
THEN     Diagnosis = b      91.1%
         Diagnosis = d       1.4%
         Diagnosis = p       7.5%

RULE_7  IF
         AGM = p
THEN     Diagnosis = a     100.0%
```

Notice the disjunction of values for the tests. KnowledgeSeeker makes this grouping during tree creation.

The Prolog rules are created for *each node* in the tree. So consultation can be done even for examples with some missing input values:

```
ks_rule_base(rule(1, [cond(AGM='X  '; AGM='g  ')], 'p  ')).
ks_rule_base(rule(2, [cond(AGM='X  '; AGM='g  '), cond(AAK='X  ')], 'p  ')).
ks_rule_base(rule(3, [cond(AGM='X  '; AGM='g  '), cond(AAK='n  ')], 'c  ')).
ks_rule_base(rule(4, [cond(AGM='X  '; AGM='g  '), cond(AAK='p  ')], 'b  ')).
ks_rule_base(rule(5, [cond(AGM='n  ')], 'b  ')).
```

```
ks_rule_base(rule(6, [cond(AGM='n  '), cond(AAK='+  '; AAK='X  ')], 'd  ')).
ks_rule_base(rule(7, [cond(AGM='n  '), cond(AAK='n  ')], 'd  ')).
ks_rule_base(rule(8, [cond(AGM='n  '), cond(AAK='p  ')], 'b  ')).
ks_rule_base(rule(9, [cond(AGM='p  ')], 'a  ')).
ks_rule_base(rule(10, [], 'b  ')).
```

In this rules, the ambiguity dissapears, since only the most frequent goal category is used as the conclusion. The last rule corresponds to the root of the tree (*default rule*), so during consultation every example is classified. The Prolog rules can be used for consultations with inference mechanism supplied by the system. When consulting for the case $AAK = n$ & $AGM = n$, the result will be *d (15/HAV)* (from the rule no. 7).

3.2 CN2

CN2 is a system of the AQ family [4]. It induces decision rules from given examples. The system performes non incremental multiple concept learning. Unlike standard AQ, CN2 can work with noisy data.

CN2 works in an iterative way each step generating a rule and then removing the examples the rule covers from the training set. In each iteration the system searches for a complex (rule) covering a large number of remaining examples of a single class C and few of other classes. This process stops when no more satisfactory complexes can be found. The system searches for complexes by carrying out a pruned general-to-specific search. A complex is specialized by either adding a new conjunctive term or removing a disjunctive element in one of its selectors.

CN2 creates unordered or ordered set of rules. Unordered rules require some numerical confidence measure to handle possible clashes. Within an ordered list of rules clashes cannot occur, because each rule in the list has precedence on all subsequent rules.

The system generates decision rules for each class separately. When learning ordered set of rules the class predicted by each rule is the majority class among the covered examples. When learning unordered set of rules, a rule, which gives better then average prediction of a rare-occurring class can be created, too. So the resulting knowledge base can contain contradictory rules:

```
 *UNORDERED-RULE-LIST*

IF    SER_ELH_AGM = p
THEN  Diagnosis = 1/HAV  [10 0 0 0 0]

IF    SER_ELH_AAK = p
  AND SER_ELH_AGM = n
THEN  Diagnosis = 3/HAV  [0 390 0 6 32]

IF    SER_ELH_AAK = p
  AND SER_ELH_AGM = X
THEN  Diagnosis = 3/HAV  [0 7 0 0 2]
```

```
IF    SER_ELH_AAK = n
  AND SER_ELH_AGM = X
THEN  Diagnosis = 6/HAV  [0 0 8 2 3]

IF    SER_ELH_AAK = n
  AND SER_ELH_AGM = n
THEN  Diagnosis = 6/HAV  [0 0 3 231 18]

IF    SER_ELH_AAK = n
  AND SER_ELH_AGM = n
THEN  Diagnosis = 15/HAV  [0 0 3 231 18]

IF    SER_ELH_AAK = g
THEN  Diagnosis = 15/HAV  [0 0 0 5 2]

IF    SER_ELH_AAK = X
  AND SER_ELH_AGM = n
THEN  Diagnosis = 15/HAV  [0 0 0 1 1]

IF    SER_ELH_AAK = X
  AND SER_ELH_AGM = X
THEN  Diagnosis = 36  [0 1 0 0 277]

IF    SER_ELH_AGM = g
THEN  Diagnosis = 36  [0 0 0 0 1]

IF    SER_ELH_AAK = X
  AND SER_ELH_AGM = n
THEN  Diagnosis = 36  [0 0 0 1 1]

(DEFAULT) Diagnosis = 3/HAV  [10 398 11 245 336]
```

The list of numbers in the square brackets gives (for each class) the number of examples covered by the rule.

When consulting for the case $AAK = n$ & $AGM = n$, the result will be *15/HAV* (from the rule no. 6).

3.3 Knowledge EXplorer

Knowledge EXplorer has been developed at the Prague School of Economics [1, 6]. The system performs symbolic empirical multiple concept learning from examples, where the induced concept description is of the form of weighted decision rules. The algorithm can deal with noisy data, unknown values, redundancy and contradictions.

Knowledge EXplorer works in an iterative way each iteration testing and expanding an implication $Ant \Longrightarrow C^*$. This process starts with "default rule" with weight computed from the relative frequency of C^* in data and stops after testing all implications which were created according to user defined criteria. The implications are evaluated according to decreasing frequency of Ant, so most reliable implications are tested first. During testing, the validity (conditional probability $P(C^*/Ant)$) of an implication is computed. If this validity significantly differs from the composed weight (value obtained when composing weights of all subrules of the implication $Ant \Longrightarrow C^*$), then this implication is added to the knowledge base. The weight of this new rule is computed from the validity and the composed weight using inverse composing function. For composing weights PROSPECTOR's [5] combining function is used. During expanding, new implications are created by adding single categories to Ant.

Unlike AQ-like systems, Knowledge EXplorer does not remove covered examples from the training data set. So more than one rule can be learned for the same class from an example.

Knowledge EXplorer displays the weighted rules together with the number of examples which fulfil the left-hand side, the number of examples which fulfil the right-hand side of the rule and with the number of examples which fulfil both sides of the rule. So the last number corresponds to the number given by CN2.

```
                    GENERATED RULES
           Frequencies
 no.    left  right  both   Weight   Implication
----------------------------------------------------------------------
   1  1000     10     10   0.0250   0-   ==>  7a
   2  1000    398    398   0.6237   0-   ==>  7b
   3  1000     11     11   0.0275   0-   ==>  7c
   4  1000    245    245   0.5281   0-   ==>  7d
   5  1000    336    336   0.5850   0-   ==>  7p
   6   689     10      0   0.0275   2n   ==>  7a
   7   689    398    390   0.6184   2n   ==>  7b
   8   689     11      3   0.2802   2n   ==>  7c
   9   689    245    243   0.5680   2n   ==>  7d
  10   689    336     53   0.1445   2n   ==>  7p
  11   448     10     10   0.6974   1p   ==>  7a
  12   448    398    397   0.8873   1p   ==>  7b
  13   448     11      0   0.0380   1p   ==>  7c
  14   448    245      6   0.0300   1p   ==>  7d
  15   448    336     35   0.1469   1p   ==>  7p
  16   428     10      0   0.4112   1p2n   ==>  7a
  17   428    398    390   0.4458   1p2n   ==>  7b
  18   428     11      0   0.7290   1p2n   ==>  7c
  19   428    245      6   0.4436   1p2n   ==>  7d
  20   428    336     32   0.8487   1p2n   ==>  7p
  21   300     10      0   0.0610   2X   ==>  7a
  22   300    398      8   0.0413   2X   ==>  7b
  23   300     11      8   0.7164   2X   ==>  7c
  24   300    245      2   0.0149   2X   ==>  7d
```

25	300	336	282	0.9479	2X ==> 7p
26	280	10	0	0.0651	1X ==> 7a
27	280	398	1	0.0054	1X ==> 7b
28	280	11	0	0.0594	1X ==> 7c
29	280	245	1	0.0080	1X ==> 7d
30	280	336	278	0.9937	1X ==> 7p
31	265	10	0	0.0685	1n ==> 7a
32	265	398	0	0.0011	1n ==> 7b
33	265	11	11	0.8037	1n ==> 7c
34	265	245	233	0.9163	1n ==> 7d
35	265	336	21	0.1491	1n ==> 7p
36	252	10	0	0.9738	1n2n ==> 7a
37	252	398	0	0.3935	1n2n ==> 7b
38	252	11	3	0.4050	1n2n ==> 7c
39	252	245	231	0.5305	1n2n ==> 7d
40	252	336	18	0.8390	1n2n ==> 7p
41	13	10	0	0.9968	1n2X ==> 7a
42	13	398	0	0.9979	1n2X ==> 7b
43	13	11	8	0.9153	1n2X ==> 7c
44	13	245	2	0.7711	1n2X ==> 7d
45	13	336	3	0.1936	1n2X ==> 7p
46	10	10	10	0.9987	2p ==> 7a
47	10	398	0	0.0293	2p ==> 7b
48	10	11	0	0.6388	2p ==> 7c
49	10	245	0	0.0428	2p ==> 7d
50	10	336	0	0.0343	2p ==> 7p
51	9	10	0	0.9353	2X1p ==> 7a
52	9	398	7	0.9168	2X1p ==> 7b
53	9	11	0	0.9517	2X1p ==> 7c
54	9	245	0	0.9906	2X1p ==> 7d
55	9	336	2	0.1930	2X1p ==> 7p
56	2	10	0	0.9998	1X2n ==> 7a
57	2	398	0	0.9448	1X2n ==> 7b
58	2	11	0	0.9972	1X2n ==> 7c
59	2	245	1	0.9946	1X2n ==> 7d
60	2	336	1	0.0552	1X2n ==> 7p

0 in the rule denotes default, 1 denotes AAK, 2 denotes AGM and 7 denotes the diagnosis. Knowledge EXplorer creates for every goal category a single rule, so in HAV_d domain a group of 5 rules with the same left-hand side corresponds to one rule created by CN2. Since weights are not relative frequencies, the sum of the weights within such a group of rules does not equal to 1. So *more then one goal concept* can be predicted during consultation.

The acquired knowledge base can be used for consultation or testing. In both cases weights of *all* classes are computed for the given case using PROSPECTOR combining function: $x \oplus y = (x * y)/(x * y + (1 - x) * (1 - y))$.

The resulting weights are in the range $< 0, 1 >$. *Weight* $=$ 0.5 indicates *undecided*, *weight* $>$ 0.5 indicates *class predicted* and *weight* $<$ 0.5 indicates *class not predicted.* For a single example, resulting weight can be greater than 0.5 for more then one class. During consultation, *all such classes* are given out as the result, during testing *the class with highest weight* is the predicted result.

When consulting for the case $AAK = n$ & $AGM = n$, using rules (1-5) (default rule), (6-9), (31-35) and (35-40), the resulting weights of all classes will be

```
   no. goal   weight   object
--------------------------------------------------------------------------
    1.  7a    0.0020   nn?????
     .  7b    0.0019    . . .
     .  7c    0.0298    . . .
     .  7d    0.9479    . . .
     .  7p    0.1786    . . .
```

So in this case the predicted concept will be *d (15/HAV)* both during consultation and testing.

Using Knowledge EXplorer we have created a second, *alternative knowledge base.* This knowledge base differs from the standard one described above in three user defined criteria which may better correspond to decision making done by expert:

1. only rules for all tests within the domain are created ("full length" rules),
2. only rules for nonzero number of examples are created,
3. the default rule is not used.

Because of (1) and (3) the resulting knowledge base will now consist of *independent* rules, each corresponding to one (or group of same) examples.
We present the rules learned in the HAV_domain in more legible form:

```
RULE   1:   IF    AAK  ==  positive
             AND  AGM  ==  negative
          THEN    Diagnosis  ==   3/HAV      (0.9445)
                  Diagnosis  ==  15/HAV      (0.0350)
                  Diagnosis  ==  36          (0.1869)

RULE   2:   IF    AAK  ==  not measured
             AND  AGM  ==  not measured
          THEN    Diagnosis  ==   3/HAV      (0.0090)
                  Diagnosis  ==  36          (0.9978)

RULE   3:   IF    AAK  ==  negative
             AND  AGM  ==  negative
          THEN    Diagnosis  ==   6/HAV      (0.0298)
                  Diagnosis  ==  15/HAV      (0.9479)
                  Diagnosis  ==  36          (0.1786)
```

```
RULE   4:   IF    AAK  ==  negative
             AND  AGM  ==  not measured
          THEN    Diagnosis  ==   6/HAV      (0.7596)
                  Diagnosis  ==  15/HAV      (0.3846)
                  Diagnosis  ==  36          (0.5192)

RULE   5:   IF    AGM  ==  positive
             AND  AAK  ==  positive
          THEN    Diagnosis  ==   1/HAV      (0.9524)

RULE   6:   IF    AGM  ==  not measured
             AND  AAK  ==  positive
          THEN    Diagnosis  ==   3/HAV      (0.8611)
                  Diagnosis  ==  36          (0.5139)

RULE   7:   IF    AAK  ==  extremely positie
             AND  AGM  ==  negative
          THEN    Diagnosis  ==  15/HAV      (0.8214)
                  Diagnosis  ==  36          (0.5536)

RULE   8:   IF    AAK  ==  not measured
             AND  AGM  ==  negative
          THEN    Diagnosis  ==  15/HAV      (0.6875)
                  Diagnosis  ==  36          (0.6875)

RULE   9:   IF    AGM  ==  extremely positive
             AND  AAK  ==  positive
          THEN    Diagnosis  ==  36          (0.6667)
```

During consultation, only one rule (group of rules with the same left-hand side) will be applicable for an example and the resulting weights of all classes will correspond to weigths in the rule (or to 0.5 if the class does not appear in the rule). In our case, the predicted class is again *d (15/HAV)* (with the weight 0.9479 from the rule no. 3).

3.4 Summary of the learning step

All three systems can work with noisy data and contradictions. The created rules contain this information; Knowledge Seeker and Knowledge EXplorer in the form of multiple conclusions in the rules (this is always done), CN2 may create "contradictory" rule for rare occurred examples (done if such rule gives better then average prediction).

Neither Knowledge Seeker, nor CN2 use this information during consultations. Both systems assign a contradictory example to the majority class. Knowledge EXplorer's inference mechanism computes weights for *all clases*, so it can assign a contradictory example to more than one class. In the HAV_d domain the class *no statement (36)* will be very often predicted together with another diagosis (see rules 4, 6, 7, 8 in the alternative knowledge base). An example of more interesting multiple diagnosis rule is taken from the HB_d domain:

```
RULE  19:   IF    CAK  ==  extremely positive
             AND  SAK  ==  extremely positive
             AND  SAG  ==  negative
          THEN    Diagnosis  ==   3/HB      (0.5982)
                  Diagnosis  ==  15/HB      (0.5179)
                  Diagnosis  ==  26/HB      (0.5179)
                  Diagnosis  ==  36         (0.6786)
```

where 3/HB stands for *immune B*, 15/HB stands for *no infection B* and 26/HB stands for *possibly immune B*. During consultation, the result will be *all four diagnoses*, during testing, the result will be *36*. The question of contradictions or multiple diagnoses has to be solved by additional analysis. In the hepatitis domain, this can be done using information about clinical problem.

During consultation, only one rule is activated in Knowledge Seeker or CN2 whereas Knowledge EXplorer combines (running standard knowledge base) a number of applicable rules using PROSPECTOR like inference mechanism.

Using Knowledge EXplorer we learn two different knowledge bases. The *alternative* knowledge base is very modular, transparent and easy to update since the rules do not interact. When consulting, "perfect match" is required, so some examples may be left unclassified. This indicates a missing rule which can be (after verification by expert) simply added to the knowledge base. So knowledge base actualisation in this case does not require learning from an expanded training set.

4 Testing

Testing was done using 3339 examples, not seen during learning phase. At first, we test in the six domains separately. The results are given as relative number of correctly classified examples. We will again describe in more details the results for the HAV_d domain.

4.1 Knowledge Seeker

RESULTS OF TESTING

Value	Right		Wrong		Total
b	1252	99.44 %	7	0.56 %	1259
p	988	80.52 %	239	19.48 %	1227
d	761	96.33 %	29	3.67 %	790
a	37	100.00 %	0	0.00 %	37
c	12	46.15 %	14	53.85 %	26
Altogether	3050	91.34 %	289	8.66 %	3339

For each class found in data, the number of correct and incorrect classifications is given in the table.

4.2 CN2

PREDICTED						
ACTUAL	_1_HAV	_3_HAV	_6_HAV	_15_HAV	_36	Accuracy
_1_HAV	37	0	0	0	0	100.0 %
_3_HAV	1	1251	0	5	2	99.4 %
_6_HAV	0	1	12	13	0	46.2 %
_15_HAV	0	16	9	761	4	96.3 %
_36	1	110	10	106	1000	81.5 %

Overall accuracy: 91.7 %

Default accuracy: 37.7 %

The number in row i, column j is the number of examples classified as class j which really belongs to class i. Default accuracy is the accuracy of the default rule (all examples classified to most frequent class).

4.3 Knowledge EXplorer

We present testing results for the standard knowledge base (first table) and for the alternative knowledge base (second table).

RESULTS OF RULE BASE TESTING

pred	total		from which		total	from which	
	abs	rel	true	false		true	false
7a	39	1%	37	2	100%	95%	5%
7b	1398	42%	1253	145	100%	90%	10%
7c	31	1%	12	19	100%	39%	61%
7d	872	26%	756	116	100%	87%	13%
7p	999	30%	992	7	100%	99%	1%
Total	3339	100%	3050	289	100%	91%	9%
not decided	0	0%	**				
not predict.	0	0%	**				
Total	3339	100%	3050	289	100%	91%	9%

RESULTS OF RULE BASE TESTING

pred	total		from which		total	from which	
	abs	rel	true	false		true	false
7a	39	1%	37	2	100%	95%	5%
7b	1377	41%	1250	127	100%	91%	9%
7c	31	1%	12	19	100%	39%	61%
7d	878	26%	759	119	100%	86%	14%
7p	1011	30%	1003	8	100%	99%	1%
Total	3336	100%	3061	275	100%	92%	8%
not decided	0	0%	***				
not predict.	3	0%	***				
Total	3339	100%	3061	275	100%	92%	8%

For every learned class (a row in the table) the number of classifications done by the system and the number of correct classifications is given. Some examples in the testing set may be unclassified; either all resulting weights were in the range $< 0.45, 0.55 >$ (the row "not decided" in the table), or there was no applicable rule in the knowledge base (the row "not predict." in the table)[3]. The resulting performance of the system is given in the row "Total".

4.4 Summary of partial test results

The tables below summarises for every domain the results (number of generated rules, successfulness of testing) of all three systems. Percentages in brackets are the results of testing in training data. The umber of rules generated by Knowledge Seeker is given in the form *number_of_Prolog_rules (number_of_generic_rules)*, the umber of rules generated by Knowledge EXplorer is given in the form *total_number (number_of_different_left-hand_sides)*, so the first number is the number of rules used by the inference mechanism.

HAV diagnosis

	Rules Generated	Correct Classifications	Incorrect Classifications	Not Classified
KnowledgeSeeker	10 (7)	91.3% (92.9%)	8.7% (7.1%)	0.0% (0.0%)
CN2	12	91.7% (93.0%)	8.3% (7.0%)	0.0% (0.0%)
Knowledge Explorer std.	60 (12)	91.3% (92.4%)	8.7% (7.6%)	0.0% (0.0%)
Knowledge Explorer alt.	19 (9)	91.7% (93.0%)	8.2% (7.0%)	0.1% (0.0%)

[3] If the knowledge base contains default rule, prediction is always done.

HB diagnosis

	Rules Generated	Correct Classifications	Incorrect Classifications	Not Classified
KnowledgeSeeker	19 (13)	90.3% (91.5%)	9.7% (8.5%)	0.0% (0.0%)
CN2	30	88.6% (89.9%)	11.4% (10.1%)	0.0% (0.0%)
Knowledge Explorer std.	216 (24)	89.8% (90.5%)	9.1% (9.1%)	1.1% (0.4%)
Knowledge Explorer alt.	48 (30)	90.1% (92.1%)	8.8% (7.8%)	1.1% (0.1%)

HCV diagnosis

	Rules Generated	Correct Classifications	Incorrect Classifications	Not Classified
KnowledgeSeeker	4 (3)	94.6% (100.0%)	5.4% (0.0%)	0.0% (0.0%)
CN2	6	94.6% (100.0%)	5.4% (0.0%)	0.0% (0.0%)
Knowledge Explorer std.	15 (5)	94.6% (100.0%)	5.4% (0.0%)	0.0% (0.0%)
Knowledge Explorer alt.	5 (5)	94.5% (100.0%)	5.4% (0.0%)	0.1% (0.0%)

HAV recommendation

	Rules Generated	Correct Classifications	Incorrect Classifications	Not Classified
KnowledgeSeeker	1 (0)	99.6% (99.8%)	0.4% (0.2%)	0.0% (0.0%)
CN2	7	99.6% (99.8%)	0.4% (0.2%)	0.0% (0.0%)
Knowledge Explorer std.	4 (2)	99.6% (99.8%)	0.4% (0.2%)	0.0% (0.0%)
Knowledge Explorer alt.	10 (9)	99.6% (99.8%)	0.3% (0.2%)	0.1% (0.0%)

HB recommendation

	Rules Generated	Correct Classifications	Incorrect Classifications	Not Classified
KnowledgeSeeker	14 (9)	96.3% (97.7%)	3.7% (2.3%)	0.0% (0.0%)
CN2	18	93.1% (93.0%)	6.9% (7.0%)	0.0% (0.0%)
Knowledge Explorer std.	187 (17)	95.7% (94.9%)	4.3% (5.1%)	0.0% (0.0%)
Knowledge Explorer alt.	39 (30)	95.6% (97.8%)	3.3% (2.1%)	1.1% (0.0%)

HCV recommendation

	Rules Generated	Correct Classifications	Incorrect Classifications	Not Classified
KnowledgeSeeker	5 (4)	78.4% (86.8%)	21.6% (13.2%)	0.0% (0.0%)
CN2	8	78.4% (86.8%)	21.6% (13.2%)	0.0% (0.0%)
Knowledge Explorer std.	12 (4)	78.2% (86.6%)	21.8% (13.4%)	0.0% (0.0%)
Knowledge Explorer alt.	10 (5)	78.5% (86.6%)	21.4% (13.4%)	0.1% (0.0%)

Within every domain, there is no great difference in performance of the used systems. Poor results in the HCV_r domain are caused by very noisy training set (missing recommendations).

The successfulness of the systems in the six subsets looks impresive but must be interpreted very carefully. Because of the high number of "class = 36" examples, simply using the default rule the system will reach 91.2%, 99.8% and 92.6% of correctly classified examples in training set for the HCV_d, HAV_r and HB_r domain, respectively. (Only the default rule was used by all systems for prediction in the HAV_r domain. In the HCV_d domain, although the class 1/HCV was changed to 34/HCV in the testing set and so corresponding examples were not classified correctly, the total successfulness is still very high.) We also cannot simply average the partial results to evaluate the performance of the systems for the whole hepatitis problem domain.

4.5 Final testing

To test the performance on the whole problem domain we must compare the results of prediction of all six partial knowledge bases with the diagnoses given by the expert. Only Knowledge EXplorer was used for this testing because it can give multiple results during consultation.

At first, we combined the six knowledge bases into one. Then we run consultation with this knowledge base for the examples in training set and testing set. From the list of valid diagnoses found by the system for a single case we removed the diagnosis *no statement*. We count the number of examples, where all diagnostic statements given by the expert were found also by the system (we denote the diagnoses given by the system as *superset*) and the number of examples, where diagnoses given by the expert were equivalent to diagnoses found by the system (we denote both diagnoses lists *equivalent*).

The listing below shows results of testing for the first ten testing examples.

```
  no. object           EXPERT                      SYSTEM
--------------------------------------------------------------------
   1  pnnXnn     3/HAV+15/HB+10/HCV,32       15/HB+3/HAV+10/HCV   3/0 Sup Equ
   2  pnnXnn     3/HAV+15/HB+10/HCV,42.32    15/HB+3/HAV+10/HCV   3/0 Sup Equ
   3  pnnpnn     1/HCV,32.164.31             1/HCV+15/HB+3/HAV   1/2 Sup
   4  pngnnn     22/HCV+15/HB+3/HAV,166.32   22/HCV+3/HAV   2/0
   5  pnnXnn     3/HAV+15/HB+10/HCV,32       15/HB+3/HAV+10/HCV   3/0 Sup Equ
   6  pnnXnn     3/HAV+15/HB+10/HCV,30       15/HB+3/HAV+10/HCV   3/0 Sup Equ
   7  nnnXnn     10/HCV+15/HAV+15/HB,111     15/HB+15/HAV+10/HCV   3/0 Sup Equ
   8  pnpXnn     10/HCV+10/CGM+3/HAV,31      3/HAV+10/HCV+10/CGM   3/0 Sup Equ
   9  nnnXnn     22/HCV+15/HAV+15/HB,111     15/HB+15/HAV+10/HCV   2/1
  10  XXXnXX     22/HCV,240                  22/HCV   1/0 Sup Equ
```

Each row in the listing shows input example, diagnoses given by expert (together with the number of question), results of the system, no. of correct decisions of the system, no. of incorrect decisions of the system, evaluation of the results (Sup for superset, Equ for equivalence). The summary of this testing is shown below:

```
                              standard knowledge base
training data = 1000,  Superset =  931 (93.1%), Equivalence =  762 (76.2%)
 testing data = 3339,  Superset = 2930 (87.8%), Equivalence = 2305 (69.0%)
```

```
                              alternative knowledge base
training data = 1000,  Superset =  932 (93.2%), Equivalence =  784 (78.4%)
 testing data = 3339,  Superset = 2933 (87.8%), Equivalence = 2367 (70.1%)
```

The resulting successfulness in the whole hepatitis domain is significantly lower then the successfulnes in separate domains. This is bacause of interactions between the six subdomains; if wrong prediction is done in one subdomain, then the total prediction is wrong. There is no great difference between standard and alternative knowledge base. Since the alternative knowledge base is easier to interpret and update, it seems to be better.

Ideally, in the training set the number of "supersets" should by the same as the number of objects since Knowledge EXplorer can learn rules with multiple valid conclusions. Because of the unregular distribution of examples for multiple classes, the weights computed for rare diagnoses were usually below 0.5 and so corresponding diagnoses were not predicted during consultation (e.g. 6/HAV for $AAK = n$ & $AGM = n$). In the testing set this difference is naturally greater because some testing examples were not used during the learning process.

The difference between the number of equivalences and the number of supersets results from the fact, that in case of possible multiple diagnoses, only one was selected by the expert according to the clinical problem, whereas the system presents all valid diagnoses. Another reason is, that in expert's evaluation some "superdiagnosis" in one subdomain (typically *infection*) suppresses diagnoses in all other domains.

By adding this knowledge to learned rules, the total performance can be improved. The number of supersets can be increased by setting all multiple diagnoses as valid. This can be done in the alternative knowledge base by increasing the correponding weights. The number of equivalences can be increased by directly modifying the rules adding the clinical problem statement (e.g. if clinical problem = immunity and AAK = n and AGM = n then Diagnosis = 6/HAV), or processing the list of system's results after the consultation (e.g. if clinical problem = immunity then don't show diagnoses about infection). Further, it will be necessary to introduce rules to handle superdiagnoses. When doing this for the alternative knowledge base, we obtain following results:

```
no.of objects = 1000,  Superset =  918 (91.8%), Equivalence =  812 (81.2%)
no.of objects = 3339,  Superset = 2939 (88.0%), Equivalence = 2455 (73.5%)
```

5 Conclusion

We present a comparison of three different knowledge acquisition systems based on a real problem domain, interpretation of virological hepatitis tests. Unlike classical machine learning problems the goal classes in this domain are not mutually exclusive. The information how to classify contradictory examples was not available for the systems during learning.

All three tested systems can learn in noisy domains but only Knowledge EXplorer uses the ambiguity of classes during consultation. During standard testing in separate subdomains all three systems gave similar (good) results.

The performance in the whole hepatitis domain is significantly lower. The acquired knowledge base must be verified and extended using additional expert knowledge about how to solve the ambiguities. This can be very easily done for the alternative knowledge base created by Knowledge EXplorer, since this knowledge base consists of independent rules each rule describing (within a subdomain) an complete example. This knowledge base can also be easily updated by adding rules for unclassified examples.

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A Data description

For every input attribute (tests AAK, AGM, CAK, HCK, SAG, SAK) following values are given:

```
p  positive (5,=,p)
n  negative (2,=,n)
l  extremely negative  (2,<,g)
g  extremely positive (5,<,g)
X  not measured
```

Output diagnosis has following valid values:

```
a  1/HAV  Infection A
b  3/HAV  Immune A
c  6/HAV  Not Immune A
d 15/HAV  No Infection A
e  1/HB   Infection B
f  3/HB   Immune B
g  4/HB   Suspicion B
h  6/HB   Not Immune B
i 15/HB   No Infection B
j 26/HB   Possibly Immune B
k 27/HB   Successful vaccination B
l 29/HB   Vaccination? B
m  1/HCV  Infection C
n  4/HCV  Suspicion C
o 34/HCV  Possibly Infection C
p 36      No statement
q 10/HAV  Test      A
r 10/AGM  Test      AGM
s 10/HB   Test      B
t 21/HB   Test 4 We B
u 10/CAK  Test      CAK
v 10/SAG  Test      SAG
w 10/SAK  Test      SAK
x  8/BVE  Test 2 We BVE
y 10/BVE  Test      BVE
z 10/CGM  Test      CGM
A 22/SAG  Test 2 Mo SAG
B 22/SAK  Test 2 Mo SAK
C 22/BVE  Test 2 Mo BVE
D 10/HCV  Test      HCV
E 22/HCV  Test 2 Mo HCV
F 41/HCV  Test PCR  C
```

B Alternative knowledge base

The resulting Knowledge EXplorer knowledge base for the whole hepatitis problem domain was obtained by combining the partial knowledge bases learned in HAV_d, HB_d, HCV_d, HAV_r, HB_r and HCV_r subdomains. This listing shows the knowledge base *without additional expert's knowledge.*

```
                     RULES IN THE KNOWLEDGE BASE


RULE   1:   IF    SER-ELH-AAK  ==   positive (5,=,p)
             AND  SER-ELH-AGM  ==   negative (2,=,n)
           THEN   Diagnosis  ==   '3/HAV'  Immun A     (0.9445)
                  Diagnosis  ==  '15/HAV'  No Infection A     (0.0350)
                  Diagnosis  ==  '36'      No statement     (0.1869)

RULE   2:   IF    SER-ELH-AAK  ==   not measured
             AND  SER-ELH-AGM  ==   not measured
           THEN   Diagnosis  ==   '3/HAV'  Immun A     (0.0090)
                  Diagnosis  ==  '36'      No statement     (0.9978)

RULE   3:   IF    SER-ELH-AAK  ==   negative (2,=,n)
             AND  SER-ELH-AGM  ==   negative (2,=,n)
           THEN   Diagnosis  ==   '6/HAV'  Nicht immun A     (0.0298)
                  Diagnosis  ==  '15/HAV'  No Infection A     (0.9479)
                  Diagnosis  ==  '36'      No statement     (0.1786)

RULE   4:   IF    SER-ELH-AAK  ==   negative (2,=,n)
             AND  SER-ELH-AGM  ==   not measured
           THEN   Diagnosis  ==   '6/HAV'  Nicht immun A     (0.7596)
                  Diagnosis  ==  '15/HAV'  No Infection A     (0.3846)
                  Diagnosis  ==  '36'      No statement     (0.5192)

RULE   5:   IF    SER-ELH-AGM  ==   positive (5,=,p)
             AND  SER-ELH-AAK  ==   positive (5,=,p)
           THEN   Diagnosis  ==   '1/HAV'  Infection A     (0.9524)

RULE   6:   IF    SER-ELH-AGM  ==   not measured
             AND  SER-ELH-AAK  ==   positive (5,=,p)
           THEN   Diagnosis  ==   '3/HAV'  Immun A     (0.8611)
                  Diagnosis  ==  '36'      No statement     (0.5139)

RULE   7:   IF    SER-ELH-AAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-AGM  ==   negative (2,=,n)
           THEN   Diagnosis  ==  '15/HAV'  No Infection A     (0.8214)
                  Diagnosis  ==  '36'      No statement     (0.5536)
```

```
RULE   8:   IF    SER-ELH-AAK  ==   not measured
             AND  SER-ELH-AGM  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '15/HAV'  No Infection A     (0.6875)
                  Diagnosis  ==  '36'      No statement     (0.6875)

RULE   9:   IF    SER-ELH-AGM  ==   extremely positive (5,<,g)
             AND  SER-ELH-AAK  ==   positive (5,=,p)
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  10:   IF    SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '6/HB'   Not Immune B     (0.0908)
                  Diagnosis  ==  '15/HB'   No Infection B     (0.9556)
                  Diagnosis  ==  '36'      No statement     (0.2647)

RULE  11:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
          THEN    Diagnosis  ==  '36'      No statement     (0.9975)

RULE  12:   IF    SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '3/HB'   Immun B     (0.9766)
                  Diagnosis  ==  '36'      No statement     (0.1875)

RULE  13:   IF    SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '15/HB'   No Infection B     (0.1125)
                  Diagnosis  ==  '36'      No statement     (0.9859)

RULE  14:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '1/HB'   Infection B     (0.8393)
                  Diagnosis  ==  '36'      No statement     (0.5982)

RULE  15:   IF    SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '15/HB'   No Infection B     (0.2647)
                  Diagnosis  ==  '27/HB'   Successful vaccination B     (0.5037)
                  Diagnosis  ==  '29/HB'   Vaccination? B     (0.9007)
```

```
RULE  16:   IF    SER-ELH-SAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '3/HB'   Immune B     (0.8594)
                  Diagnosis  ==  '26/HB'   Possibly Immune B     (0.3750)
                  Diagnosis  ==  '36'      No statement     (0.5313)

RULE  17:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '3/HB'   Immune B     (0.8313)
                  Diagnosis  ==  '26/HB'   Possibly Immune B     (0.4500)
                  Diagnosis  ==  '36'      No statement     (0.5500)

RULE  18:   IF    SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '15/HB'   No Infection B     (0.8125)
                  Diagnosis  ==  '36'      No statement     (0.6250)

RULE  19:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '3/HB'   Immune B     (0.5982)
                  Diagnosis  ==  '15/HB'   No Infection B     (0.5179)
                  Diagnosis  ==  '26/HB'   Possibly Immune B     (0.5179)
                  Diagnosis  ==  '36'      No statement     (0.6786)

RULE  20:   IF    SER-ELH-SAG  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '15/HB'   No inf. B     (0.9231)

RULE  21:   IF    SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
          THEN    Diagnosis  ==   '1/HB'   Infection B     (0.7188)
                  Diagnosis  ==  '36'      No statement     (0.7188)

RULE  22:   IF    SER-ELH-SAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '29/HB'   Vaccination? B     (0.8125)
                  Diagnosis  ==  '36'      No statement     (0.6250)
```

```
RULE  23:   IF    SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.8000)

RULE  24:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '15/HB'   No inf. B     (0.7188)
                  Diagnosis  ==  '36'      No statement     (0.7188)

RULE  25:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.8000)

RULE  26:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.8000)

RULE  27:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  28:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  29:   IF    SER-ELH-SAK  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '15/HB'   No Infection B     (0.6667)

RULE  30:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '4/HB'   Suspicion B     (0.6667)

RULE  31:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '4/HB'   Suspicion B     (0.6667)
```

```
RULE  32:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   not measured
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  33:   IF    SER-ELH-SAG  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  34:   IF    SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '29/HB'   Vaccination? B     (0.6667)

RULE  35:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '1/HB'   Infection B     (0.6667)

RULE  36:   IF    SER-ELH-SAG  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  37:   IF    SER-ELH-CAK  ==   extremely negative (2,<,g)
             AND  SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '3/HB'   Immune B     (0.6667)

RULE  38:   IF    SER-ELH-SAG  ==   extremely negative (2,<,g)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '6/HB'   Not Immune B     (0.6667)

RULE  39:   IF    SER-ELH-SAK  ==   extremely negative (2,<,g)
             AND  SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
          THEN    Diagnosis  ==   '1/HB'   Infection B     (0.6667)

RULE  40:   IF    SER-ELH-HCK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.9989)

RULE  41:   IF    SER-ELH-HCK  ==   not measured
          THEN    Diagnosis  ==  '36'      No statement     (0.9989)
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RULE  42:   IF    SER-ELH-HCK  ==   positive (5,=,p)
           THEN   Diagnosis  ==   '1/HCV'  Infection C       (0.9942)

RULE  43:   IF    SER-ELH-HCK  ==   extremely negative (2,<,g)
           THEN   Diagnosis  ==  '36'      No statement    (0.8000)

RULE  44:   IF    SER-ELH-HCK  ==   extremely positive (5,<,g)
           THEN   Diagnosis  ==   '4/HCV'  Suspicion C    (0.8000)

RULE  45:   IF    SER-ELH-AAK  ==   positive (5,=,p)
             AND  SER-ELH-AGM  ==   negative (2,=,n)
           THEN   Diagnosis  ==  '36'      No statement    (0.9988)

RULE  46:   IF    SER-ELH-AAK  ==   not measured
             AND  SER-ELH-AGM  ==   not measured
           THEN   Diagnosis  ==  '36'      No statement    (0.9982)

RULE  47:   IF    SER-ELH-AAK  ==   negative (2,=,n)
             AND  SER-ELH-AGM  ==   negative (2,=,n)
           THEN   Diagnosis  ==  '36'      No statement    (0.9980)

RULE  48:   IF    SER-ELH-AAK  ==   negative (2,=,n)
             AND  SER-ELH-AGM  ==   not measured
           THEN   Diagnosis  ==  '36'      No statement    (0.9630)

RULE  49:   IF    SER-ELH-AGM  ==   positive (5,=,p)
             AND  SER-ELH-AAK  ==   positive (5,=,p)
           THEN   Diagnosis  ==  '36'      No statement    (0.9524)

RULE  50:   IF    SER-ELH-AGM  ==   not measured
             AND  SER-ELH-AAK  ==   positive (5,=,p)
           THEN   Diagnosis  ==  '36'      No statement    (0.8333)
                  Diagnosis  ==  '10/AGM'  Test      AGM    (0.3333)

RULE  51:   IF    SER-ELH-AAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-AGM  ==   negative (2,=,n)
           THEN   Diagnosis  ==  '36'      No statement    (0.9333)

RULE  52:   IF    SER-ELH-AAK  ==   not measured
             AND  SER-ELH-AGM  ==   negative (2,=,n)
           THEN   Diagnosis  ==  '36'      No statement    (0.8000)

RULE  53:   IF    SER-ELH-AGM  ==   extremely positive (5,<,g)
             AND  SER-ELH-AAK  ==   positive (5,=,p)
           THEN   Diagnosis  ==  '36'      No statement    (0.6667)
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RULE  54:   IF    SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.9982)
                  Diagnosis  ==  '21/HB'   Test 4 We B     (0.0202)

RULE  55:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
          THEN    Diagnosis  ==  '36'      No statement     (0.9945)
                  Diagnosis  ==  '10/HB'   Test      B     (0.0302)

RULE  56:   IF    SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.9897)

RULE  57:   IF    SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.5773)
                  Diagnosis  ==  '10/CGM'  Test      CGM       (0.8773)

RULE  58:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.4286)
                  Diagnosis  ==   '8/BVE'  Test 2 We BVE     (0.9026)
                  Diagnosis  ==  '22/SAG'  Test 2 Mo SAG     (0.2143)
                  Diagnosis  ==  '22/BVE'  Test 2 Mo BVE     (0.4286)

RULE  59:   IF    SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.9714)

RULE  60:   IF    SER-ELH-SAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.9600)

RULE  61:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.9524)
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RULE  62:   IF    SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.9474)

RULE  63:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.9333)

RULE  64:   IF    SER-ELH-SAG  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.9231)

RULE  65:   IF    SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
          THEN    Diagnosis  ==  '36'      No statement    (0.5909)
                  Diagnosis  ==  '10/SAK'  Test      SAK    (0.7273)
                  Diagnosis  ==   '8/BVE'  Test 2 We BVE    (0.5909)

RULE  66:   IF    SER-ELH-SAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.8571)

RULE  67:   IF    SER-ELH-CAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '10/SAG'  Test      SAG    (0.8000)

RULE  68:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.7273)
                  Diagnosis  ==  '10/CAK'  Test      CAK    (0.7273)

RULE  69:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '10/CGM'  Test      CGM      (0.8000)
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RULE  70:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.8000)

RULE  71:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.6667)

RULE  72:   IF    SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.6667)

RULE  73:   IF    SER-ELH-SAK  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.6667)

RULE  74:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.6667)

RULE  75:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '10/BVE'  Test      BVE     (0.6667)

RULE  76:   IF    SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   not measured
             AND  SER-ELH-SAK  ==   not measured
          THEN    Diagnosis  ==  '10/BVE'  Test      BVE     (0.6667)

RULE  77:   IF    SER-ELH-SAG  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.6667)

RULE  78:   IF    SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   not measured
             AND  SER-ELH-CAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement    (0.6667)
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RULE  79:   IF    SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==   '8/BVE'  Test 2 We BVE     (0.6667)

RULE  80:   IF    SER-ELH-SAG  ==   extremely positive (5,<,g)
             AND  SER-ELH-CAK  ==   extremely positive (5,<,g)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '10/CGM'  Test      CGM       (0.6667)

RULE  81:   IF    SER-ELH-CAK  ==   extremely negative (2,<,g)
             AND  SER-ELH-SAK  ==   positive (5,=,p)
             AND  SER-ELH-SAG  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  82:   IF    SER-ELH-SAG  ==   extremely negative (2,<,g)
             AND  SER-ELH-CAK  ==   negative (2,=,n)
             AND  SER-ELH-SAK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.6667)

RULE  83:   IF    SER-ELH-SAK  ==   extremely negative (2,<,g)
             AND  SER-ELH-SAG  ==   positive (5,=,p)
             AND  SER-ELH-CAK  ==   positive (5,=,p)
          THEN    Diagnosis  ==   '8/BVE'  Test 2 We BVE     (0.6667)

RULE  84:   IF    SER-ELH-HCK  ==   negative (2,=,n)
          THEN    Diagnosis  ==  '36'      No statement     (0.0725)
                  Diagnosis  ==  '10/HCV'  Test      HCV     (0.0171)
                  Diagnosis  ==  '22/HCV'  Test 2 Mo HCV     (0.9701)

RULE  85:   IF    SER-ELH-HCK  ==   not measured
          THEN    Diagnosis  ==  '36'      No statement     (0.4807)
                  Diagnosis  ==  '10/HCV'  Test      HCV     (0.8337)
                  Diagnosis  ==  '22/HCV'  Test 2 Mo HCV     (0.0181)

RULE  86:   IF    SER-ELH-HCK  ==   positive (5,=,p)
          THEN    Diagnosis  ==  '36'      No statement     (0.9942)

RULE  87:   IF    SER-ELH-HCK  ==   extremely negative (2,<,g)
          THEN    Diagnosis  ==  '10/HCV'  Test      HCV     (0.6667)
                  Diagnosis  ==  '22/HCV'  Test 2 Mo HCV     (0.6667)

RULE  88:   IF    SER-ELH-HCK  ==   extremely positive (5,<,g)
          THEN    Diagnosis  ==  '36'      No statement     (0.8000)
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