Garg_Bheeni_Stat6620_Homework4

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Chapter 5: Classification using Decision Trees and Rules ————————-

Question 1

Part 1: Decision Trees ————————-

Identifying Risky Bank Loans —-

Step 1: Collecting Data

The credit dataset includes 1,000 examples of loans, plus a combination of numeric and nominal features indicating characteristics of the loan and the loan applicant. A class variable indicates whether the loan went into default.

Step 2: Exploring and preparing the data —-

```
credit <- read.csv("credit.csv")
str(credit)
```

```
## 'data.frame':    1000 obs. of  17 variables:
##  $ checking_balance    : Factor w/ 4 levels "< 0 DM","> 200 DM",..: 1 3 4 1 1 4 4 3 4 3 ...
##  $ months_loan_duration: int  6 48 12 42 24 36 24 36 12 30 ...
##  $ credit_history      : Factor w/ 5 levels "critical","good",..: 1 2 1 2 4 2 2 2 2 1 ...
##  $ purpose             : Factor w/ 6 levels "business","car",..: 5 5 4 5 2 4 5 2 5 2 ...
##  $ amount              : int  1169 5951 2096 7882 4870 9055 2835 6948 3059 5234 ...
##  $ savings_balance     : Factor w/ 5 levels "< 100 DM","> 1000 DM",..: 5 1 1 1 1 5 4 1 2 1 ...
##  $ employment_duration : Factor w/ 5 levels "< 1 year","> 7 years",..: 2 3 4 4 3 3 2 3 4 5 ...
##  $ percent_of_income   : int  4 2 2 2 3 2 3 2 2 4 ...
##  $ years_at_residence  : int  4 2 3 4 4 4 4 2 4 2 ...
##  $ age                 : int  67 22 49 45 53 35 53 35 61 28 ...
##  $ other_credit        : Factor w/ 3 levels "bank","none",..: 2 2 2 2 2 2 2 2 2 2 ...
##  $ housing             : Factor w/ 3 levels "other","own",..: 2 2 2 1 1 1 2 3 2 2 ...
##  $ existing_loans_count: int  2 1 1 1 2 1 1 1 1 2 ...
##  $ job                 : Factor w/ 4 levels "management","skilled",..: 2 2 4 2 2 4 2 1 4 1 ...
##  $ dependents          : int  1 1 2 2 2 2 1 1 1 1 ...
##  $ phone               : Factor w/ 2 levels "no","yes": 2 1 1 1 1 2 1 2 1 1 ...
##  $ default             : Factor w/ 2 levels "no","yes": 1 2 1 1 2 1 1 1 1 2 ...
```

```
# look at two characteristics of the applicant
table(credit$checking_balance)
```

```
##
##     < 0 DM   > 200 DM 1 - 200 DM    unknown
##        274         63        269        394
```

```r
table(credit$savings_balance)
```

```
##
##      < 100 DM     > 1000 DM  100 - 500 DM 500 - 1000 DM       unknown
##           603            48           103            63           183
```

```r
# look at two characteristics of the loan
summary(credit$months_loan_duration)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##     4.0    12.0    18.0    20.9    24.0    72.0
```

```r
summary(credit$amount)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##     250    1366    2320    3271    3972   18420
```

```r
# look at the class variable
table(credit$default)
```

```
##
##  no yes
## 700 300
```

```r
# create a random sample for training and test data
# use set.seed to use the same random number sequence as the tutorial
set.seed(123)
train_sample <- sample(1000, 900)

str(train_sample)
```

```
##  int [1:900] 288 788 409 881 937 46 525 887 548 453 ...
```

```r
# split the data frames
credit_train <- credit[train_sample, ]
credit_test  <- credit[-train_sample, ]

# check the proportion of class variable
prop.table(table(credit_train$default))
```

```
##
##        no       yes
## 0.7033333 0.2966667
```

```r
prop.table(table(credit_test$default))
```

```
##
##   no  yes
## 0.67 0.33
```

```
## Step 3: Training a model on the data ----
# build the simplest decision tree
library(C50)
credit_model <- C5.0(credit_train[-17], credit_train$default)

# display simple facts about the tree
credit_model
```

```
##
## Call:
## C5.0.default(x = credit_train[-17], y = credit_train$default)
##
## Classification Tree
## Number of samples: 900
## Number of predictors: 16
##
## Tree size: 57
##
## Non-standard options: attempt to group attributes
```

```
# display detailed information about the tree
summary(credit_model)
```

```
##
## Call:
## C5.0.default(x = credit_train[-17], y = credit_train$default)
##
##
## C5.0 [Release 2.07 GPL Edition]      Sat May 14 22:12:17 2016
## -------------------------------
##
## Class specified by attribute `outcome'
##
## Read 900 cases (17 attributes) from undefined.data
##
## Decision tree:
##
## checking_balance in {> 200 DM,unknown}: no (412/50)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...credit_history in {perfect,very good}: yes (59/18)
##     credit_history in {critical,good,poor}:
##     :...months_loan_duration <= 22:
##         :...credit_history = critical: no (72/14)
##         :   credit_history = poor:
##         :   :...dependents > 1: no (5)
##         :   :   dependents <= 1:
##         :   :   :...years_at_residence <= 3: yes (4/1)
##         :   :       years_at_residence > 3: no (5/1)
##         :   credit_history = good:
##         :   :...savings_balance in {> 1000 DM,500 - 1000 DM}: no (15/1)
##         :       savings_balance = 100 - 500 DM:
##         :       :...other_credit = bank: yes (3)
##         :       :   other_credit in {none,store}: no (9/2)
```

```
##          :       savings_balance = unknown:
##          :       :...other_credit = bank: yes (1)
##          :       :   other_credit in {none,store}: no (21/8)
##          :       savings_balance = < 100 DM:
##          :       :...purpose in {business,car0,renovations}: no (8/2)
##          :           purpose = education:
##          :           :...checking_balance = < 0 DM: yes (4)
##          :           :   checking_balance = 1 - 200 DM: no (1)
##          :           purpose = car:
##          :           :...employment_duration = > 7 years: yes (5)
##          :           :   employment_duration = unemployed: no (4/1)
##          :           :   employment_duration = < 1 year:
##          :           :   :...years_at_residence <= 2: yes (5)
##          :           :   :   years_at_residence > 2: no (3/1)
##          :           :   employment_duration = 1 - 4 years:
##          :           :   :...years_at_residence <= 2: yes (2)
##          :           :   :   years_at_residence > 2: no (6/1)
##          :           :   employment_duration = 4 - 7 years:
##          :           :   :...amount <= 1680: yes (2)
##          :           :       amount > 1680: no (3)
##          :           purpose = furniture/appliances:
##          :           :...job in {management,unskilled}: no (23/3)
##          :               job = unemployed: yes (1)
##          :               job = skilled:
##          :               :...months_loan_duration > 13: [S1]
##          :                   months_loan_duration <= 13:
##          :                   :...housing in {other,own}: no (23/4)
##          :                       housing = rent:
##          :                       :...percent_of_income <= 3: yes (3)
##          :                           percent_of_income > 3: no (2)
##          months_loan_duration > 22:
##          :...savings_balance = > 1000 DM: no (2)
##              savings_balance = 500 - 1000 DM: yes (4/1)
##              savings_balance = 100 - 500 DM:
##              :...credit_history in {critical,poor}: no (14/3)
##              :   credit_history = good:
##              :   :...other_credit = bank: no (1)
##              :       other_credit in {none,store}: yes (12/2)
##              savings_balance = unknown:
##              :...checking_balance = 1 - 200 DM: no (17)
##              :   checking_balance = < 0 DM:
##              :   :...credit_history = critical: no (1)
##              :       credit_history in {good,poor}: yes (12/3)
##              savings_balance = < 100 DM:
##              :...months_loan_duration > 47: yes (21/2)
##                  months_loan_duration <= 47:
##                  :...housing = other:
##                      :...percent_of_income <= 2: no (6)
##                      :   percent_of_income > 2: yes (9/3)
##                      housing = rent:
##                      :...other_credit = bank: no (1)
##                      :   other_credit in {none,store}: yes (16/3)
##                      housing = own:
##                      :...employment_duration = > 7 years: no (13/4)
```

```
##                         employment_duration = 4 - 7 years:
##                         :...job in {management,skilled,
##                         :   :       unemployed}: yes (9/1)
##                         :   job = unskilled: no (1)
##                         employment_duration = unemployed:
##                         :...years_at_residence <= 2: yes (4)
##                         :   years_at_residence > 2: no (3)
##                         employment_duration = 1 - 4 years:
##                         :...purpose in {business,car0,education}: yes (7/1)
##                         :   purpose in {furniture/appliances,
##                         :   :           renovations}: no (7)
##                         :   purpose = car:
##                         :   :...years_at_residence <= 3: yes (3)
##                         :       years_at_residence > 3: no (3)
##                         employment_duration = < 1 year:
##                         :...years_at_residence > 3: yes (5)
##                             years_at_residence <= 3:
##                             :...other_credit = bank: no (0)
##                                 other_credit = store: yes (1)
##                                 other_credit = none:
##                                 :...checking_balance = 1 - 200 DM: no (8/2)
##                                     checking_balance = < 0 DM:
##                                     :...job in {management,skilled,
##                                         :       unemployed}: yes (2)
##                                         job = unskilled: no (3/1)
##
## SubTree [S1]
##
## employment_duration in {< 1 year,4 - 7 years}: no (4)
## employment_duration in {> 7 years,1 - 4 years,unemployed}: yes (10)
##
##
## Evaluation on training data (900 cases):
##
##      Decision Tree
##    ----------------
##    Size      Errors
##
##      56  133(14.8%)   <<
##
##
##     (a)   (b)    <-classified as
##    ----  ----
##     598    35    (a): class no
##      98   169    (b): class yes
##
##
##  Attribute usage:
##
##  100.00% checking_balance
##   54.22% credit_history
##   47.67% months_loan_duration
##   38.11% savings_balance
##   14.33% purpose
```

```
##   14.33% housing
##   12.56% employment_duration
##    9.00% job
##    8.67% other_credit
##    6.33% years_at_residence
##    2.22% percent_of_income
##    1.56% dependents
##    0.56% amount
##
##
## Time: 0.0 secs
```

```
## Step 4: Evaluating model performance ----
# create a factor vector of predictions on test data
credit_pred <- predict(credit_model, credit_test)

# first 10 prediction output
credit_pred[1:10]
```

```
##  [1] no  no  no  yes no  no  no  no  yes yes
## Levels: no yes
```

```
# cross tabulation of predicted versus actual classes
library(gmodels)
CrossTable(credit_test$default, credit_pred,
           prop.chisq = FALSE, prop.c = FALSE, prop.r = FALSE,
           dnn = c('actual default', 'predicted default'))
```

```
##
##
##    Cell Contents
## |-------------------------|
## |                       N |
## |         N / Table Total |
## |-------------------------|
##
##
## Total Observations in Table:  100
##
##
##                | predicted default
## actual default |        no |       yes | Row Total |
## ---------------|-----------|-----------|-----------|
##             no |        59 |         8 |        67 |
##                |     0.590 |     0.080 |           |
## ---------------|-----------|-----------|-----------|
##            yes |        19 |        14 |        33 |
##                |     0.190 |     0.140 |           |
## ---------------|-----------|-----------|-----------|
##   Column Total |        78 |        22 |       100 |
## ---------------|-----------|-----------|-----------|
##
##
```

```
# Accuracy
(59+14)/100
```

```
## [1] 0.73
```

The accuracy 0.73 is decent. We use boosting to further improve our accuracy.

```
## Step 5: Improving model performance ----

## Boosting the accuracy of decision trees
# boosted decision tree with 10 trials
credit_boost10 <- C5.0(credit_train[-17], credit_train$default,
                       trials = 10)
credit_boost10
```

```
##
## Call:
## C5.0.default(x = credit_train[-17], y = credit_train$default, trials = 10)
##
## Classification Tree
## Number of samples: 900
## Number of predictors: 16
##
## Number of boosting iterations: 10
## Average tree size: 47.5
##
## Non-standard options: attempt to group attributes
```

```
summary(credit_boost10)
```

```
##
## Call:
## C5.0.default(x = credit_train[-17], y = credit_train$default, trials = 10)
##
##
## C5.0 [Release 2.07 GPL Edition]      Sat May 14 22:12:17 2016
## -------------------------------
##
## Class specified by attribute `outcome'
##
## Read 900 cases (17 attributes) from undefined.data
##
## -----  Trial 0:  -----
##
## Decision tree:
##
## checking_balance in {> 200 DM,unknown}: no (412/50)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...credit_history in {perfect,very good}: yes (59/18)
##     credit_history in {critical,good,poor}:
##     :...months_loan_duration <= 22:
##         :...credit_history = critical: no (72/14)
```

```
##          :   credit_history = poor:
##          :   :...dependents > 1: no (5)
##          :   :   dependents <= 1:
##          :   :   :...years_at_residence <= 3: yes (4/1)
##          :   :       years_at_residence > 3: no (5/1)
##          :   credit_history = good:
##          :   :...savings_balance in {> 1000 DM,500 - 1000 DM}: no (15/1)
##          :       savings_balance = 100 - 500 DM:
##          :       :...other_credit = bank: yes (3)
##          :       :   other_credit in {none,store}: no (9/2)
##          :       savings_balance = unknown:
##          :       :...other_credit = bank: yes (1)
##          :       :   other_credit in {none,store}: no (21/8)
##          :       savings_balance = < 100 DM:
##          :       :...purpose in {business,car0,renovations}: no (8/2)
##          :           purpose = education:
##          :           :...checking_balance = < 0 DM: yes (4)
##          :           :   checking_balance = 1 - 200 DM: no (1)
##          :           purpose = car:
##          :           :...employment_duration = > 7 years: yes (5)
##          :           :   employment_duration = unemployed: no (4/1)
##          :           :   employment_duration = < 1 year:
##          :           :   :...years_at_residence <= 2: yes (5)
##          :           :   :   years_at_residence > 2: no (3/1)
##          :           :   employment_duration = 1 - 4 years:
##          :           :   :...years_at_residence <= 2: yes (2)
##          :           :   :   years_at_residence > 2: no (6/1)
##          :           :   employment_duration = 4 - 7 years:
##          :           :   :...amount <= 1680: yes (2)
##          :           :       amount > 1680: no (3)
##          :           purpose = furniture/appliances:
##          :           :...job in {management,unskilled}: no (23/3)
##          :               job = unemployed: yes (1)
##          :               job = skilled:
##          :               :...months_loan_duration > 13: [S1]
##          :                   months_loan_duration <= 13:
##          :                   :...housing in {other,own}: no (23/4)
##          :                       housing = rent:
##          :                       :...percent_of_income <= 3: yes (3)
##          :                           percent_of_income > 3: no (2)
##          months_loan_duration > 22:
##          :...savings_balance = > 1000 DM: no (2)
##              savings_balance = 500 - 1000 DM: yes (4/1)
##              savings_balance = 100 - 500 DM:
##              :...credit_history in {critical,poor}: no (14/3)
##              :   credit_history = good:
##              :   :...other_credit = bank: no (1)
##              :       other_credit in {none,store}: yes (12/2)
##              savings_balance = unknown:
##              :...checking_balance = 1 - 200 DM: no (17)
##              :   checking_balance = < 0 DM:
##              :   :...credit_history = critical: no (1)
##              :       credit_history in {good,poor}: yes (12/3)
##              savings_balance = < 100 DM:
```

```
##             :...months_loan_duration > 47: yes (21/2)
##                 months_loan_duration <= 47:
##                 :...housing = other:
##                     :...percent_of_income <= 2: no (6)
##                     :   percent_of_income > 2: yes (9/3)
##                     housing = rent:
##                     :...other_credit = bank: no (1)
##                     :   other_credit in {none,store}: yes (16/3)
##                     housing = own:
##                     :...employment_duration = > 7 years: no (13/4)
##                         employment_duration = 4 - 7 years:
##                         :...job in {management,skilled,
##                         :   :       unemployed}: yes (9/1)
##                         :   job = unskilled: no (1)
##                         employment_duration = unemployed:
##                         :...years_at_residence <= 2: yes (4)
##                         :   years_at_residence > 2: no (3)
##                         employment_duration = 1 - 4 years:
##                         :...purpose in {business,car0,education}: yes (7/1)
##                         :   purpose in {furniture/appliances,
##                         :   :           renovations}: no (7)
##                         :   purpose = car:
##                         :   :...years_at_residence <= 3: yes (3)
##                         :       years_at_residence > 3: no (3)
##                         employment_duration = < 1 year:
##                         :...years_at_residence > 3: yes (5)
##                             years_at_residence <= 3:
##                             :...other_credit = bank: no (0)
##                                 other_credit = store: yes (1)
##                                 other_credit = none:
##                                 :...checking_balance = 1 - 200 DM: no (8/2)
##                                     checking_balance = < 0 DM:
##                                     :...job in {management,skilled,
##                                         :       unemployed}: yes (2)
##                                         job = unskilled: no (3/1)
##
## SubTree [S1]
##
## employment_duration in {< 1 year,4 - 7 years}: no (4)
## employment_duration in {> 7 years,1 - 4 years,unemployed}: yes (10)
##
## -----  Trial 1:  -----
##
## Decision tree:
##
## checking_balance = unknown:
## :...other_credit in {bank,store}:
## :   :...purpose in {business,education,renovations}: yes (19.5/6.3)
## :   :   purpose in {car0,furniture/appliances}: no (24.8/6.6)
## :   :   purpose = car:
## :   :   :...dependents <= 1: yes (20.1/4.8)
## :   :       dependents > 1: no (2.4)
## :   other_credit = none:
## :   :...credit_history in {critical,perfect,very good}: no (102.8/4.4)
```

```
## :       credit_history = good:
## :       :...existing_loans_count <= 1: no (112.7/17.5)
## :       :   existing_loans_count > 1: yes (18.9/7.9)
## :       credit_history = poor:
## :       :...years_at_residence <= 1: yes (4.4)
## :           years_at_residence > 1:
## :           :...percent_of_income <= 3: no (11.9)
## :               percent_of_income > 3: yes (14.3/5.6)
## checking_balance in {< 0 DM,> 200 DM,1 - 200 DM}:
## :...savings_balance in {> 1000 DM,500 - 1000 DM}: no (42.9/11.3)
##     savings_balance = unknown:
##     :...credit_history in {perfect,poor}: no (8.5)
##     :   credit_history in {critical,good,very good}:
##     :   :...employment_duration in {< 1 year,> 7 years,4 - 7 years,
##     :       :                       unemployed}: no (52.3/17.3)
##     :       employment_duration = 1 - 4 years: yes (19.7/5.6)
##     savings_balance = 100 - 500 DM:
##     :...existing_loans_count > 3: yes (3)
##     :   existing_loans_count <= 3:
##     :   :...credit_history in {critical,poor,very good}: no (24.6/7.6)
##     :       credit_history = perfect: yes (2.4)
##     :       credit_history = good:
##     :       :...months_loan_duration <= 27: no (23.7/10.5)
##     :           months_loan_duration > 27: yes (5.6)
##     savings_balance = < 100 DM:
##     :...months_loan_duration > 42: yes (28/5.2)
##         months_loan_duration <= 42:
##         :...percent_of_income <= 2:
##             :...employment_duration in {1 - 4 years,4 - 7 years,
##             :   :                       unemployed}: no (86.2/23.8)
##             :   employment_duration in {< 1 year,> 7 years}:
##             :   :...housing = other: no (4.8/1.6)
##             :       housing = rent: yes (10.7/2.4)
##             :       housing = own:
##             :       :...phone = yes: yes (12.9/4)
##             :           phone = no:
##             :           :...percent_of_income <= 1: no (7.1/0.8)
##             :               percent_of_income > 1: yes (17.5/7.1)
##             percent_of_income > 2:
##             :...years_at_residence <= 1: no (31.6/8.5)
##                 years_at_residence > 1:
##                 :...credit_history in {perfect,poor}: yes (20.9/1.6)
##                     credit_history in {critical,good,very good}:
##                     :...job = skilled: yes (95/34.7)
##                         job = unemployed: no (1.6)
##                         job = management:
##                         :...amount <= 11590: no (23.8/7)
##                         :   amount > 11590: yes (3.8)
##                         job = unskilled:
##                         :...checking_balance in {< 0 DM,
##                             :                    > 200 DM}: yes (23.8/9.5)
##                             checking_balance = 1 - 200 DM: no (17.9/6.2)
##
## -----  Trial 2:  -----
```

```
##
## Decision tree:
##
## checking_balance = unknown:
## :...other_credit = bank:
## :   :...existing_loans_count > 2: no (3.3)
## :   :   existing_loans_count <= 2:
## :   :   :...months_loan_duration <= 8: no (4)
## :   :       months_loan_duration > 8: yes (43/16.6)
## :   other_credit in {none,store}:
## :   :...employment_duration in {< 1 year,unemployed}:
## :       :...purpose in {business,renovations}: yes (6.4)
## :       :   purpose in {car,car0,education}: no (13.2)
## :       :   purpose = furniture/appliances:
## :       :   :...amount <= 4594: no (22.5/7.3)
## :       :       amount > 4594: yes (9.1)
## :       employment_duration in {> 7 years,1 - 4 years,4 - 7 years}:
## :       :...percent_of_income <= 3: no (92.7/3.6)
## :           percent_of_income > 3:
## :           :...age > 30: no (73.6/5.5)
## :               age <= 30:
## :               :...job in {management,unemployed,unskilled}: yes (14/4)
## :                   job = skilled:
## :                   :...credit_history = very good: no (0)
## :                       credit_history = poor: yes (3.6)
## :                       credit_history in {critical,good,perfect}:
## :                       :...age <= 29: no (20.4/4.6)
## :                           age > 29: yes (2.7)
## checking_balance in {< 0 DM,> 200 DM,1 - 200 DM}:
## :...housing = other:
##     :...dependents > 1: yes (28.3/7.6)
##     :   dependents <= 1:
##     :   :...employment_duration in {< 1 year,4 - 7 years,
##     :       :                       unemployed}: no (22.9/4.5)
##     :       employment_duration in {> 7 years,1 - 4 years}: yes (29.6/10.5)
##     housing = rent:
##     :...credit_history = perfect: yes (5.3)
##     :   credit_history = poor: no (7.1/0.7)
##     :   credit_history in {critical,good,very good}:
##     :   :...employment_duration = < 1 year: yes (28.3/9.3)
##     :       employment_duration in {> 7 years,4 - 7 years,
##     :       :                       unemployed}: no (33.9/12.3)
##     :       employment_duration = 1 - 4 years:
##     :       :...checking_balance = > 200 DM: no (2)
##     :           checking_balance in {< 0 DM,1 - 200 DM}:
##     :           :...years_at_residence <= 3: no (10.3/3.8)
##     :               years_at_residence > 3: yes (20.4/3.1)
##     housing = own:
##     :...job in {management,unemployed}: yes (55.8/19.8)
##         job in {skilled,unskilled}:
##         :...months_loan_duration <= 7: no (25.3/2)
##             months_loan_duration > 7:
##             :...years_at_residence > 3: no (92.2/29.6)
##                 years_at_residence <= 3:
```

```
##                 :...purpose = renovations: yes (7/1.3)
##                     purpose in {business,car0,education}: no (32.2/5.3)
##                     purpose = car:
##                     :...months_loan_duration > 40: no (7.2/0.7)
##                     :   months_loan_duration <= 40:
##                     :   :...amount <= 947: yes (12.9)
##                     :       amount > 947:
##                     :       :...months_loan_duration <= 16: no (23.2/8.5)
##                     :           months_loan_duration > 16: [S1]
##                     purpose = furniture/appliances:
##                     :...savings_balance in {> 1000 DM,unknown}: no (15.4/3.2)
##                         savings_balance in {100 - 500 DM,
##                         :                   500 - 1000 DM}: yes (14.6/4.5)
##                         savings_balance = < 100 DM:
##                         :...months_loan_duration > 36: yes (7.1)
##                             months_loan_duration <= 36:
##                             :...existing_loans_count > 1: no (14.1/4.3)
##                                 existing_loans_count <= 1: [S2]
##
## SubTree [S1]
##
## savings_balance in {< 100 DM,> 1000 DM,500 - 1000 DM,unknown}: yes (22.5/2.7)
## savings_balance = 100 - 500 DM: no (4.5/0.7)
##
## SubTree [S2]
##
## checking_balance = < 0 DM: no (22.4/9.1)
## checking_balance in {> 200 DM,1 - 200 DM}: yes (46.7/20)
##
## -----  Trial 3:  -----
##
## Decision tree:
##
## checking_balance in {> 200 DM,unknown}:
## :...employment_duration = > 7 years: no (98.9/17.1)
## :   employment_duration = unemployed: yes (16/6.7)
## :   employment_duration = < 1 year:
## :   :...amount <= 1333: no (11.7)
## :   :   amount > 1333:
## :   :   :...amount <= 6681: no (38.2/16.3)
## :   :       amount > 6681: yes (5.3)
## :   employment_duration = 4 - 7 years:
## :   :...checking_balance = > 200 DM: yes (9.6/3.6)
## :   :   checking_balance = unknown:
## :   :   :...age <= 22: yes (6.5/1.6)
## :   :       age > 22: no (42.6/1.5)
## :   employment_duration = 1 - 4 years:
## :   :...percent_of_income <= 1: no (20.6/1.5)
## :       percent_of_income > 1:
## :       :...job in {skilled,unemployed}: no (64.9/17.6)
## :           job in {management,unskilled}:
## :           :...existing_loans_count > 2: yes (2.4)
## :               existing_loans_count <= 2:
## :               :...age <= 34: yes (26.4/10.7)
```

```
## :                   age > 34: no (10.5)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...savings_balance in {> 1000 DM,500 - 1000 DM}: no (35.8/12)
##     savings_balance = 100 - 500 DM:
##     :...amount <= 1285: yes (12.8/0.5)
##     :   amount > 1285:
##     :   :...existing_loans_count <= 1: no (27/9.2)
##     :       existing_loans_count > 1: yes (15.8/4.9)
##     savings_balance = unknown:
##     :...credit_history in {critical,perfect,poor}: no (15.5)
##     :   credit_history in {good,very good}:
##     :   :...age > 56: no (4.5)
##     :       age <= 56:
##     :       :...months_loan_duration <= 18: yes (24.5/5.6)
##     :           months_loan_duration > 18: no (28.4/12.3)
##     savings_balance = < 100 DM:
##     :...months_loan_duration <= 11:
##         :...job = management: yes (13.7/4.9)
##         :   job in {skilled,unemployed,unskilled}: no (45.9/10)
##         months_loan_duration > 11:
##         :...percent_of_income <= 1:
##             :...credit_history in {critical,poor,very good}: no (11.1)
##             :   credit_history in {good,perfect}: yes (24.4/11)
##             percent_of_income > 1:
##             :...job = unemployed: yes (7/3.1)
##                 job = management:
##                 :...years_at_residence <= 1: no (6.6)
##                 :   years_at_residence > 1:
##                 :   :...checking_balance = < 0 DM: no (23.1/7)
##                 :       checking_balance = 1 - 200 DM: yes (15.8/4)
##                 job = unskilled:
##                 :...housing in {other,rent}: yes (12.2/2.2)
##                 :   housing = own:
##                 :   :...purpose = car: yes (18.1/3.9)
##                 :       purpose in {business,car0,education,
##                 :                   furniture/appliances,
##                 :                   renovations}: no (32.1/11.1)
##                 job = skilled:
##                 :...checking_balance = < 0 DM:
##                     :...credit_history in {poor,very good}: yes (16.6)
##                     :   credit_history in {critical,good,perfect}:
##                     :   :...purpose in {business,car0,education,
##                     :       :           renovations}: yes (10.2/1.5)
##                     :       purpose = car:
##                     :       :...age <= 51: yes (34.6/8.1)
##                     :       :   age > 51: no (4.4)
##                     :       purpose = furniture/appliances:
##                     :       :...years_at_residence <= 1: no (4.4)
##                     :           years_at_residence > 1:
##                     :           :...other_credit = bank: yes (2.4)
##                     :               other_credit = store: no (0.5)
##                     :               other_credit = none:
##                     :               :...amount <= 1743: no (11.5/2.4)
##                     :                   amount > 1743: yes (29/6.6)
```

```
##                     checking_balance = 1 - 200 DM:
##                     :...months_loan_duration > 36: yes (6.5)
##                         months_loan_duration <= 36:
##                         :...other_credit in {bank,store}: yes (8/1.5)
##                             other_credit = none:
##                             :...dependents > 1: yes (7.4/3.1)
##                                 dependents <= 1:
##                                 :...percent_of_income <= 2: no (12.7/1.1)
##                                     percent_of_income > 2: [S1]
##
## SubTree [S1]
##
## purpose in {business,renovations}: yes (3.9)
## purpose in {car,car0,education,furniture/appliances}: no (19.8/6.1)
##
## -----  Trial 4:  -----
##
## Decision tree:
##
## checking_balance in {> 200 DM,unknown}:
## :...other_credit = store: no (20.6/9.6)
## :   other_credit = none:
## :   :...employment_duration in {> 7 years,1 - 4 years,4 - 7 years,
## :   :   :                       unemployed}: no (211.3/45.7)
## :   :   employment_duration = < 1 year:
## :   :   :...amount <= 1333: no (8.8)
## :   :       amount > 1333:
## :   :       :...purpose in {business,car0,education,furniture/appliances,
## :   :           :           renovations}: yes (32.9/8.1)
## :   :           purpose = car: no (4.9)
## :   other_credit = bank:
## :   :...age > 44: no (14.4/1.2)
## :       age <= 44:
## :       :...years_at_residence <= 1: no (5)
## :           years_at_residence > 1:
## :           :...housing = rent: yes (4.3)
## :               housing in {other,own}:
## :               :...job = unemployed: yes (0)
## :                   job = management: no (4)
## :                   job in {skilled,unskilled}:
## :                   :...age <= 26: no (3.7)
## :                       age > 26:
## :                       :...savings_balance in {< 100 DM,500 - 1000 DM,
## :                           :                   unknown}: yes (30.6/7.4)
## :                           savings_balance in {> 1000 DM,
## :                                               100 - 500 DM}: no (4)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...credit_history = perfect:
##     :...housing in {other,rent}: yes (7.8)
##     :   housing = own: no (20.5/9)
##     credit_history = poor:
##     :...checking_balance = < 0 DM: yes (10.4/2.2)
##     :   checking_balance = 1 - 200 DM:
##     :   :...other_credit in {bank,none}: no (24/4.3)
```

```
##     :       other_credit = store: yes (5.8/1.2)
##     credit_history = very good:
##     :...age <= 23: no (5.7)
##     :   age > 23:
##     :   :...months_loan_duration <= 27: yes (28.4/3.7)
##     :       months_loan_duration > 27: no (6.9/2)
##     credit_history = critical:
##     :...years_at_residence <= 1: no (6.7)
##     :   years_at_residence > 1:
##     :   :...purpose in {business,car,car0,renovations}: no (62.2/21.9)
##     :       purpose = education: yes (7.9/0.9)
##     :       purpose = furniture/appliances:
##     :       :...phone = yes: no (14.5/2.8)
##     :           phone = no:
##     :           :...amount <= 1175: no (5.2)
##     :               amount > 1175: yes (30.1/7.6)
##     credit_history = good:
##     :...savings_balance in {> 1000 DM,500 - 1000 DM}: no (15.7/4.7)
##         savings_balance = 100 - 500 DM: yes (32.1/11.7)
##         savings_balance = unknown:
##         :...job = unskilled: no (4.4)
##         :   job in {management,skilled,unemployed}:
##         :   :...checking_balance = < 0 DM: yes (27.8/6)
##         :       checking_balance = 1 - 200 DM: no (26.8/10.4)
##         savings_balance = < 100 DM:
##         :...dependents > 1:
##             :...existing_loans_count > 1: no (2.6/0.4)
##             :   existing_loans_count <= 1:
##             :   :...years_at_residence <= 2: yes (10.2/2.9)
##             :       years_at_residence > 2: no (20.4/5.9)
##             dependents <= 1:
##             :...purpose in {business,car0}: no (9.7/2.5)
##                 purpose in {education,renovations}: yes (13/5.1)
##                 purpose = car:
##                 :...employment_duration in {< 1 year,> 7 years,
##                 :   :                       4 - 7 years}: yes (32/8.3)
##                 :   employment_duration in {1 - 4 years,
##                 :                           unemployed}: no (24.9/9)
##                 purpose = furniture/appliances:
##                 :...months_loan_duration > 39: yes (4.8)
##                     months_loan_duration <= 39:
##                     :...phone = yes: yes (21.9/9.2)
##                         phone = no:
##                         :...employment_duration in {< 1 year,> 7 years,
##                             :                       4 - 7 years}: no (34.1/8.1)
##                             employment_duration = unemployed: yes (3.3/0.4)
##                             employment_duration = 1 - 4 years:
##                             :...percent_of_income <= 1: yes (3.8)
##                                 percent_of_income > 1:
##                                 :...months_loan_duration > 21: no (4.9/0.4)
##                                     months_loan_duration <= 21:
##                                     :...years_at_residence <= 3: no (20.9/8.8)
##                                         years_at_residence > 3: yes (5.8)
##
```

```
## -----  Trial 5:  -----
##
## Decision tree:
##
## checking_balance = unknown:
## :...other_credit = store: yes (16.9/7.5)
## :   other_credit = bank:
## :   :...housing = other: no (8.3/1.8)
## :   :   housing = rent: yes (4.4/0.8)
## :   :   housing = own:
## :   :   :...phone = no: no (26.9/9.7)
## :   :       phone = yes: yes (12.1/5)
## :   other_credit = none:
## :   :...credit_history in {critical,perfect,very good}: no (60.4/5.1)
## :       credit_history in {good,poor}:
## :       :...purpose in {business,car,car0,education}: no (53.6/12.8)
## :           purpose = renovations: yes (7.3/1.1)
## :           purpose = furniture/appliances:
## :           :...job = unemployed: no (0)
## :               job in {management,unskilled}: yes (19.2/7)
## :               job = skilled:
## :               :...phone = yes: no (14.6/1.8)
## :                   phone = no:
## :                   :...age > 32: no (9.2)
## :                       age <= 32:
## :                       :...employment_duration = 1 - 4 years: no (4.1)
## :                           employment_duration in {< 1 year,> 7 years,
## :                           :                       4 - 7 years,unemployed}:
## :                           :...savings_balance in {< 100 DM,
## :                               :                   100 - 500 DM}: yes (20.5/3)
## :                               savings_balance in {> 1000 DM,500 - 1000 DM,
## :                                                   unknown}: no (3.4)
## checking_balance in {< 0 DM,> 200 DM,1 - 200 DM}:
## :...percent_of_income <= 2:
##     :...amount > 11054: yes (14.2/1.2)
##     :   amount <= 11054:
##     :   :...other_credit = bank: no (32.3/9.7)
##     :       other_credit = store: yes (8.9/2.6)
##     :       other_credit = none:
##     :       :...purpose in {business,renovations}: yes (20.3/9.1)
##     :           purpose in {car0,education}: no (8.4/3.7)
##     :           purpose = car:
##     :           :...savings_balance in {< 100 DM,> 1000 DM,500 - 1000 DM,
##     :           :   :                   unknown}: no (46.6/7.9)
##     :           :   savings_balance = 100 - 500 DM: yes (13.8/3.3)
##     :           purpose = furniture/appliances:
##     :           :...employment_duration in {> 7 years,
##     :               :                       4 - 7 years}: no (18.2/2.6)
##     :               employment_duration in {1 - 4 years,
##     :               :                       unemployed}: yes (50.8/19.5)
##     :               employment_duration = < 1 year:
##     :               :...job in {management,skilled,unemployed}: no (16.3/2.9)
##     :                   job = unskilled: yes (6/1.6)
##     percent_of_income > 2:
```

```
##     :...years_at_residence <= 1:
##         :...other_credit in {bank,store}: no (7.6)
##         :   other_credit = none:
##         :   :...months_loan_duration > 42: no (2.9)
##         :       months_loan_duration <= 42:
##         :       :...age <= 36: no (26.6/8.4)
##         :           age > 36: yes (5.3)
##         years_at_residence > 1:
##         :...job = unemployed: no (5.2)
##             job in {management,skilled,unskilled}:
##             :...credit_history = perfect: yes (10.9)
##                 credit_history in {critical,good,poor,very good}:
##                 :...employment_duration = < 1 year:
##                     :...checking_balance = > 200 DM: no (2.7)
##                     :   checking_balance in {< 0 DM,1 - 200 DM}:
##                     :   :...months_loan_duration > 21: yes (23.4/0.7)
##                     :       months_loan_duration <= 21:
##                     :       :...amount <= 1928: yes (18.4/4.4)
##                     :           amount > 1928: no (4.5)
##                     employment_duration in {> 7 years,1 - 4 years,4 - 7 years,
##                     :                       unemployed}:
##                     :...months_loan_duration <= 11:
##                         :...age > 47: no (12.2)
##                         :   age <= 47:
##                         :   :...purpose in {business,car,car0,
##                         :       :           furniture/appliances,
##                         :       :           renovations}: no (25/9.2)
##                         :       purpose = education: yes (3.5)
##                         months_loan_duration > 11:
##                         :...savings_balance in {> 1000 DM,100 - 500 DM}:
##                             :...age <= 58: no (22.7/3.4)
##                             :   age > 58: yes (4.4)
##                             savings_balance in {< 100 DM,500 - 1000 DM,unknown}:
##                             :...years_at_residence <= 2: yes (76.1/22.8)
##                                 years_at_residence > 2:
##                                 :...purpose in {business,car0,
##                                     :           education}: yes (24.7/7.1)
##                                     purpose = renovations: no (1.1)
##                                     purpose = furniture/appliances: [S1]
##                                     purpose = car:
##                                     :...amount <= 1388: yes (17.8/2.2)
##                                         amount > 1388:
##                                         :...housing = own: no (10.9)
##                                             housing in {other,rent}: [S2]
##
## SubTree [S1]
##
## employment_duration = unemployed: no (4.4)
## employment_duration in {> 7 years,1 - 4 years,4 - 7 years}:
## :...checking_balance = < 0 DM: yes (35.6/12.4)
##     checking_balance in {> 200 DM,1 - 200 DM}: no (29/10.5)
##
## SubTree [S2]
##
```

```
## savings_balance in {< 100 DM,500 - 1000 DM}: yes (21.4/6.4)
## savings_balance = unknown: no (6.8/1.5)
##
## -----  Trial 6:  -----
##
## Decision tree:
##
## checking_balance in {> 200 DM,unknown}:
## :...purpose = car0: no (2.2)
## :   purpose = renovations: yes (8.4/3.3)
## :   purpose = education:
## :   :...age <= 44: yes (19.8/7.7)
## :   :   age > 44: no (4.4)
## :   purpose = business:
## :   :...existing_loans_count > 2: yes (3.3)
## :   :   existing_loans_count <= 2:
## :   :   :...amount <= 1823: no (8.1)
## :   :       amount > 1823:
## :   :       :...percent_of_income <= 3: no (12.1/3.3)
## :   :           percent_of_income > 3: yes (13.2/3.4)
## :   purpose = car:
## :   :...job in {management,unemployed}: no (20.8/1.6)
## :   :   job = unskilled:
## :   :   :...years_at_residence <= 3: no (11/1.3)
## :   :   :   years_at_residence > 3: yes (14.5/3.2)
## :   :   job = skilled:
## :   :   :...other_credit in {bank,store}: yes (17.6/4.9)
## :   :       other_credit = none:
## :   :       :...existing_loans_count <= 2: no (24.6)
## :   :           existing_loans_count > 2: yes (2.4/0.3)
## :   purpose = furniture/appliances:
## :   :...age > 44: no (22.7)
## :       age <= 44:
## :       :...job = unemployed: no (0)
## :           job = unskilled:
## :           :...existing_loans_count <= 1: yes (20.9/5.6)
## :           :   existing_loans_count > 1: no (4.5)
## :           job in {management,skilled}:
## :           :...dependents > 1: no (6.6)
## :               dependents <= 1:
## :               :...existing_loans_count <= 1:
## :                   :...savings_balance in {> 1000 DM,100 - 500 DM,
## :                   :   :                   500 - 1000 DM,
## :                   :   :                   unknown}: no (16.9)
## :                   :   savings_balance = < 100 DM:
## :                   :   :...age <= 22: yes (8.5/1.3)
## :                   :       age > 22: no (43.1/8.8)
## :                   existing_loans_count > 1:
## :                   :...housing in {other,rent}: yes (9.9/2.1)
## :                       housing = own:
## :                       :...credit_history in {critical,poor,
## :                           :                  very good}: no (18.6/1.6)
## :                           credit_history in {good,perfect}: yes (14.9/4.3)
## checking_balance in {< 0 DM,1 - 200 DM}:
```

```
## :...credit_history = perfect: yes (28.1/9.6)
##     credit_history = very good:
##     :...age <= 23: no (5.5)
##     :   age > 23: yes (30/8.1)
##     credit_history = poor:
##     :...percent_of_income <= 1: no (6.5)
##     :   percent_of_income > 1:
##     :   :...savings_balance in {500 - 1000 DM,unknown}: no (6.4)
##     :       savings_balance in {< 100 DM,> 1000 DM,100 - 500 DM}:
##     :       :...dependents <= 1: yes (25.1/8)
##     :           dependents > 1: no (5/0.9)
##     credit_history = critical:
##     :...savings_balance = unknown: no (8.4)
##     :   savings_balance in {< 100 DM,> 1000 DM,100 - 500 DM,500 - 1000 DM}:
##     :   :...other_credit = bank: yes (16.2/4.3)
##     :       other_credit = store: no (3.7/0.9)
##     :       other_credit = none:
##     :       :...savings_balance in {> 1000 DM,500 - 1000 DM}: yes (7.3/2.3)
##     :           savings_balance = 100 - 500 DM: no (5.9)
##     :           savings_balance = < 100 DM:
##     :           :...purpose = business: no (4.5/2.2)
##     :               purpose in {car0,education,renovations}: yes (8.5/2.2)
##     :               purpose = car:
##     :               :...age <= 29: yes (6.9)
##     :               :   age > 29: no (25.6/6.9)
##     :               purpose = furniture/appliances:
##     :               :...months_loan_duration <= 36: no (38.4/10.9)
##     :                   months_loan_duration > 36: yes (3.8)
##     credit_history = good:
##     :...amount > 8086: yes (24/3.8)
##         amount <= 8086:
##         :...phone = yes:
##             :...age <= 28: yes (23.9/7.5)
##             :   age > 28: no (69.4/17.9)
##             phone = no:
##             :...other_credit in {bank,store}: yes (25.1/7.2)
##                 other_credit = none:
##                 :...percent_of_income <= 2:
##                     :...job in {management,unemployed,unskilled}: no (15.6/2.7)
##                     :   job = skilled:
##                     :   :...amount <= 1386: yes (9.9/1)
##                     :       amount > 1386:
##                     :       :...age <= 24: yes (13.4/4.6)
##                     :           age > 24: no (27.8/3.1)
##                     percent_of_income > 2:
##                     :...checking_balance = < 0 DM: yes (62.5/21.4)
##                         checking_balance = 1 - 200 DM:
##                         :...months_loan_duration > 42: yes (4.9)
##                             months_loan_duration <= 42:
##                             :...existing_loans_count > 1: no (5)
##                                 existing_loans_count <= 1:
##                                 :...age <= 35: no (39.4/13.2)
##                                     age > 35: yes (14.7/4.2)
##
```

```
## -----  Trial 7:  -----
##
## Decision tree:
##
## checking_balance = unknown:
## :...employment_duration in {> 7 years,4 - 7 years}: no (101.1/20.4)
## :   employment_duration = unemployed: yes (16.6/8)
## :   employment_duration = < 1 year:
## :   :...amount <= 4594: no (30/5.7)
## :   :   amount > 4594: yes (10.6/0.3)
## :   employment_duration = 1 - 4 years:
## :   :...dependents > 1: no (8)
## :       dependents <= 1:
## :       :...months_loan_duration <= 16: no (32.8/5.3)
## :           months_loan_duration > 16:
## :           :...existing_loans_count > 2: yes (2.7)
## :               existing_loans_count <= 2:
## :               :...percent_of_income <= 3: no (20.9/5.9)
## :                   percent_of_income > 3:
## :                   :...purpose in {business,car0,education}: yes (10.8)
## :                       purpose in {car,furniture/appliances,
## :                                   renovations}: no (19.7/7.5)
## checking_balance in {< 0 DM,> 200 DM,1 - 200 DM}:
## :...purpose in {car0,education,renovations}: no (67.2/29.2)
##     purpose = business:
##     :...age > 46: yes (5.2)
##     :   age <= 46:
##     :   :...months_loan_duration <= 18: no (17.5)
##     :       months_loan_duration > 18:
##     :       :...other_credit in {bank,store}: no (10/0.5)
##     :           other_credit = none:
##     :           :...employment_duration in {> 7 years,
##     :               :                       unemployed}: yes (6.6)
##     :               employment_duration in {< 1 year,1 - 4 years,4 - 7 years}:
##     :               :...age <= 25: yes (4)
##     :                   age > 25: no (19.2/5.6)
##     purpose = car:
##     :...amount <= 1297: yes (52.4/12.9)
##     :   amount > 1297:
##     :   :...percent_of_income <= 2:
##     :       :...phone = no: no (32.7/6.1)
##     :       :   phone = yes:
##     :       :   :...years_at_residence <= 3: no (20/4.9)
##     :       :       years_at_residence > 3: yes (14.7/3.8)
##     :       percent_of_income > 2:
##     :       :...percent_of_income <= 3: yes (33.1/11.3)
##     :           percent_of_income > 3:
##     :           :...months_loan_duration <= 18: no (18.2/1.6)
##     :               months_loan_duration > 18:
##     :               :...existing_loans_count <= 1: no (19.5/7.2)
##     :                   existing_loans_count > 1: yes (13.8/1)
##     purpose = furniture/appliances:
##     :...savings_balance = > 1000 DM: no (5.2)
##         savings_balance = 100 - 500 DM: yes (18.6/6)
```

```
##         savings_balance in {< 100 DM,500 - 1000 DM,unknown}:
##         :...existing_loans_count > 1:
##             :...existing_loans_count > 2: no (3.6)
##             :   existing_loans_count <= 2:
##             :   :...housing = other: yes (3.3)
##             :       housing in {own,rent}:
##             :       :...savings_balance = 500 - 1000 DM: yes (3.5/1)
##             :           savings_balance = unknown: no (6.9)
##             :           savings_balance = < 100 DM:
##             :           :...age > 54: yes (2.1)
##             :               age <= 54: [S1]
##             existing_loans_count <= 1:
##             :...credit_history in {critical,perfect}: yes (20.3/7.6)
##                 credit_history in {poor,very good}: no (20.8/9.5)
##                 credit_history = good:
##                 :...months_loan_duration <= 7: no (11.4)
##                     months_loan_duration > 7:
##                     :...other_credit = bank: no (14.2/4.6)
##                         other_credit = store: yes (11.7/3.9)
##                         other_credit = none:
##                         :...percent_of_income <= 1: no (20.5/5.2)
##                             percent_of_income > 1:
##                             :...amount > 6078: yes (10.9/1.1)
##                                 amount <= 6078:
##                                 :...dependents > 1: yes (8.7/2.5)
##                                     dependents <= 1: [S2]
##
## SubTree [S1]
##
## employment_duration in {< 1 year,4 - 7 years}: yes (15/2.5)
## employment_duration in {> 7 years,1 - 4 years,unemployed}: no (25.7/2.9)
##
## SubTree [S2]
##
## employment_duration = > 7 years: no (17.9/2.5)
## employment_duration in {< 1 year,1 - 4 years,4 - 7 years,unemployed}:
## :...job = management: no (6.6)
##     job = unemployed: yes (1.1)
##     job in {skilled,unskilled}:
##     :...years_at_residence <= 1: no (11.8/1.8)
##         years_at_residence > 1:
##         :...checking_balance = > 200 DM: no (14.7/6.3)
##             checking_balance = 1 - 200 DM: yes (25.1/8.8)
##             checking_balance = < 0 DM:
##             :...months_loan_duration <= 16: no (13.8/3.4)
##                 months_loan_duration > 16: yes (19.1/5.5)
##
## -----  Trial 8:  -----
##
## Decision tree:
##
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...credit_history = perfect:
## :   :...housing in {other,rent}: yes (8.3)
```

```
## :   :   housing = own:
## :   :   :...age <= 34: no (16.6/4.7)
## :   :       age > 34: yes (5.8)
## :   credit_history = poor:
## :   :...checking_balance = < 0 DM: yes (12/2.7)
## :   :   checking_balance = 1 - 200 DM:
## :   :   :...housing = rent: no (8.6)
## :   :       housing in {other,own}:
## :   :       :...amount <= 2279: yes (6.8/0.6)
## :   :           amount > 2279: no (20/5.7)
## :   credit_history = very good:
## :   :...existing_loans_count > 1: yes (2.5)
## :   :   existing_loans_count <= 1:
## :   :   :...age <= 23: no (3.7)
## :   :       age > 23:
## :   :       :...amount <= 8386: yes (32.9/8.1)
## :   :           amount > 8386: no (2.5)
## :   credit_history = critical:
## :   :...years_at_residence <= 1: no (8)
## :   :   years_at_residence > 1:
## :   :   :...savings_balance in {> 1000 DM,100 - 500 DM,500 - 1000 DM,
## :   :       :                   unknown}: no (25.5/5.7)
## :   :       savings_balance = < 100 DM:
## :   :       :...age > 61: no (6)
## :   :           age <= 61:
## :   :           :...existing_loans_count > 2: no (10.7/2.4)
## :   :               existing_loans_count <= 2:
## :   :               :...age > 56: yes (5.4)
## :   :                   age <= 56:
## :   :                   :...amount > 2483: yes (34.1/8.9)
## :   :                       amount <= 2483:
## :   :                       :...purpose in {business,education}: yes (4.4)
## :   :                           purpose in {car,car0,furniture/appliances,
## :   :                                       renovations}: no (41.4/10.8)
## :   credit_history = good:
## :   :...amount > 8086: yes (26.6/4.8)
## :       amount <= 8086:
## :       :...savings_balance in {> 1000 DM,500 - 1000 DM}: no (17.5/5.1)
## :           savings_balance = 100 - 500 DM:
## :           :...months_loan_duration <= 27: no (21.3/7.1)
## :           :   months_loan_duration > 27: yes (5.1)
## :           savings_balance = unknown:
## :           :...age <= 56: yes (44.7/16.9)
## :           :   age > 56: no (4.4)
## :           savings_balance = < 100 DM:
## :           :...job = unemployed: yes (0.9)
## :               job = management:
## :               :...employment_duration in {< 1 year,1 - 4 years,4 - 7 years,
## :               :   :                       unemployed}: no (17.3/1.6)
## :               :   employment_duration = > 7 years: yes (8/1.2)
## :               job = unskilled:
## :               :...months_loan_duration <= 26: no (59/19.7)
## :               :   months_loan_duration > 26: yes (3.3)
## :               job = skilled:
```

```
## :               :...purpose in {business,car0,education,
## :                   :           renovations}: yes (16.6/4.1)
## :                   purpose = car:
## :                   :...dependents <= 1: yes (27.7/10.6)
## :                   :   dependents > 1: no (8.1/1.4)
## :                   purpose = furniture/appliances:
## :                   :...years_at_residence <= 1: no (18.7/6.5)
## :                       years_at_residence > 1:
## :                       :...other_credit = bank: yes (4.5)
## :                           other_credit = store: no (2.3)
## :                           other_credit = none:
## :                           :...percent_of_income <= 3: yes (33.5/15)
## :                               percent_of_income > 3: no (27.3/9.3)
## checking_balance in {> 200 DM,unknown}:
## :...years_at_residence > 2: no (135.6/32.2)
##     years_at_residence <= 2:
##     :...months_loan_duration <= 8: no (12.9)
##         months_loan_duration > 8:
##         :...months_loan_duration <= 9: yes (10.4/1.3)
##             months_loan_duration > 9:
##             :...months_loan_duration <= 16: no (31.3/4.2)
##                 months_loan_duration > 16:
##                 :...purpose in {business,car0,renovations}: no (21.3/8.4)
##                     purpose = education: yes (6.3/0.8)
##                     purpose = car:
##                     :...credit_history in {critical,very good}: yes (17.3/2.6)
##                     :   credit_history in {good,perfect,poor}: no (9.6)
##                     purpose = furniture/appliances:
##                     :...credit_history in {critical,perfect,
##                         :                  very good}: no (5.6)
##                         credit_history = poor: yes (4.9)
##                         credit_history = good:
##                         :...housing in {other,rent}: no (2.6)
##                             housing = own:
##                             :...age <= 25: no (6.8)
##                                 age > 25: yes (29.2/10.2)
##
## -----  Trial 9:  -----
##
## Decision tree:
##
## checking_balance = unknown:
## :...dependents > 1: no (26)
## :   dependents <= 1:
## :   :...amount <= 1474: no (39.7)
## :       amount > 1474:
## :       :...employment_duration in {> 7 years,4 - 7 years}:
## :           :...years_at_residence > 2: no (21.8)
## :           :   years_at_residence <= 2:
## :           :   :...age <= 23: yes (4.1)
## :           :       age > 23: no (19.7/4.2)
## :           employment_duration in {< 1 year,1 - 4 years,unemployed}:
## :           :...purpose in {business,renovations}: yes (23.2/3.6)
## :               purpose in {car,car0,education,furniture/appliances}:
```

```
## :               :...other_credit in {bank,store}: yes (29.1/10.5)
## :                   other_credit = none:
## :                   :...purpose in {car,car0}: no (12.3)
## :                       purpose in {education,furniture/appliances}:
## :                       :...amount <= 4455: no (23.7/4.4)
## :                           amount > 4455: yes (11.1/1.3)
## checking_balance in {< 0 DM,> 200 DM,1 - 200 DM}:
## :...percent_of_income <= 2:
##     :...amount > 11054: yes (15.7/3.6)
##     :   amount <= 11054:
##     :   :...savings_balance in {> 1000 DM,500 - 1000 DM,
##     :       :                   unknown}: no (41.5/11.2)
##     :       savings_balance = 100 - 500 DM:
##     :       :...other_credit = bank: no (5.1)
##     :       :   other_credit in {none,store}: yes (21.7/9.4)
##     :       savings_balance = < 100 DM:
##     :       :...employment_duration in {> 7 years,unemployed}: no (34.6/11.5)
##     :           employment_duration = 1 - 4 years:
##     :           :...job = management: yes (5.1/0.8)
##     :           :   job in {skilled,unemployed,unskilled}: no (65.4/15.8)
##     :           employment_duration = < 1 year:
##     :           :...amount <= 2327:
##     :           :   :...age <= 34: yes (20.5/1.9)
##     :           :   :   age > 34: no (3)
##     :           :   amount > 2327:
##     :           :   :...other_credit = bank: yes (2.8)
##     :           :       other_credit in {none,store}: no (20.1/3.9)
##     :           employment_duration = 4 - 7 years:
##     :           :...dependents > 1: no (4.6)
##     :               dependents <= 1:
##     :               :...amount <= 6527: no (16.8/7.2)
##     :                   amount > 6527: yes (7)
##     percent_of_income > 2:
##     :...housing = rent:
##         :...checking_balance in {< 0 DM,1 - 200 DM}: yes (69/22.1)
##         :   checking_balance = > 200 DM: no (3.4)
##         housing = other:
##         :...existing_loans_count > 1: yes (18.7/5.3)
##         :   existing_loans_count <= 1:
##         :   :...savings_balance in {< 100 DM,> 1000 DM,
##         :       :                   500 - 1000 DM}: yes (29.1/8.6)
##         :       savings_balance in {100 - 500 DM,unknown}: no (15.3/3.2)
##         housing = own:
##         :...credit_history in {perfect,poor}: yes (26.9/7.4)
##             credit_history = very good: no (14.9/5.6)
##             credit_history = critical:
##             :...other_credit = bank: yes (11.7/3.4)
##             :   other_credit in {none,store}: no (63/20.3)
##             credit_history = good:
##             :...other_credit = store: yes (8.9/1.4)
##                 other_credit in {bank,none}:
##                 :...age > 54: no (9.5)
##                     age <= 54:
##                     :...existing_loans_count > 1: no (10.2/2.7)
```

```
##                           existing_loans_count <= 1:
##                           :...purpose in {business,renovations}: no (10.1/3.6)
##                               purpose in {car0,education}: yes (4.7)
##                               purpose = car:
##                               :...other_credit = bank: yes (4.9)
##                               :   other_credit = none:
##                               :   :...years_at_residence > 2: no (14.8/4.5)
##                               :       years_at_residence <= 2:
##                               :       :...amount <= 2150: no (14.9/6.2)
##                               :           amount > 2150: yes (11.1)
##                               purpose = furniture/appliances:
##                               :...savings_balance = 100 - 500 DM: yes (3.8)
##                                   savings_balance in {> 1000 DM,
##                                   :                   500 - 1000 DM}: no (2.8)
##                                   savings_balance in {< 100 DM,unknown}:
##                                   :...months_loan_duration > 39: yes (3.3)
##                                       months_loan_duration <= 39:
##                                       :...dependents <= 1: no (57.6/19.4)
##                                           dependents > 1: yes (4.6/1.1)
##
##
## Evaluation on training data (900 cases):
##
## Trial        Decision Tree
## -----      ----------------
##    Size      Errors
##
##    0     56  133(14.8%)
##    1     34  211(23.4%)
##    2     39  201(22.3%)
##    3     47  179(19.9%)
##    4     46  174(19.3%)
##    5     50  197(21.9%)
##    6     55  187(20.8%)
##    7     50  190(21.1%)
##    8     51  192(21.3%)
##    9     47  169(18.8%)
## boost             34( 3.8%)   <<
##
##
##     (a)   (b)    <-classified as
##    ----  ----
##     629     4    (a): class no
##      30   237    (b): class yes
##
##
##  Attribute usage:
##
##  100.00% checking_balance
##  100.00% purpose
##   97.11% years_at_residence
##   96.67% employment_duration
##   94.78% credit_history
##   94.67% other_credit
```

```
##   92.56% job
##   92.11% percent_of_income
##   90.33% amount
##   85.11% months_loan_duration
##   82.78% age
##   82.78% existing_loans_count
##   75.78% dependents
##   71.56% housing
##   70.78% savings_balance
##   49.22% phone
##
##
## Time: 0.2 secs
```

```
credit_boost_pred10 <- predict(credit_boost10, credit_test)
CrossTable(credit_test$default, credit_boost_pred10,
           prop.chisq = FALSE, prop.c = FALSE, prop.r = FALSE,
           dnn = c('actual default', 'predicted default'))
```

```
##
##
##    Cell Contents
## |-------------------------|
## |                       N |
## |         N / Table Total |
## |-------------------------|
##
##
## Total Observations in Table:  100
##
##
##                | predicted default
## actual default |        no |       yes | Row Total |
## ---------------|-----------|-----------|-----------|
##             no |        62 |         5 |        67 |
##                |     0.620 |     0.050 |           |
## ---------------|-----------|-----------|-----------|
##            yes |        13 |        20 |        33 |
##                |     0.130 |     0.200 |           |
## ---------------|-----------|-----------|-----------|
##   Column Total |        75 |        25 |       100 |
## ---------------|-----------|-----------|-----------|
##
##
```

```
## Accuracy
(62+20)/100
```

```
## [1] 0.82
```

It can be noted that the boosting algorithm improves accuracy to 0.82.

```
## Making some mistakes more costly than others

# create dimensions for a cost matrix
matrix_dimensions <- list(c("no", "yes"), c("no", "yes"))
names(matrix_dimensions) <- c("predicted", "actual")
matrix_dimensions
```

```
## $predicted
## [1] "no"  "yes"
##
## $actual
## [1] "no"  "yes"
```

```
# build the matrix
error_cost <- matrix(c(0, 1, 4, 0), nrow = 2, dimnames = matrix_dimensions)
error_cost
```

```
##          actual
## predicted no yes
##       no   0   4
##       yes  1   0
```

```
# apply the cost matrix to the tree
credit_cost <- C5.0(credit_train[-17], credit_train$default,
                    costs = error_cost)
credit_cost_pred <- predict(credit_cost, credit_test)

CrossTable(credit_test$default, credit_cost_pred,
           prop.chisq = FALSE, prop.c = FALSE, prop.r = FALSE,
           dnn = c('actual default', 'predicted default'))
```

```
##
##
##    Cell Contents
## |-------------------------|
## |                       N |
## |         N / Table Total |
## |-------------------------|
##
##
## Total Observations in Table:  100
##
##
##                | predicted default
## actual default |        no |       yes | Row Total |
## ---------------|-----------|-----------|-----------|
##             no |        37 |        30 |        67 |
##                |     0.370 |     0.300 |           |
## ---------------|-----------|-----------|-----------|
##            yes |         7 |        26 |        33 |
##                |     0.070 |     0.260 |           |
## ---------------|-----------|-----------|-----------|
```

```
##   Column Total |        44 |        56 |       100 |
## ---------------|-----------|-----------|-----------|
##
##
```

```
## Accuracy
(37+26)/100
```

```
## [1] 0.63
```

In our case of credit defaults, giving out loan to applicants who are likely to default is far more costlier than that to reject a large number of borderline applicants. Hence, we prefer making errors of false positives than false negatives and thus intend to reduce false negatives. Using the cost matrix, we see a drop in accuracy, however, our goal of reduced false negatives(7 against 13) is being met.

Question 2

Part 2: Rule Learners ————————-

Identifying Poisonous Mushrooms —-

Step 1: Collecting Data

The dataset includes information on 8,124 mushroom samples from 23 species of gilled mushrooms listed in the Audubon Society Field Guide to North American Mushrooms (1981). In the Field Guide, each of mushroom species is identi ed as "de nitely edible", "de nitely poisonous", "likely poisonous, and not recommended to be eaten". For the purposes of this dataset, the latter group was combined with the de nitely poisonous group to make two classes: poisonous and non-poisonous. The data dictionary available on the UCI website describes the 22 features of the mushroom samples, including characteristics such as cap shape, cap color, odor, gill size and color, stalk shape, and habitat.

```
## Step 2: Exploring and preparing the data ----
mushrooms <- read.csv("mushrooms.csv", stringsAsFactors = TRUE)

# examine the structure of the data frame
str(mushrooms)
```

```
## 'data.frame':    8124 obs. of  23 variables:
##  $ type                    : Factor w/ 2 levels "edible","poisonous": 2 1 1 2 1 1 1 1 2 1 ...
##  $ cap_shape               : Factor w/ 6 levels "bell","conical",..: 3 3 1 3 3 3 1 1 3 1 ...
##  $ cap_surface             : Factor w/ 4 levels "fibrous","grooves",..: 4 4 4 3 4 3 4 3 3 4 ...
##  $ cap_color               : Factor w/ 10 levels "brown","buff",..: 1 10 9 9 4 10 9 9 9 10 ...
##  $ bruises                 : Factor w/ 2 levels "no","yes": 2 2 2 2 1 2 2 2 2 2 ...
##  $ odor                    : Factor w/ 9 levels "almond","anise",..: 8 1 2 8 7 1 1 2 8 1 ...
##  $ gill_attachment         : Factor w/ 2 levels "attached","free": 2 2 2 2 2 2 2 2 2 2 ...
##  $ gill_spacing            : Factor w/ 2 levels "close","crowded": 1 1 1 1 2 1 1 1 1 1 ...
##  $ gill_size               : Factor w/ 2 levels "broad","narrow": 2 1 1 2 1 1 1 1 2 1 ...
##  $ gill_color              : Factor w/ 12 levels "black","brown",..: 1 1 2 2 1 2 5 2 8 5 ...
##  $ stalk_shape             : Factor w/ 2 levels "enlarging","tapering": 1 1 1 1 2 1 1 1 1 1 ...
##  $ stalk_root              : Factor w/ 5 levels "bulbous","club",..: 3 2 2 3 3 2 2 2 3 2 ...
##  $ stalk_surface_above_ring: Factor w/ 4 levels "fibrous","scaly",..: 4 4 4 4 4 4 4 4 4 4 ...
```

```
##  $ stalk_surface_below_ring: Factor w/ 4 levels "fibrous","scaly",..: 4 4 4 4 4 4 4 4 4 4 ...
##  $ stalk_color_above_ring  : Factor w/ 9 levels "brown","buff",..: 8 8 8 8 8 8 8 8 8 8 ...
##  $ stalk_color_below_ring  : Factor w/ 9 levels "brown","buff",..: 8 8 8 8 8 8 8 8 8 8 ...
##  $ veil_type               : Factor w/ 1 level "partial": 1 1 1 1 1 1 1 1 1 1 ...
##  $ veil_color              : Factor w/ 4 levels "brown","orange",..: 3 3 3 3 3 3 3 3 3 3 ...
##  $ ring_number             : Factor w/ 3 levels "none","one","two": 2 2 2 2 2 2 2 2 2 2 ...
##  $ ring_type               : Factor w/ 5 levels "evanescent","flaring",..: 5 5 5 5 1 5 5 5 5 5 ...
##  $ spore_print_color       : Factor w/ 9 levels "black","brown",..: 1 2 2 1 2 1 1 2 1 1 ...
##  $ population              : Factor w/ 6 levels "abundant","clustered",..: 4 3 3 4 1 3 3 4 5 4 ...
##  $ habitat                 : Factor w/ 7 levels "grasses","leaves",..: 5 1 3 5 1 1 3 3 1 3 ...
```

```
# drop the veil_type feature
mushrooms$veil_type <- NULL

# examine the class distribution
table(mushrooms$type)
```

```
##
##    edible poisonous
##      4208      3916
```

```
## Step 3: Training a model on the data ----
library(RWeka)

# train OneR() on the data
mushroom_1R <- OneR(type ~ ., data = mushrooms)

## Step 4: Evaluating model performance ----
mushroom_1R
```

```
## odor:
##  almond  -> edible
##  anise   -> edible
##  creosote    -> poisonous
##  fishy   -> poisonous
##  foul    -> poisonous
##  musty   -> poisonous
##  none    -> edible
##  pungent -> poisonous
##  spicy   -> poisonous
## (8004/8124 instances correct)
```

```
summary(mushroom_1R)
```

```
##
## === Summary ===
##
## Correctly Classified Instances        8004               98.5229 %
## Incorrectly Classified Instances       120                1.4771 %
## Kappa statistic                          0.9704
## Mean absolute error                      0.0148
## Root mean squared error                  0.1215
```

```
## Relative absolute error                  2.958  %
## Root relative squared error             24.323  %
## Coverage of cases (0.95 level)          98.5229 %
## Mean rel. region size (0.95 level)      50      %
## Total Number of Instances             8124
##
## === Confusion Matrix ===
##
##     a    b   <-- classified as
##  4208    0 |    a = edible
##   120 3796 |    b = poisonous
```

```
## Step 5: Improving model performance ----
mushroom_JRip <- JRip(type ~ ., data = mushrooms)
mushroom_JRip
```

```
## JRIP rules:
## ===========
##
## (odor = foul) => type=poisonous (2160.0/0.0)
## (gill_size = narrow) and (gill_color = buff) => type=poisonous (1152.0/0.0)
## (gill_size = narrow) and (odor = pungent) => type=poisonous (256.0/0.0)
## (odor = creosote) => type=poisonous (192.0/0.0)
## (spore_print_color = green) => type=poisonous (72.0/0.0)
## (stalk_surface_below_ring = scaly) and (stalk_surface_above_ring = silky) => type=poisonous (68.0/0.0
## (habitat = leaves) and (cap_color = white) => type=poisonous (8.0/0.0)
## (stalk_color_above_ring = yellow) => type=poisonous (8.0/0.0)
##  => type=edible (4208.0/0.0)
##
## Number of Rules : 9
```

```
summary(mushroom_JRip)
```

```
##
## === Summary ===
##
## Correctly Classified Instances        8124               100      %
## Incorrectly Classified Instances         0                 0      %
## Kappa statistic                          1
## Mean absolute error                      0
## Root mean squared error                  0
## Relative absolute error                  0      %
## Root relative squared error              0      %
## Coverage of cases (0.95 level)         100      %
## Mean rel. region size (0.95 level)      50      %
## Total Number of Instances             8124
##
## === Confusion Matrix ===
##
##     a    b   <-- classified as
##  4208    0 |    a = edible
##     0 3916 |    b = poisonous
```

```r
# Rule Learner Using C5.0 Decision Trees (not in text)
library(C50)
mushroom_c5rules <- C5.0(type ~ odor + gill_size, data = mushrooms, rules = TRUE)
summary(mushroom_c5rules)
```

```
##
## Call:
## C5.0.formula(formula = type ~ odor + gill_size, data = mushrooms, rules
##  = TRUE)
##
##
## C5.0 [Release 2.07 GPL Edition]      Sat May 14 22:12:23 2016
## -------------------------------
##
## Class specified by attribute `outcome'
##
## Read 8124 cases (3 attributes) from undefined.data
##
## Rules:
##
## Rule 1: (4328/120, lift 1.9)
##  odor in {almond, anise, none}
##  ->  class edible  [0.972]
##
## Rule 2: (3796, lift 2.1)
##  odor in {creosote, fishy, foul, musty, pungent, spicy}
##  ->  class poisonous  [1.000]
##
## Default class: edible
##
##
## Evaluation on training data (8124 cases):
##
##          Rules
##    ----------------
##      No      Errors
##
##       2  120( 1.5%)   <<
##
##
##     (a)   (b)    <-classified as
##    ----  ----
##    4208          (a): class edible
##     120  3796    (b): class poisonous
##
##
##  Attribute usage:
##
##  100.00% odor
##
##
## Time: 0.0 secs
```

Question 3
Credit data analysis done on Weka with 10-fold cross-validation

=== Run information ===

Scheme: weka.classifiers.trees.J48 -C 0.25 -M 2
Relation: credit
Instances: 1000
Attributes: 17
checking_balance
months_loan_duration
credit_history
purpose
amount
savings_balance
employment_duration
percent_of_income
years_at_residence
age
other_credit
housing
existing_loans_count
job
dependents
phone
default
Test mode: 10-fold cross-validation

=== Classifier model (full training set) ===

J48 pruned tree
---

checking_balance = < 0 DM
| months_loan_duration <= 11
| | existing_loans_count <= 1
| | | housing = own: no (14.0/3.0)
| | | housing = other: yes (2.0)
| | | housing = rent
| | | | savings_balance = unknown: no (0.0)
| | | | savings_balance = < 100 DM: yes (2.0)
| | | | savings_balance = 500 - 1000 DM: no (2.0)
| | | | savings_balance = > 1000 DM: no (0.0)

```
|   |   |   |   savings_balance = 100 - 500 DM: no (0.0)
|   |   existing_loans_count > 1: no (19.0)
|   months_loan_duration > 11
|   |   job = skilled
|   |   |   savings_balance = unknown
|   |   |   |   phone = yes: no (6.0/1.0)
|   |   |   |   phone = no
|   |   |   |   |   percent_of_income <= 2: no (3.0/1.0)
|   |   |   |   |   percent_of_income > 2: yes (8.0)
|   |   |   savings_balance = < 100 DM
|   |   |   |   credit_history = critical
|   |   |   |   |   other_credit = none
|   |   |   |   |   |   months_loan_duration <= 13: yes (6.0/2.0)
|   |   |   |   |   |   months_loan_duration > 13: no (13.0/3.0)
|   |   |   |   |   other_credit = bank: yes (4.0)
|   |   |   |   |   other_credit = store: no (0.0)
|   |   |   |   credit_history = good
|   |   |   |   |   existing_loans_count <= 1
|   |   |   |   |   |   phone = yes: yes (11.0/2.0)
|   |   |   |   |   |   phone = no
|   |   |   |   |   |   |   purpose = furniture/appliances
|   |   |   |   |   |   |   |   years_at_residence <= 1: no (7.0)
|   |   |   |   |   |   |   |   years_at_residence > 1
|   |   |   |   |   |   |   |   |   other_credit = none
|   |   |   |   |   |   |   |   |   |   percent_of_income <= 1: no (3.0)
|   |   |   |   |   |   |   |   |   |   percent_of_income > 1
|   |   |   |   |   |   |   |   |   |   |   housing = own
|   |   |   |   |   |   |   |   |   |   |   |   months_loan_duration <= 16: no (3.0)
|   |   |   |   |   |   |   |   |   |   |   |   months_loan_duration > 16
|   |   |   |   |   |   |   |   |   |   |   |   |   years_at_residence <= 3: yes (8.0)
|   |   |   |   |   |   |   |   |   |   |   |   |   years_at_residence > 3: no (4.0/1.0)
|   |   |   |   |   |   |   |   |   |   |   housing = other: no (1.0)
|   |   |   |   |   |   |   |   |   |   |   housing = rent: yes (4.0/1.0)
|   |   |   |   |   |   |   |   |   other_credit = bank: yes (3.0)
|   |   |   |   |   |   |   |   |   other_credit = store: no (1.0)
|   |   |   |   |   |   |   purpose = education: yes (2.0)
|   |   |   |   |   |   |   purpose = car
|   |   |   |   |   |   |   |   years_at_residence <= 2: yes (4.0)
|   |   |   |   |   |   |   |   years_at_residence > 2
|   |   |   |   |   |   |   |   |   amount <= 1386: yes (2.0)
|   |   |   |   |   |   |   |   |   amount > 1386: no (7.0/1.0)
|   |   |   |   |   |   |   purpose = business: yes (2.0)
|   |   |   |   |   |   |   purpose = renovations: yes (0.0)
|   |   |   |   |   |   |   purpose = car0: yes (0.0)
```

```
|   |   |   |   |   existing_loans_count > 1: yes (6.0)
|   |   |   |   credit_history = poor: yes (8.0)
|   |   |   |   credit_history = perfect
|   |   |   |   |   years_at_residence <= 2: no (3.0/1.0)
|   |   |   |   |   years_at_residence > 2: yes (9.0)
|   |   |   |   credit_history = very good: yes (9.0/1.0)
|   |   |   savings_balance = 500 - 1000 DM
|   |   |   |   amount <= 3079: no (3.0)
|   |   |   |   amount > 3079: yes (2.0)
|   |   |   savings_balance = > 1000 DM: no (4.0)
|   |   |   savings_balance = 100 - 500 DM
|   |   |   |   credit_history = critical: no (2.0)
|   |   |   |   credit_history = good: yes (3.0)
|   |   |   |   credit_history = poor: no (0.0)
|   |   |   |   credit_history = perfect: no (0.0)
|   |   |   |   credit_history = very good: no (1.0)
|   |   job = unskilled
|   |   |   savings_balance = unknown: no (4.0/1.0)
|   |   |   savings_balance = < 100 DM
|   |   |   |   years_at_residence <= 3: no (23.0/8.0)
|   |   |   |   years_at_residence > 3
|   |   |   |   |   percent_of_income <= 1: no (2.0)
|   |   |   |   |   percent_of_income > 1: yes (15.0/4.0)
|   |   |   savings_balance = 500 - 1000 DM: no (0.0)
|   |   |   savings_balance = > 1000 DM: no (0.0)
|   |   |   savings_balance = 100 - 500 DM: yes (3.0/1.0)
|   |   job = management: no (31.0/9.0)
|   |   job = unemployed: yes (5.0/1.0)
checking_balance = 1 - 200 DM
|   amount <= 9857
|   |   savings_balance = unknown: no (41.0/5.0)
|   |   savings_balance = < 100 DM
|   |   |   months_loan_duration <= 22: no (90.0/24.0)
|   |   |   months_loan_duration > 22
|   |   |   |   months_loan_duration <= 42
|   |   |   |   |   other_credit = none
|   |   |   |   |   |   job = skilled: no (21.0/8.0)
|   |   |   |   |   |   job = unskilled: yes (5.0/1.0)
|   |   |   |   |   |   job = management
|   |   |   |   |   |   |   years_at_residence <= 3
|   |   |   |   |   |   |   |   phone = yes: no (4.0/1.0)
|   |   |   |   |   |   |   |   phone = no: yes (2.0)
|   |   |   |   |   |   |   years_at_residence > 3: yes (3.0)
|   |   |   |   |   |   job = unemployed: yes (0.0)
```

```
|   |   |   |   other_credit = bank
|   |   |   |   |   months_loan_duration <= 39: yes (4.0)
|   |   |   |   |   months_loan_duration > 39: no (2.0)
|   |   |   |   other_credit = store: yes (2.0)
|   |   |   months_loan_duration > 42: yes (7.0)
|   |   savings_balance = 500 - 1000 DM
|   |   |   phone = yes: no (3.0)
|   |   |   phone = no
|   |   |   |   percent_of_income <= 2: no (4.0)
|   |   |   |   percent_of_income > 2: yes (4.0/1.0)
|   |   savings_balance = > 1000 DM: no (13.0/3.0)
|   |   savings_balance = 100 - 500 DM
|   |   |   purpose = furniture/appliances: yes (12.0/3.0)
|   |   |   purpose = education: no (0.0)
|   |   |   purpose = car
|   |   |   |   job = skilled
|   |   |   |   |   housing = own: no (10.0/3.0)
|   |   |   |   |   housing = other: no (1.0)
|   |   |   |   |   housing = rent: yes (2.0)
|   |   |   |   job = unskilled: yes (2.0)
|   |   |   |   job = management: yes (3.0)
|   |   |   |   job = unemployed: yes (0.0)
|   |   |   purpose = business
|   |   |   |   housing = own: no (6.0)
|   |   |   |   housing = other: yes (1.0)
|   |   |   |   housing = rent
|   |   |   |   |   existing_loans_count <= 1: no (2.0)
|   |   |   |   |   existing_loans_count > 1: yes (2.0)
|   |   |   purpose = renovations: no (2.0)
|   |   |   purpose = car0: no (1.0)
|   amount > 9857: yes (20.0/3.0)
checking_balance = unknown: no (394.0/46.0)
checking_balance = > 200 DM
|   dependents <= 1: no (54.0/10.0)
|   dependents > 1
|   |   months_loan_duration <= 8: no (4.0)
|   |   months_loan_duration > 8: yes (5.0/1.0)

Number of Leaves  :    89

Size of the tree :         136


Time taken to build model: 0.02 seconds
```

=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances	733	73.3 %
Incorrectly Classified Instances	267	26.7 %
Kappa statistic	0.3054	
Mean absolute error	0.3294	
Root mean squared error	0.4615	
Relative absolute error	78.4024 %	
Root relative squared error	100.6978 %	
Total Number of Instances	1000	

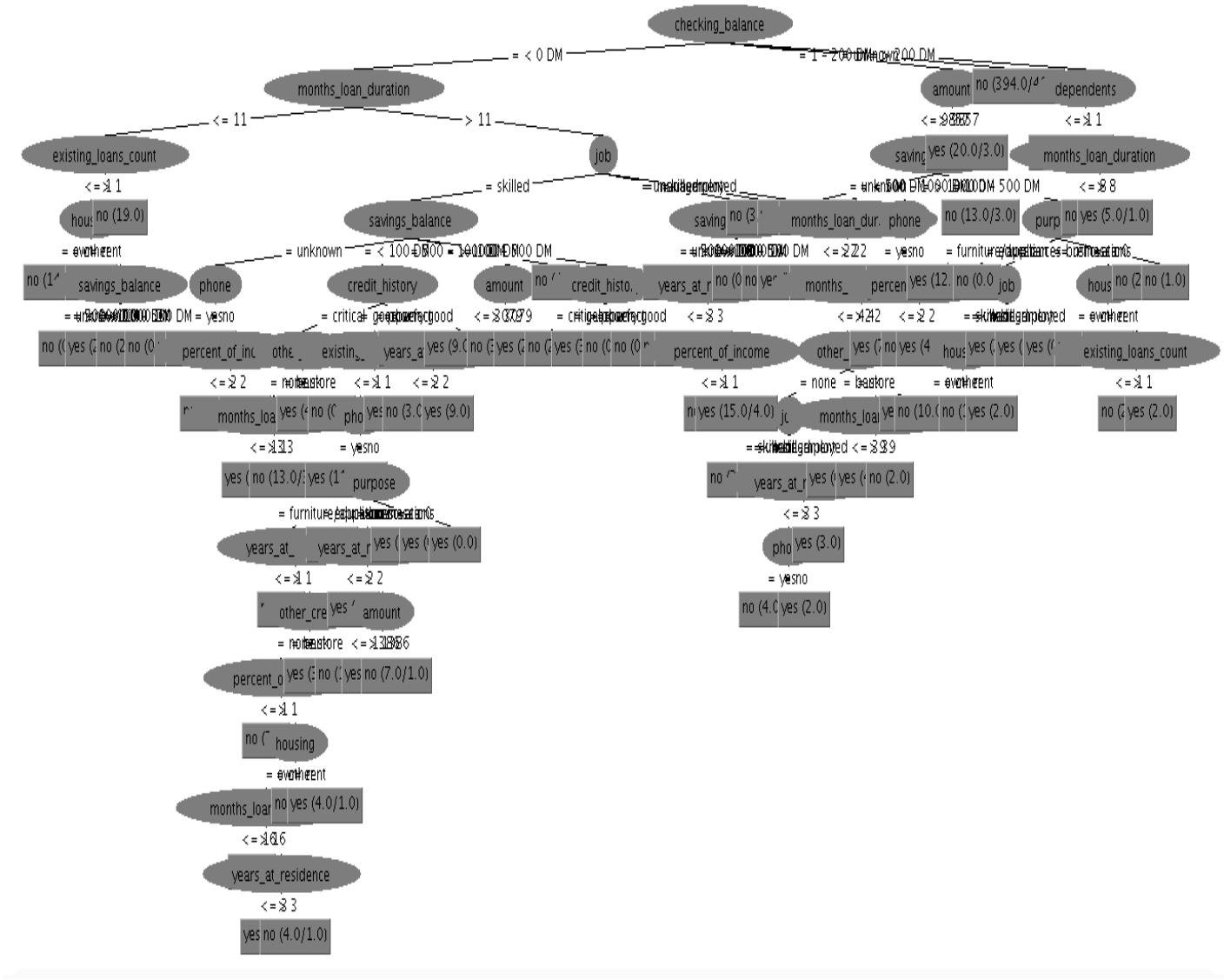
=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.873	0.593	0.774	0.873	0.821	0.314	0.670	0.772	no
	0.407	0.127	0.578	0.407	0.477	0.314	0.670	0.479	yes
Weighted Avg.	0.733	0.453	0.716	0.733	0.718	0.314	0.670	0.684	

=== Confusion Matrix ===

a	b	<-- classified as
611	89	a = no
178	122	b = yes

The analysis on Weka gives nearly the same accuracy (73.3%) as was obtained in R (73%).


checking_balance
months_loan_duration
amount
dependents
existing_loans_count
job
savings_balance
phone
credit_history
purpose
years_at_residence
housing
percent_of_income
other_credit
months_loan_duration
yes (20.0/3.0)
no (13.0/3.0)
yes (5.0/1.0)
no (19.0)
no (394.0/
no (4.0/1.0)
yes (4.0/1.0)
yes (15.0/4.0)
yes (9.0)
yes (7.0/1.0)
yes (3.0)
yes (2.0)
no (4.0)
no (2.0)
no (1.0)