Decision Tree

```r
credit <- read.csv("/cloud/project/credit.csv")
str(credit)
```

```
## 'data.frame':    1000 obs. of  21 variables:
##  $ checking_balance    : chr  "< 0 DM" "1 - 200 DM" "unknown" "< 0 DM" ...
##  $ months_loan_duration: int  6 48 12 42 24 36 24 36 12 30 ...
##  $ credit_history      : chr  "critical" "repaid" "critical" "repaid" ...
##  $ purpose             : chr  "radio/tv" "radio/tv" "education" "furniture" ...
##  $ amount              : int  1169 5951 2096 7882 4870 9055 2835 6948 3059 5234 ...
##  $ savings_balance     : chr  "unknown" "< 100 DM" "< 100 DM" "< 100 DM" ...
##  $ employment_length   : chr  "> 7 yrs" "1 - 4 yrs" "4 - 7 yrs" "4 - 7 yrs" ...
##  $ installment_rate    : int  4 2 2 2 3 2 3 2 2 4 ...
##  $ personal_status     : chr  "single male" "female" "single male" "single male" ...
##  $ other_debtors       : chr  "none" "none" "none" "guarantor" ...
##  $ residence_history   : int  4 2 3 4 4 4 4 2 4 2 ...
##  $ property            : chr  "real estate" "real estate" "real estate" "building society savings" .
##  $ age                 : int  67 22 49 45 53 35 53 35 61 28 ...
##  $ installment_plan    : chr  "none" "none" "none" "none" ...
##  $ housing             : chr  "own" "own" "own" "for free" ...
##  $ existing_credits    : int  2 1 1 1 2 1 1 1 1 2 ...
##  $ default             : int  1 2 1 1 2 1 1 1 1 2 ...
##  $ dependents          : int  1 1 2 2 2 2 1 1 1 1 ...
##  $ telephone           : chr  "yes" "none" "none" "none" ...
##  $ foreign_worker      : chr  "yes" "yes" "yes" "yes" ...
##  $ job                 : chr  "skilled employee" "skilled employee" "unskilled resident" "skilled emp
```

```r
head(credit,10)
```

```
##    checking_balance months_loan_duration credit_history    purpose amount
## 1            < 0 DM                    6       critical   radio/tv   1169
## 2        1 - 200 DM                   48         repaid   radio/tv   5951
## 3           unknown                   12       critical  education   2096
## 4            < 0 DM                   42         repaid  furniture   7882
## 5            < 0 DM                   24        delayed  car (new)   4870
## 6           unknown                   36         repaid  education   9055
## 7           unknown                   24         repaid  furniture   2835
## 8        1 - 200 DM                   36         repaid car (used)   6948
## 9           unknown                   12         repaid   radio/tv   3059
## 10       1 - 200 DM                   30       critical  car (new)   5234
##    savings_balance employment_length installment_rate personal_status
## 1          unknown           > 7 yrs                4     single male
## 2         < 100 DM         1 - 4 yrs                2          female
## 3         < 100 DM         4 - 7 yrs                2     single male
## 4         < 100 DM         4 - 7 yrs                2     single male
## 5         < 100 DM         1 - 4 yrs                3     single male
## 6          unknown         1 - 4 yrs                2     single male
## 7    501 - 1000 DM           > 7 yrs                3     single male
```

```
## 8          < 100 DM        1 - 4 yrs              2       single male
## 9          > 1000 DM       4 - 7 yrs              2    divorced male
## 10         < 100 DM      unemployed               4     married male
##     other_debtors residence_history                 property age
## 1            none               4              real estate  67
## 2            none               2              real estate  22
## 3            none               3              real estate  49
## 4        guarantor              4 building society savings  45
## 5            none               4           unknown/none    53
## 6            none               4           unknown/none    35
## 7            none               4 building society savings  53
## 8            none               2                   other  35
## 9            none               4              real estate  61
## 10           none               2                   other  28
##     installment_plan  housing existing_credits default dependents telephone
## 1              none      own                2       1          1      yes
## 2              none      own                1       2          1     none
## 3              none      own                1       1          2     none
## 4              none for free                1       1          2     none
## 5              none for free                2       2          2     none
## 6              none for free                1       1          2      yes
## 7              none      own                1       1          1     none
## 8              none     rent                1       1          1      yes
## 9              none      own                1       1          1     none
## 10             none      own                2       2          1     none
##     foreign_worker                     job
## 1             yes         skilled employee
## 2             yes         skilled employee
## 3             yes       unskilled resident
## 4             yes         skilled employee
## 5             yes         skilled employee
## 6             yes       unskilled resident
## 7             yes         skilled employee
## 8             yes mangement self-employed
## 9             yes       unskilled resident
## 10            yes mangement self-employed
```

```r
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  101 - 500 DM 501 - 1000 DM        unknown
##          603           48          103           63            183
```

```r
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    18424
```
```
table(credit$default)
```
```
##
##   1   2
## 700 300
```
```
#changing the default indicator to Yes and No
credit$default<- factor(credit$default, levels = c("1", "2"),labels = c("No", "Yes"))
```

Data preparation – creating random training and test datasets We will use 90 percent of the data for training and 10 percent for testing, which will provide us with 100 records to simulate new applicants.

```
nrow(credit)
```
```
## [1] 1000
```
```
set.seed(123)
train_sample <- sample(nrow(credit), 900)
str(train_sample)
```
```
##  int [1:900] 415 463 179 526 195 938 818 118 299 229 ...
```
```
credit_train <- credit[train_sample, ]
credit_test  <- credit[-train_sample, ]
#If randomization was done correctly, we should have about 30 percent of loans with default in each of
prop.table(table(credit_train$default))
```
```
##
##         No       Yes
## 0.7055556 0.2944444
```
```
#install.packages("C50")
library(C50)
credit_model <- C5.0(credit_train[-17], credit_train$default)
#The credit_model object now contains a C5.0 decision tree.
credit_model
```
```
##
## Call:
## C5.0.default(x = credit_train[-17], y = credit_train$default)
##
## Classification Tree
## Number of samples: 900
## Number of predictors: 20
##
## Tree size: 42
##
## Non-standard options: attempt to group attributes
```
```
summary(credit_model)
```
```
##
## Call:
## C5.0.default(x = credit_train[-17], y = credit_train$default)
##
##
## C5.0 [Release 2.07 GPL Edition]       Sun Nov 29 23:25:31 2020
```

```
## --------------------------------
##
## Class specified by attribute `outcome'
##
## Read 900 cases (21 attributes) from undefined.data
##
## Decision tree:
##
## checking_balance in {unknown,> 200 DM}: No (412/54)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...credit_history in {fully repaid this bank,fully repaid}:
##     :...housing = rent: Yes (16/1)
##     :   housing = for free:
##     :   :...other_debtors in {none,guarantor}: Yes (12/1)
##     :   :   other_debtors = co-applicant: No (2)
##     :   housing = own:
##     :   :...purpose in {radio/tv,education,repairs,domestic appliances,
##     :   :               others}: Yes (6/1)
##     :       purpose in {car (used),business,retraining}: No (10/2)
##     :       purpose = car (new):
##     :       :...months_loan_duration <= 22: Yes (6)
##     :       :   months_loan_duration > 22: No (2)
##     :       purpose = furniture:
##     :       :...installment_plan in {none,stores}: No (4)
##     :           installment_plan = bank: Yes (5/1)
##     credit_history in {repaid,critical,delayed}:
##     :...months_loan_duration <= 15: No (180/45)
##         months_loan_duration > 15:
##         :...savings_balance in {unknown,> 1000 DM}:
##             :...credit_history in {critical,delayed}: No (14)
##             :   credit_history = repaid:
##             :   :...purpose = car (new): Yes (7/1)
##             :       purpose in {business,education,repairs,domestic appliances,
##             :       :           retraining,others}: No (5)
##             :       purpose = furniture:
##             :       :...age <= 27: Yes (2)
##             :       :   age > 27: No (5)
##             :       purpose = radio/tv:
##             :       :...amount <= 6110: No (5)
##             :       :   amount > 6110: Yes (2)
##             :       purpose = car (used):
##             :       :...amount <= 6967: No (4)
##             :           amount > 6967: Yes (2)
##             savings_balance in {< 100 DM,101 - 500 DM,501 - 1000 DM}:
##             :...months_loan_duration > 47: Yes (23/3)
##                 months_loan_duration <= 47:
##                 :...employment_length = 0 - 1 yrs:
##                     :...residence_history <= 1: No (16/6)
##                     :   residence_history > 1: Yes (27/6)
##                     employment_length = unemployed:
##                     :...residence_history <= 2: Yes (7)
##                     :   residence_history > 2: No (12/2)
##                     employment_length = > 7 yrs:
##                     :...purpose = car (new): Yes (11/3)
```

```
##                            :     purpose in {radio/tv,car (used),education,repairs,
##                            :     :          domestic appliances,retraining,
##                            :     :          others}: No (13/1)
##                            :     purpose = furniture:
##                            :     :...job in {skilled employee,unskilled resident,
##                            :     :   :       unemployed non-resident}: No (5/1)
##                            :     :   job = mangement self-employed: Yes (2)
##                            :     purpose = business:
##                            :     :...personal_status in {female,divorced male}: Yes (3)
##                            :         personal_status in {single male,
##                            :                             married male}: No (3)
##                    employment_length = 1 - 4 yrs:
##                    :...installment_rate > 3: Yes (20/3)
##                    :   installment_rate <= 3:
##                    :   :...other_debtors = guarantor: No (2)
##                    :       other_debtors = co-applicant: Yes (3)
##                    :       other_debtors = none:
##                    :       :...checking_balance = 1 - 200 DM: No (8/1)
##                    :           checking_balance = < 0 DM: [S1]
##                    employment_length = 4 - 7 yrs:
##                    :...savings_balance in {101 - 500 DM,
##                    :                      501 - 1000 DM}: No (8)
##                        savings_balance = < 100 DM:
##                        :...job in {mangement self-employed,unskilled resident,
##                        :          unemployed non-resident}: No (6)
##                            job = skilled employee:
##                            :...dependents > 1: No (3/1)
##                                dependents <= 1:
##                                :...months_loan_duration <= 22: No (3)
##                                    months_loan_duration > 22: Yes (8)
##
## SubTree [S1]
##
## personal_status in {female,single male}: Yes (13/3)
## personal_status in {married male,divorced male}: No (3)
##
##
## Evaluation on training data (900 cases):
##
##        Decision Tree
##      ----------------
##      Size      Errors
##
##       42    136(15.1%)    <<
##
##
##      (a)    (b)     <-classified as
##      ----   ----
##      612     23     (a): class No
##      113    152     (b): class Yes
##
##
##   Attribute usage:
##
```

5

```
## 100.00% checking_balance
##  54.22% credit_history
##  48.11% months_loan_duration
##  27.22% savings_balance
##  19.56% employment_length
##  11.33% purpose
##   7.00% housing
##   6.89% residence_history
##   5.44% installment_rate
##   4.78% other_debtors
##   3.00% job
##   2.44% personal_status
##   1.56% dependents
##   1.44% amount
##   1.00% installment_plan
##   0.78% age
##
##
## Time: 0.0 secs
```

The first three lines could be represented in plain language as: 1.If the checking account balance is unknown or greater than 200 DM, then classify as "not likely to default." 2.Otherwise, if the checking account balance is less than zero DM or between one and 200 DM...3... and the credit history is perfect or very good, then classify as "likely to default."

```
plot(credit_model)
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
```

```
## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
```

```
## introduced by coercion

## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion

## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion

## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion

## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion

## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion

## Warning in partysplit(varid = as.integer(i), breaks = as.numeric(j[1]), : NAs
## introduced by coercion
## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion

## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion

## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion

## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion

## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion

## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion

## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion

## Warning in .bincode(as.numeric(x), breaks = unique(c(-Inf,
## breaks_split(split), : NAs introduced by coercion
```
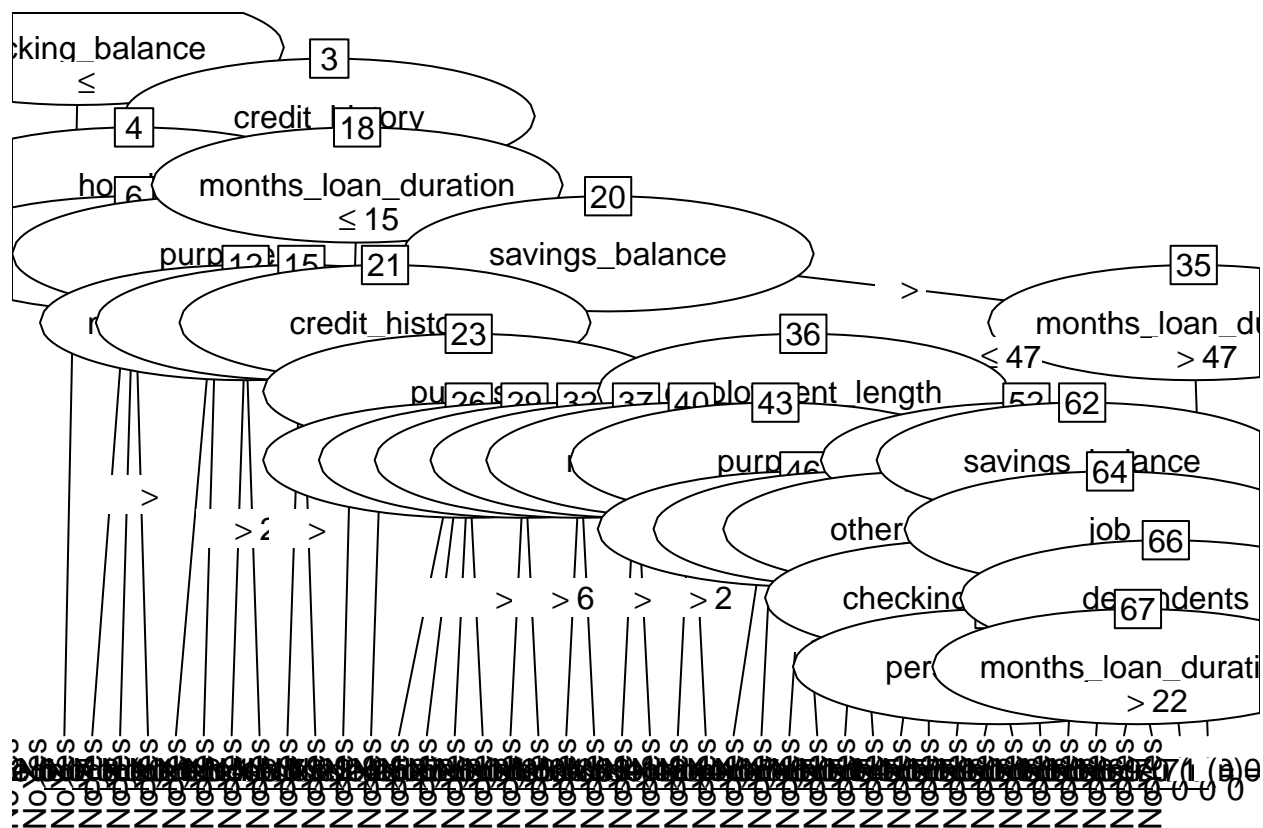
```
#install.packages("partykit")
#library(partykit)


#evaluating model performance
#To apply our decision tree to the test dataset, we use the predict() function as shown in the followin

credit_pred <- predict(credit_model, credit_test)
```

This creates a vector of predicted class values, which we can compare to the actual class values using the CrossTable() function in the gmodels package. Setting the prop.c and prop.r parameters to FALSE removes the column and row percentages from the table. The remaining percentage (prop.t) indicates the proportion of records in the cell out of the total number of records:

```
library(gmodels)
CrossTable(credit_test$default, credit_pred,prop.chisq = FALSE, prop.c = FALSE, prop.r = FALSE, dnn = c
```

```
##
##
##    Cell Contents
## |-------------------------|
## |                       N |
## |         N / Table Total |
## |-------------------------|
##
##
## Total Observations in Table:  100
##
##
##                 | predicted default
```

```
## actual default |         No |        Yes | Row Total |
## ---------------|-----------|-----------|-----------|
##             No |         55 |        10 |        65 |
##                |      0.550 |     0.100 |           |
## ---------------|-----------|-----------|-----------|
##            Yes |         22 |        13 |        35 |
##                |      0.220 |     0.130 |           |
## ---------------|-----------|-----------|-----------|
##   Column Total |         77 |        23 |       100 |
## ---------------|-----------|-----------|-----------|
##
##
```

Improving model performance

Boosting

The C5.0() function makes it easy to add boosting to our decision tree. We simply need to add an additional trials parameter indicating the number of separate decision trees to use in the boosted team. The trials parameter sets an upper limit; the algorithm will stop adding trees if it recognizes that additional trials do not seem to be improving the accuracy. We'll start with 10 trials, a number that has become the de facto standard, as research suggests that this reduces error rates on test data by about 25 percent. Aside from the new parameter, the command is similar to before:

```
credit_boost10 <- C5.0(credit_train[-17], credit_train$default,trials = 10)
summary(credit_boost10)
```

```
##
## Call:
## C5.0.default(x = credit_train[-17], y = credit_train$default, trials = 10)
##
##
## C5.0 [Release 2.07 GPL Edition]      Sun Nov 29 23:25:33 2020
## -------------------------------
##
## Class specified by attribute `outcome'
##
## Read 900 cases (21 attributes) from undefined.data
##
## -----  Trial 0:  -----
##
## Decision tree:
##
## checking_balance in {unknown,> 200 DM}: No (412/54)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...credit_history in {fully repaid this bank,fully repaid}:
##     :...housing = rent: Yes (16/1)
##     :   housing = for free:
##     :   :...other_debtors in {none,guarantor}: Yes (12/1)
##     :   :   other_debtors = co-applicant: No (2)
##     :   housing = own:
##     :   :...purpose in {radio/tv,education,repairs,domestic appliances,
##     :   :              others}: Yes (6/1)
##     :       purpose in {car (used),business,retraining}: No (10/2)
```

9

```
##     :          purpose = car (new):
##     :          :...months_loan_duration <= 22: Yes (6)
##     :          :   months_loan_duration > 22: No (2)
##     :          purpose = furniture:
##     :          :...installment_plan in {none,stores}: No (4)
##     :              installment_plan = bank: Yes (5/1)
##     credit_history in {repaid,critical,delayed}:
##     :...months_loan_duration <= 15: No (180/45)
##         months_loan_duration > 15:
##         :...savings_balance in {unknown,> 1000 DM}:
##             :...credit_history in {critical,delayed}: No (14)
##             :   credit_history = repaid:
##             :   :...purpose = car (new): Yes (7/1)
##             :       purpose in {business,education,repairs,domestic appliances,
##             :       :               retraining,others}: No (5)
##             :       purpose = furniture:
##             :       :...age <= 27: Yes (2)
##             :       :   age > 27: No (5)
##             :       purpose = radio/tv:
##             :       :...amount <= 6110: No (5)
##             :       :   amount > 6110: Yes (2)
##             :       purpose = car (used):
##             :       :...amount <= 6967: No (4)
##             :           amount > 6967: Yes (2)
##           savings_balance in {< 100 DM,101 - 500 DM,501 - 1000 DM}:
##           :...months_loan_duration > 47: Yes (23/3)
##               months_loan_duration <= 47:
##               :...employment_length = 0 - 1 yrs:
##                   :...residence_history <= 1: No (16/6)
##                   :   residence_history > 1: Yes (27/6)
##                   employment_length = unemployed:
##                   :...residence_history <= 2: Yes (7)
##                   :   residence_history > 2: No (12/2)
##                   employment_length = > 7 yrs:
##                   :...purpose = car (new): Yes (11/3)
##                   :   purpose in {radio/tv,car (used),education,repairs,
##                   :   :              domestic appliances,retraining,
##                   :   :              others}: No (13/1)
##                   :   purpose = furniture:
##                   :   :...job in {skilled employee,unskilled resident,
##                   :   :   :           unemployed non-resident}: No (5/1)
##                   :   :   job = mangement self-employed: Yes (2)
##                   :   purpose = business:
##                   :   :...personal_status in {female,divorced male}: Yes (3)
##                   :       personal_status in {single male,
##                   :                              married male}: No (3)
##                   employment_length = 1 - 4 yrs:
##                   :...installment_rate > 3: Yes (20/3)
##                   :   installment_rate <= 3:
##                   :   :...other_debtors = guarantor: No (2)
##                   :       other_debtors = co-applicant: Yes (3)
##                   :       other_debtors = none:
##                   :       :...checking_balance = 1 - 200 DM: No (8/1)
##                   :           checking_balance = < 0 DM: [S1]
```

```
##                      employment_length = 4 - 7 yrs:
##                      :...savings_balance in {101 - 500 DM,
##                      :                       501 - 1000 DM}: No (8)
##                      savings_balance = < 100 DM:
##                      :...job in {mangement self-employed,unskilled resident,
##                      :           unemployed non-resident}: No (6)
##                          job = skilled employee:
##                          :...dependents > 1: No (3/1)
##                              dependents <= 1:
##                              :...months_loan_duration <= 22: No (3)
##                                  months_loan_duration > 22: Yes (8)
##
## SubTree [S1]
##
## personal_status in {female,single male}: Yes (13/3)
## personal_status in {married male,divorced male}: No (3)
##
## -----  Trial 1:  -----
##
## Decision tree:
##
## checking_balance = unknown:
## :...installment_plan = none: No (264.1/49.6)
## :   installment_plan in {bank,stores}:
## :   :...other_debtors in {guarantor,co-applicant}: No (3.2)
## :       other_debtors = none:
## :       :...employment_length in {1 - 4 yrs,0 - 1 yrs,
## :       :                         unemployed}: Yes (40.5/10.3)
## :           employment_length in {4 - 7 yrs,> 7 yrs}: No (29.3/8.6)
## checking_balance in {< 0 DM,1 - 200 DM,> 200 DM}:
## :...other_debtors = guarantor: No (35.3/7.2)
##     other_debtors in {none,co-applicant}:
##     :...savings_balance in {unknown,501 - 1000 DM,> 1000 DM}:
##         :...amount > 1530: No (63.4/13.8)
##         :   amount <= 1530:
##         :   :...installment_rate <= 2: No (6.4)
##         :       installment_rate > 2:
##         :       :...dependents > 1: Yes (5.1)
##         :           dependents <= 1:
##         :           :...months_loan_duration <= 11: No (5.6)
##         :               months_loan_duration > 11: Yes (25.6/7.9)
##         savings_balance in {< 100 DM,101 - 500 DM}:
##         :...credit_history in {critical,delayed}:
##             :...savings_balance = 101 - 500 DM: No (16.2/2.4)
##             :   savings_balance = < 100 DM:
##             :   :...other_debtors = co-applicant: Yes (7.5/2.4)
##             :       other_debtors = none:
##             :       :...personal_status = female: No (26.9/10.7)
##             :           personal_status in {married male,
##             :           :                   divorced male}: Yes (13.8/4)
##             :           personal_status = single male:
##             :           :...installment_rate <= 1: No (9.3)
##             :               installment_rate > 1:
##             :               :...credit_history = critical: No (38.8/10.7)
```

11

```
##            :                      credit_history = delayed: Yes (14.4/3.2)
##          credit_history in {repaid,fully repaid this bank,fully repaid}:
##          :...amount > 11054: Yes (16.9/0.8)
##              amount <= 11054:
##              :...job = mangement self-employed: No (36.5/13.6)
##                  job = unemployed non-resident: Yes (4.5)
##                  job in {skilled employee,unskilled resident}:
##                  :...installment_rate <= 2:
##                      :...dependents > 1: Yes (11.2/2.4)
##                      :   dependents <= 1:
##                      :   :...installment_rate <= 1: Yes (24.8/9.3)
##                      :       installment_rate > 1: No (42.6/14.4)
##                      installment_rate > 2:
##                      :...personal_status in {female,married male,
##                      :                       divorced male}: Yes (79.5/19.9)
##                         personal_status = single male:
##                         :...savings_balance = 101 - 500 DM: No (9.1/1.6)
##                             savings_balance = < 100 DM:
##                             :...months_loan_duration <= 11: No (9.9/2.2)
##                                 months_loan_duration > 11: Yes (59.6/13.8)
##
## -----  Trial 2:  -----
##
## Decision tree:
##
## foreign_worker = no: No (27.8/3.9)
## foreign_worker = yes:
## :...checking_balance in {< 0 DM,1 - 200 DM,> 200 DM}:
##     :...property = unknown/none:
##     :   :...housing in {own,rent}: Yes (31.8/5.2)
##     :   :   housing = for free:
##     :   :   :...dependents > 1: Yes (23.5/5.4)
##     :   :       dependents <= 1:
##     :   :       :...employment_length in {0 - 1 yrs,4 - 7 yrs,
##     :   :       :                         unemployed}: No (18.3/2.4)
##     :   :           employment_length in {1 - 4 yrs,> 7 yrs}:
##     :   :           :...savings_balance in {unknown,< 100 DM,501 - 1000 DM,
##     :   :           :                       > 1000 DM}: Yes (31.3/7.9)
##     :   :               savings_balance = 101 - 500 DM: No (4.5/0.7)
##     :   property in {building society savings,real estate,other}:
##     :   :...purpose in {car (used),business,repairs,retraining,
##     :   :               others}: No (81.6/25.7)
##     :       purpose in {education,domestic appliances}: Yes (28.2/10.3)
##     :       purpose = radio/tv:
##     :       :...months_loan_duration > 36: Yes (15.1/1.3)
##     :       :   months_loan_duration <= 36:
##     :       :   :...credit_history in {repaid,critical,fully repaid this bank,
##     :       :   :                      delayed}: No (112.3/35.6)
##     :       :       credit_history = fully repaid: Yes (4.1)
##     :       purpose = car (new):
##     :       :...savings_balance = > 1000 DM: No (4.8)
##     :       :   savings_balance in {unknown,< 100 DM,101 - 500 DM,
##     :       :   :                   501 - 1000 DM}:
##     :       :   :...installment_plan = bank: Yes (15.7/2.6)
```

```
##    :           :             installment_plan = stores: No (1.3/0.7)
##    :           :             installment_plan = none:
##    :           :             :...dependents > 1: No (15.8/5.3)
##    :           :                 dependents <= 1:
##    :           :                 :...installment_rate <= 1: No (13.3/5.2)
##    :           :                     installment_rate > 1: Yes (67.9/19.4)
##    :        purpose = furniture:
##    :        :...installment_plan = stores: No (5.5)
##    :             installment_plan in {none,bank}:
##    :             :...other_debtors = guarantor: No (3.9)
##    :                 other_debtors in {none,co-applicant}:
##    :                 :...savings_balance in {unknown,> 1000 DM}: No (10.1/2.9)
##    :                     savings_balance in {101 - 500 DM,
##    :                     :                   501 - 1000 DM}: Yes (3.5)
##    :                     savings_balance = < 100 DM:
##    :                     :...amount <= 4473: No (66.2/30.1)
##    :                         amount > 4473: Yes (7)
##    checking_balance = unknown:
##    :...other_debtors = guarantor: No (3.9)
##        other_debtors = co-applicant: Yes (13.6/5.2)
##        other_debtors = none:
##        :...installment_plan = bank: Yes (50/21.1)
##            installment_plan in {none,stores}:
##            :...purpose in {radio/tv,car (used),domestic appliances,retraining,
##            :               others}: No (101.9/8.4)
##                purpose in {car (new),furniture,business,education,repairs}:
##                :...amount > 7763: Yes (14.9/2)
##                    amount <= 7763:
##                    :...credit_history in {critical,
##                        :                  fully repaid this bank}: No (42.2/4.6)
##                        credit_history in {repaid,delayed,fully repaid}:
##                        :...savings_balance in {unknown,101 - 500 DM,
##                            :                   501 - 1000 DM}: No (28.8/8.4)
##                            savings_balance = > 1000 DM: Yes (8.2/2.6)
##                            savings_balance = < 100 DM:
##                            :...amount <= 1778: No (10.5)
##                                amount > 1778: Yes (32.3/9.2)
##
## -----  Trial 3:  -----
##
## Decision tree:
##
## checking_balance in {unknown,> 200 DM}:
## :...foreign_worker = no: No (9.9)
## :   foreign_worker = yes:
## :   :...employment_length in {4 - 7 yrs,> 7 yrs}:
## :       :...dependents <= 1: No (112.3/11.8)
## :       :   dependents > 1:
## :       :   :...checking_balance = unknown: No (34.4/11.6)
## :       :       checking_balance = > 200 DM: Yes (5/0.5)
## :       employment_length in {1 - 4 yrs,0 - 1 yrs,unemployed}:
## :       :...other_debtors = guarantor: No (2.7)
## :           other_debtors = co-applicant: Yes (12.8/3.5)
## :           other_debtors = none:
```

```
## :              :...purpose in {car (used),education,domestic appliances,
## :              :                retraining,others}: No (36.8/9.2)
## :              purpose in {business,repairs}: Yes (33.3/9.6)
## :              purpose = car (new):
## :              :...housing in {own,for free}: No (28.7/9.2)
## :              :   housing = rent: Yes (5.6)
## :              purpose = furniture:
## :              :...job in {skilled employee,
## :              :   :        unemployed non-resident}: No (18.3/2.3)
## :              :   job in {mangement self-employed,
## :              :           unskilled resident}: Yes (18.6/6.9)
## :              purpose = radio/tv:
## :              :...job = unemployed non-resident: No (0)
## :                  job in {mangement self-employed,
## :                  :       unskilled resident}: Yes (16.8/5.6)
## :                  job = skilled employee:
## :                  :...amount <= 4057: No (28.2/1.5)
## :                      amount > 4057: Yes (9.1/3.5)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...credit_history in {fully repaid this bank,fully repaid}: Yes (64.1/18.1)
##      credit_history in {repaid,critical,delayed}:
##      :...other_debtors = guarantor: No (27.7/9.1)
##          other_debtors = co-applicant: Yes (23.3/9.6)
##          other_debtors = none:
##          :...purpose in {furniture,education,repairs,domestic appliances,
##          :               retraining}: Yes (134/54.6)
##              purpose in {business,others}: No (31/7.6)
##              purpose = car (used):
##              :...amount <= 8086: No (28.8/7.8)
##              :   amount > 8086: Yes (11.8/1.2)
##              purpose = car (new):
##              :...amount > 11054: Yes (6.5)
##              :   amount <= 11054:
##              :   :...personal_status = married male: No (5.7/2.6)
##              :       personal_status = divorced male: Yes (7.5/2.4)
##              :       personal_status = female:
##              :       :...amount <= 7418: Yes (26/5.7)
##              :       :   amount > 7418: No (4.4)
##              :       personal_status = single male:
##              :       :...months_loan_duration <= 42: No (55.8/16.6)
##              :           months_loan_duration > 42: Yes (2.9)
##              purpose = radio/tv:
##              :...foreign_worker = no: No (2.4)
##                  foreign_worker = yes:
##                  :...savings_balance in {unknown,501 - 1000 DM,
##                  :                       > 1000 DM}: No (22.5/7.8)
##                      savings_balance = 101 - 500 DM: Yes (10.8/1.1)
##                      savings_balance = < 100 DM:
##                      :...months_loan_duration > 39: Yes (6.1)
##                          months_loan_duration <= 39:
##                          :...amount > 3275: No (7.4)
##                              amount <= 3275:
##                              :...months_loan_duration <= 13: No (19.4/6.9)
##                                  months_loan_duration > 13: Yes (29/7.4)
```

```
##
## -----  Trial 4:  -----
##
## Decision tree:
##
## checking_balance in {unknown,> 200 DM}:
## :...purpose in {radio/tv,car (used),education,domestic appliances,retraining,
## :   :          others}: No (169.6/44.2)
## :   purpose = repairs: Yes (8.9/4.1)
## :   purpose = business:
## :   :...employment_length in {1 - 4 yrs,4 - 7 yrs,> 7 yrs}: No (29.9/6.4)
## :   :   employment_length in {0 - 1 yrs,unemployed}: Yes (12.5/1.1)
## :   purpose = car (new):
## :   :...installment_plan in {bank,stores}: Yes (20.3/7)
## :   :   installment_plan = none:
## :   :   :...amount <= 11760: No (51.5/14.6)
## :   :       amount > 11760: Yes (2.8)
## :   purpose = furniture:
## :   :...credit_history in {critical,fully repaid this bank,
## :   :                      fully repaid}: No (15.2)
## :       credit_history in {repaid,delayed}:
## :       :...other_debtors = guarantor: No (0)
## :           other_debtors = co-applicant: Yes (3.9)
## :           other_debtors = none:
## :           :...months_loan_duration <= 30: No (36.8/11.6)
## :               months_loan_duration > 30: Yes (4.4/0.5)
## checking_balance in {< 0 DM,1 - 200 DM}:
## :...savings_balance in {unknown,> 1000 DM}:
##     :...credit_history in {critical,delayed,fully repaid}: No (23.5/3.2)
##     :   credit_history = fully repaid this bank: Yes (5.2/2.1)
##     :   credit_history = repaid:
##     :   :...amount <= 5771: No (41.4/8.8)
##     :       amount > 5771: Yes (15/2.2)
##     savings_balance in {< 100 DM,101 - 500 DM,501 - 1000 DM}:
##     :...months_loan_duration > 42: Yes (37.3/8.8)
##         months_loan_duration <= 42:
##         :...purpose in {car (used),domestic appliances,retraining,
##             :          others}: No (47.4/17.5)
##             purpose in {education,repairs}: Yes (34.4/15)
##             purpose = business:
##             :...months_loan_duration <= 18: No (10.2)
##             :   months_loan_duration > 18: Yes (20.1/5.7)
##             purpose = car (new):
##             :...other_debtors in {guarantor,co-applicant}: Yes (15/3.5)
##             :   other_debtors = none:
##             :   :...installment_rate <= 3:
##             :       :...residence_history <= 1: Yes (5.9)
##             :       :   residence_history > 1: No (44.1/15.8)
##             :       installment_rate > 3:
##             :       :...amount <= 609: No (4.6)
##             :           amount > 609: Yes (37.7/7.8)
##             purpose = radio/tv:
##             :...foreign_worker = no: No (2.9)
##             :   foreign_worker = yes:
```

```
##                 :     :...employment_length in {0 - 1 yrs,unemployed}: Yes (33.9/12.6)
##                 :          employment_length in {4 - 7 yrs,> 7 yrs}: No (26.5/8.4)
##                 :          employment_length = 1 - 4 yrs:
##                 :          :...months_loan_duration <= 11: No (6.2)
##                 :              months_loan_duration > 11: Yes (28.4/10.8)
##             purpose = furniture:
##             :...installment_plan = stores: No (4.9)
##                 installment_plan in {none,bank}:
##                 :...credit_history in {critical,fully repaid}: No (32.9/13.4)
##                     credit_history in {fully repaid this bank,
##                     :                  delayed}: Yes (8.1/1.1)
##                     credit_history = repaid:
##                     :...checking_balance = 1 - 200 DM: Yes (17.6/6)
##                         checking_balance = < 0 DM:
##                         :...months_loan_duration <= 15: No (16.5/2)
##                             months_loan_duration > 15: Yes (24.3/11)
##
## -----  Trial 5:  -----
##
## Decision tree:
##
## foreign_worker = no: No (23.7/4.5)
## foreign_worker = yes:
## :...checking_balance = < 0 DM:
##     :...job = mangement self-employed:
##     :   :...installment_rate <= 1: Yes (4.3)
##     :   :   installment_rate > 1: No (37.5/9.2)
##     :   job in {skilled employee,unskilled resident,unemployed non-resident}:
##     :   :...months_loan_duration <= 8: No (11.8/1.4)
##     :       months_loan_duration > 8:
##     :       :...purpose in {car (new),car (used),education,repairs,
##     :       :               domestic appliances,retraining}: Yes (102.3/33)
##     :           purpose in {furniture,business,others}: No (73.2/31.3)
##     :           purpose = radio/tv:
##     :           :...employment_length in {1 - 4 yrs,0 - 1 yrs,4 - 7 yrs,
##     :               :                     unemployed}: Yes (33.9/9.2)
##     :               employment_length = > 7 yrs: No (4)
##     checking_balance = > 200 DM:
##     :...dependents > 1: Yes (7.3/0.9)
##     :   dependents <= 1:
##     :   :...age > 39: No (14.2)
##     :       age <= 39:
##     :       :...age <= 24: No (7.4)
##     :           age > 24:
##     :           :...installment_plan in {none,stores}: Yes (31.1/8.4)
##     :               installment_plan = bank: No (3.7)
##     checking_balance = 1 - 200 DM:
##     :...employment_length = 4 - 7 yrs: No (42/8.4)
##     :   employment_length in {1 - 4 yrs,0 - 1 yrs,> 7 yrs,unemployed}:
##     :   :...amount > 12204: Yes (12.4)
##     :       amount <= 12204:
##     :       :...dependents > 1: Yes (24.6/7.7)
##     :           dependents <= 1:
##     :           :...housing = for free: No (20.7/4.2)
```

```
##     :                      housing = rent:
##     :                      :...savings_balance = 101 - 500 DM: Yes (11.1)
##     :                      :   savings_balance in {unknown,< 100 DM,501 - 1000 DM,
##     :                      :   :                              > 1000 DM}:
##     :                      :   :...employment_length in {1 - 4 yrs,
##     :                      :   :                           unemployed}: No (8.3)
##     :                      :       employment_length in {0 - 1 yrs,
##     :                      :                               > 7 yrs}: Yes (23.4/7.5)
##     :                      housing = own:
##     :                      :...residence_history <= 1: No (36.1/6.9)
##     :                          residence_history > 1:
##     :                          :...savings_balance = unknown: No (12.9/1)
##     :                              savings_balance in {< 100 DM,101 - 500 DM,
##     :                              :                     501 - 1000 DM,> 1000 DM}:
##     :                              :...job in {mangement self-employed,
##     :                              :           unemployed non-resident}: Yes (13.4/1.7)
##     :                                  job in {skilled employee,unskilled resident}: [S1]
##     checking_balance = unknown:
##     :...credit_history in {critical,fully repaid this bank}: No (97.7/24.4)
##         credit_history = fully repaid: Yes (7/3.5)
##         credit_history = delayed:
##         :...installment_rate <= 3: No (14.3/2.7)
##         :   installment_rate > 3: Yes (23.2/5.4)
##         credit_history = repaid:
##         :...savings_balance = 101 - 500 DM: No (9.8)
##             savings_balance in {unknown,< 100 DM,501 - 1000 DM,> 1000 DM}:
##             :...existing_credits > 1: Yes (24.7/8.8)
##                 existing_credits <= 1:
##                 :...age > 41: No (14.8/1.6)
##                     age <= 41:
##                     :...residence_history <= 1: No (4.3)
##                         residence_history > 1:
##                         :...savings_balance in {unknown,
##                             :                     > 1000 DM}: No (16.1/1.8)
##                             savings_balance in {< 100 DM,501 - 1000 DM}:
##                             :...personal_status in {married male,
##                                 :                     divorced male}: No (3.8)
##                                 personal_status in {female,single male}:
##                                 :...telephone = yes: No (13.8/5.3)
##                                     telephone = none: [S2]
##
## SubTree [S1]
##
## employment_length = 0 - 1 yrs: Yes (17.4/6.5)
## employment_length in {> 7 yrs,unemployed}: No (14.3/2.9)
## employment_length = 1 - 4 yrs:
## :...months_loan_duration > 22: Yes (7.2/0.4)
##     months_loan_duration <= 22:
##     :...age <= 55: No (26.1/5.7)
##         age > 55: Yes (5.6/0.8)
##
## SubTree [S2]
##
## job = unemployed non-resident: Yes (0)
```

17

```
## job = mangement self-employed: No (2.4)
## job in {skilled employee,unskilled resident}:
## :...months_loan_duration <= 30: Yes (35.3/7.8)
##      months_loan_duration > 30: No (2.9)
##
## -----  Trial 6:  -----
##
## Decision tree:
##
## amount > 6419: Yes (134.8/52.8)
## amount <= 6419:
## :...months_loan_duration <= 7: No (54.4/10.7)
##      months_loan_duration > 7:
##      :...checking_balance = unknown:
##          :...installment_plan = stores: No (14.1/6.9)
##          :   installment_plan = bank:
##          :   :...age > 43: No (8.3)
##          :   :   age <= 43:
##          :   :   :...age <= 31: No (11.9/2.9)
##          :   :       age > 31: Yes (20.4/3.4)
##          :   installment_plan = none:
##          :   :...credit_history in {critical,fully repaid this bank,
##          :   :                      fully repaid}: No (43.1)
##          :       credit_history in {repaid,delayed}:
##          :       :...residence_history <= 1: Yes (10.4/2.6)
##          :           residence_history > 1:
##          :           :...savings_balance in {unknown,
##          :           :                       101 - 500 DM}: No (19.9)
##          :               savings_balance in {< 100 DM,501 - 1000 DM,> 1000 DM}:
##          :               :...other_debtors = guarantor: No (0.3)
##          :                   other_debtors = co-applicant: Yes (4.1/0.7)
##          :                   other_debtors = none:
##          :                   :...age > 29: No (35.2/6.9)
##          :                       age <= 29:
##          :                       :...installment_rate <= 3: No (17.4/5.7)
##          :                           installment_rate > 3: Yes (18.5/3.6)
##          checking_balance in {< 0 DM,1 - 200 DM,> 200 DM}:
##          :...residence_history <= 1:
##              :...installment_plan in {bank,stores}: No (16.5)
##              :   installment_plan = none:
##              :   :...other_debtors in {guarantor,co-applicant}: No (3.5)
##              :       other_debtors = none:
##              :       :...job = mangement self-employed: No (5)
##              :           job in {unskilled resident,
##              :           :       unemployed non-resident}: Yes (9.7/0.9)
##              :           job = skilled employee:
##              :           :...housing in {rent,for free}: Yes (7.8/1.2)
##              :               housing = own:
##              :               :...checking_balance = < 0 DM: Yes (8.8/1.9)
##              :                   checking_balance in {1 - 200 DM,
##              :                                        > 200 DM}: No (32.2/5.5)
##          residence_history > 1:
##          :...installment_rate > 2:
##              :...job = unemployed non-resident: No (5.4)
```

```
##                      :      job in {skilled employee,mangement self-employed,
##                      :      :         unskilled resident}:
##                      :      :...telephone = none:
##                      :          :...installment_plan in {bank,stores}: Yes (40.7/7.7)
##                      :          :   installment_plan = none:
##                      :          :   :...personal_status = female: Yes (44.5/13.9)
##                      :          :       personal_status in {married male,
##                      :          :                               divorced male}: No (20.3/8.8)
##                      :          :       personal_status = single male: [S1]
##                      :          telephone = yes:
##                      :          :...other_debtors in {guarantor,
##                      :          :                       co-applicant}: No (12.3/0.9)
##                      :              other_debtors = none:
##                      :              :...savings_balance in {unknown,101 - 500 DM,
##                      :              :                         > 1000 DM}: No (24.5/5.1)
##                      :                  savings_balance = 501 - 1000 DM: Yes (6.3/2.7)
##                      :                  savings_balance = < 100 DM: [S2]
##                  installment_rate <= 2:
##                  :...credit_history = delayed: No (9)
##                      credit_history in {repaid,critical,fully repaid this bank,
##                      :                       fully repaid}:
##                      :...housing in {rent,for free}: No (49.7/15.4)
##                          housing = own:
##                          :...foreign_worker = no: Yes (2.6/0.3)
##                              foreign_worker = yes:
##                              :...installment_rate <= 1: No (15.2/4.8)
##                                  installment_rate > 1:
##                                  :...months_loan_duration > 36: Yes (5)
##                                      months_loan_duration <= 36: [S3]
##
## SubTree [S1]
##
## savings_balance in {unknown,101 - 500 DM}: No (18.4/3.8)
## savings_balance in {501 - 1000 DM,> 1000 DM}: Yes (5.9/0.7)
## savings_balance = < 100 DM:
## :...property in {building society savings,real estate}: No (37.6/13)
##     property in {other,unknown/none}: Yes (22.4/4.7)
##
## SubTree [S2]
##
## credit_history in {fully repaid this bank,delayed,fully repaid}: Yes (11.2)
## credit_history in {repaid,critical}:
## :...job in {skilled employee,unskilled resident}: Yes (28.2/9.4)
##     job = mangement self-employed: No (10.6/2)
##
## SubTree [S3]
##
## other_debtors = guarantor: No (2.7)
## other_debtors = co-applicant: Yes (4.6/1.9)
## other_debtors = none:
## :...amount <= 3416: Yes (33.8/14.4)
##     amount > 3416: No (11.6/1.3)
##
## -----  Trial 7:  -----
```

```
## 
## Decision tree:
## 
## credit_history in {fully repaid this bank,fully repaid}:
## :...property in {building society savings,unknown/none}: Yes (47.1/12.3)
## :    property in {real estate,other}:
## :    :...savings_balance in {unknown,< 100 DM}: Yes (41.9/17.7)
## :        savings_balance in {101 - 500 DM,501 - 1000 DM,
## :                             > 1000 DM}: No (15.2/1.3)
## credit_history in {repaid,critical,delayed}:
## :...checking_balance in {unknown,> 200 DM}: No (304.8/95)
##     checking_balance in {< 0 DM,1 - 200 DM}:
##     :...property = real estate:
##         :...savings_balance in {unknown,101 - 500 DM,501 - 1000 DM,
##         :   :                    > 1000 DM}: No (28.1/3.9)
##         :   savings_balance = < 100 DM:
##         :   :...age > 33: No (43.4/7.3)
##         :       age <= 33:
##         :       :...amount <= 1217: No (17.7/3.7)
##         :           amount > 1217: Yes (33/7.9)
##         property in {building society savings,other,unknown/none}:
##         :...amount <= 959: Yes (37.7/8.2)
##             amount > 959:
##             :...dependents > 1: No (50/16.5)
##                 dependents <= 1:
##                 :...months_loan_duration > 27:
##                     :...job = unskilled resident: Yes (6.5)
##                     :   job = unemployed non-resident: No (2.7)
##                     :   job in {skilled employee,mangement self-employed}:
##                     :   :...credit_history = delayed: No (17.1/7.4)
##                     :       credit_history in {repaid,critical}:
##                     :       :...residence_history <= 1: No (6.3/1.1)
##                     :           residence_history > 1: Yes (49.2/14.5)
##                     months_loan_duration <= 27:
##                     :...personal_status = married male: Yes (16.7/4.4)
##                         personal_status in {female,single male,divorced male}:
##                         :...credit_history in {critical,
##                             :                  delayed}: No (64.6/13.5)
##                             credit_history = repaid:
##                             :...amount > 10222: Yes (5.8)
##                                 amount <= 10222:
##                                 :...age > 54: No (10.3/1.3)
##                                     age <= 54:
##                                     :...age <= 31: No (66.7/19.4)
##                                         age > 31: Yes (32/8.5)
## 
## -----  Trial 8:  -----
## 
## Decision tree:
## 
## housing in {rent,for free}:
## :...purpose in {business,repairs,domestic appliances,
## :   :              retraining}: Yes (31.2/6.8)
## :   purpose in {education,others}: No (30.1/11.4)
```

```
## :     purpose = car (used):
## :     :...amount <= 11054: No (40.8/12.4)
## :     :    amount > 11054: Yes (5.8)
## :     purpose = car (new):
## :     :...employment_length = unemployed: No (8.8/0.7)
## :     :    employment_length in {1 - 4 yrs,0 - 1 yrs,4 - 7 yrs,> 7 yrs}:
## :     :    :...months_loan_duration <= 9: No (3.9)
## :     :        months_loan_duration > 9: Yes (59.7/16.1)
## :     purpose = furniture:
## :     :...credit_history = delayed: No (0)
## :     :    credit_history in {fully repaid this bank,fully repaid}: Yes (6.1)
## :     :    credit_history in {repaid,critical}:
## :     :    :...job in {skilled employee,unskilled resident,
## :     :    :            unemployed non-resident}: No (45.9/15.3)
## :     :        job = mangement self-employed: Yes (12.6/3.2)
## :     purpose = radio/tv:
## :     :...job in {mangement self-employed,unemployed non-resident}: No (10.8)
## :         job in {skilled employee,unskilled resident}:
## :         :...employment_length in {1 - 4 yrs,0 - 1 yrs,4 - 7 yrs,
## :         :                        unemployed}: Yes (28.6/8)
## :             employment_length = > 7 yrs: No (3.9)
## housing = own:
## :...purpose in {car (used),repairs,domestic appliances,
##     :            retraining}: No (72.6/14.3)
##     purpose in {education,others}: Yes (27.1/11.7)
##     purpose = car (new):
##     :...foreign_worker = no: No (5.2)
##     :    foreign_worker = yes:
##     :    :...installment_rate <= 2:
##     :        :...existing_credits > 3: Yes (2.2)
##     :        :    existing_credits <= 3:
##     :        :    :...age <= 23: Yes (3.9)
##     :        :        age > 23: No (42.6/10.5)
##     :        installment_rate > 2:
##     :        :...installment_plan in {bank,stores}: Yes (13.1)
##     :            installment_plan = none:
##     :            :...checking_balance in {< 0 DM,1 - 200 DM,
##     :            :                        > 200 DM}: Yes (57.9/24.1)
##     :                checking_balance = unknown: No (8.7)
##     purpose = furniture:
##     :...installment_plan = stores: No (9)
##     :    installment_plan in {none,bank}:
##     :    :...credit_history = fully repaid this bank: Yes (4.1)
##     :        credit_history = fully repaid: No (5.3)
##     :        credit_history in {repaid,critical,delayed}:
##     :        :...telephone = none:
##     :            :...months_loan_duration <= 15: No (26.7/7.9)
##     :            :    months_loan_duration > 15: Yes (42.8/12.8)
##     :            telephone = yes:
##     :            :...job in {skilled employee,unskilled resident,
##     :            :            unemployed non-resident}: No (19.9/1.2)
##     :                job = mangement self-employed: Yes (11.9/4.7)
##     purpose = radio/tv:
##     :...checking_balance = unknown: No (49.7/5.9)
```

```
##      :     checking_balance in {< 0 DM,1 - 200 DM,> 200 DM}:
##      :     :...months_loan_duration > 36: Yes (13.4/1.5)
##      :          months_loan_duration <= 36:
##      :          :...other_debtors = guarantor: No (12.1)
##      :               other_debtors = co-applicant: Yes (2.3)
##      :               other_debtors = none:
##      :               :...employment_length in {1 - 4 yrs,4 - 7 yrs,
##      :               :                         > 7 yrs}: No (61.4/17.7)
##      :                    employment_length in {0 - 1 yrs,unemployed}: Yes (29.2/8.7)
##      purpose = business:
##      :...savings_balance in {unknown,101 - 500 DM,501 - 1000 DM}: No (23.1/4)
##          savings_balance = > 1000 DM: Yes (6.4/3.1)
##          savings_balance = < 100 DM:
##          :...amount > 7596: Yes (6.3)
##              amount <= 7596:
##              :...installment_plan = bank: No (5.7)
##                   installment_plan in {none,stores}:
##                   :...telephone = none: No (16.9/4.3)
##                        telephone = yes: Yes (23.1/8.5)
##
## -----  Trial 9:  -----
##
## Decision tree:
##
## checking_balance = unknown:
## :...employment_length in {4 - 7 yrs,> 7 yrs}: No (89.1/5.2)
## :   employment_length in {1 - 4 yrs,0 - 1 yrs,unemployed}:
## :   :...installment_plan in {bank,stores}:
## :       :...other_debtors in {guarantor,co-applicant}: No (3.9)
## :       :   other_debtors = none:
## :       :   :...residence_history <= 1: No (3.2)
## :       :        residence_history > 1:
## :       :        :...purpose in {car (new),furniture,car (used),business,
## :       :        :               repairs,domestic appliances,retraining,
## :       :        :               others}: Yes (30.3/4.6)
## :       :             purpose in {radio/tv,education}: No (4.7)
## :       installment_plan = none:
## :       :...other_debtors = co-applicant: Yes (7.9/1.4)
## :            other_debtors in {none,guarantor}:
## :            :...months_loan_duration <= 16: No (31)
## :                 months_loan_duration > 16:
## :                 :...property in {building society savings,
## :                 :               unknown/none}: No (15.6)
## :                      property in {real estate,other}:
## :                      :...credit_history in {repaid,delayed}: Yes (27.6/10.8)
## :                           credit_history in {critical,fully repaid this bank,
## :                                              fully repaid}: No (9.7)
## checking_balance in {< 0 DM,1 - 200 DM,> 200 DM}:
## :...savings_balance in {unknown,501 - 1000 DM,> 1000 DM}:
##     :...savings_balance = > 1000 DM: No (26.7/6.9)
##     :    savings_balance in {unknown,501 - 1000 DM}:
##     :    :...installment_rate > 3:
##     :         :...residence_history <= 3: Yes (30.5/9.5)
##     :         :    residence_history > 3: No (24.2/2.5)
```

```
##      :           installment_rate <= 3:
##      :           :...housing = rent: No (8.7)
##      :               housing = for free: Yes (5.9/1.6)
##      :               housing = own:
##      :               :...age <= 23: Yes (4.8)
##      :                   age > 23: No (30.2/1.8)
##      savings_balance in {< 100 DM,101 - 500 DM}:
##      :...months_loan_duration > 47: Yes (31.5/6.1)
##          months_loan_duration <= 47:
##          :...other_debtors = co-applicant: Yes (27.6/13.5)
##              other_debtors = guarantor:
##              :...installment_plan in {none,stores}: No (20.5/3)
##              :   installment_plan = bank: Yes (11.7/4.3)
##              other_debtors = none:
##              :...credit_history in {fully repaid this bank,
##                  :                  fully repaid}: Yes (51.4/17.4)
##                  credit_history = delayed:
##                  :...installment_rate <= 1: No (6.1)
##                  :   installment_rate > 1:
##                  :   :...savings_balance = < 100 DM: Yes (23/8)
##                  :       savings_balance = 101 - 500 DM: No (10.3/2.9)
##                  credit_history = critical:
##                  :...savings_balance = 101 - 500 DM: No (7.4/1)
##                  :   savings_balance = < 100 DM:
##                  :   :...personal_status = divorced male: Yes (9/1.3)
##                  :       personal_status in {female,single male,married male}:
##                  :       :...telephone = yes: No (31.3/6.8)
##                  :           telephone = none: [S1]
##                  credit_history = repaid:
##                  :...installment_rate <= 1: Yes (31/9.9)
##                      installment_rate > 1:
##                      :...job = unemployed non-resident: Yes (1.5)
##                          job = mangement self-employed:
##                          :...amount <= 7582: No (26.9/3.8)
##                          :   amount > 7582: Yes (4.2)
##                          job in {skilled employee,unskilled resident}:
##                          :...foreign_worker = no: No (2.2)
##                              foreign_worker = yes:
##                              :...installment_plan = stores: No (4.4)
##                                  installment_plan in {none,bank}:
##                                  :...installment_rate > 3: Yes (85.2/32.7)
##                                      installment_rate <= 3: [S2]
##
## SubTree [S1]
##
## property in {building society savings,real estate,unknown/none}: No (37.7/10)
## property = other: Yes (7.9/0.2)
##
## SubTree [S2]
##
## personal_status in {single male,married male}: No (50.5/13.1)
## personal_status in {female,divorced male}:
## :...existing_credits > 1: Yes (3.9)
##     existing_credits <= 1:
```

```
##      :...savings_balance = < 100 DM: Yes (36.5/13.2)
##          savings_balance = 101 - 500 DM: No (3.2)
##
##
## Evaluation on training data (900 cases):
##
## Trial         Decision Tree
## -----         ---------------
##    Size         Errors
##
##     0     42  136(15.1%)
##     1     27  189(21.0%)
##     2     33  215(23.9%)
##     3     36  210(23.3%)
##     4     36  180(20.0%)
##     5     42  199(22.1%)
##     6     44  216(24.0%)
##     7     21  190(21.1%)
##     8     41  211(23.4%)
##     9     41  181(20.1%)
## boost            45( 5.0%)   <<
##
##
##     (a)   (b)    <-classified as
##    ----  ----
##     628    7    (a): class No
##      38  227    (b): class Yes
##
##
##  Attribute usage:
##
##  100.00% checking_balance
##  100.00% credit_history
##  100.00% purpose
##  100.00% amount
##  100.00% housing
##  100.00% foreign_worker
##   99.56% other_debtors
##   96.78% months_loan_duration
##   87.56% employment_length
##   85.89% installment_plan
##   83.89% savings_balance
##   74.22% residence_history
##   70.11% dependents
##   70.00% property
##   68.56% installment_rate
##   68.00% job
##   51.33% personal_status
##   49.44% age
##   47.00% telephone
##   23.22% existing_credits
##
##
## Time: 0.0 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 |         59 |          6 |        65 |
##                |      0.590 |      0.060 |           |
## ---------------|-----------|-----------|-----------|
##            Yes |         17 |         18 |        35 |
##                |      0.170 |      0.180 |           |
## ---------------|-----------|-----------|-----------|
##   Column Total |         76 |         24 |       100 |
## ---------------|-----------|-----------|-----------|
##
##
```

Making some mistakes cost more than others:

Giving a loan to an applicant who is likely to default can be an expensive mistake. One solution to reduce the number of false negatives may be to reject a larger number of borderline applicants under the assumption that the interest that the bank would earn from a risky loan is far outweighed by the massive loss it would incur if the money is not paid back at all.

To begin constructing the cost matrix, we need to start by specifying the dimensions. Since the predicted and actual values can both take two values, yes or no, we need to describe a 2x2 matrix using a list of two vectors, each with two values. At the same time, we'll also name the matrix dimensions to avoid confusion later on:

```
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"
```

```
#Examining the new object shows that our dimensions have been set up correctly:

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
```

```
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 |        43 |        22 |        65 |
##                |     0.430 |     0.220 |           |
## ---------------|-----------|-----------|-----------|
##            Yes |         8 |        27 |        35 |
##                |     0.080 |     0.270 |           |
## ---------------|-----------|-----------|-----------|
##   Column Total |        51 |        49 |       100 |
## ---------------|-----------|-----------|-----------|
##
##
```

Compared to our boosted model, this version makes more mistakes overall: 41 percent error here versus 18 percent in the boosted case.However, the types of mistakes are very different. Where the previous models classified only 42 and 61 percent of defaults correctly, in this model, 26 / 33 = 79% of the actual defaults were correctly predicted to be defaults. This trade-off resulting in a reduction of false negatives at the expense of increasing false positives may be acceptable if our cost estimates were accurate.