we will now go a step further and try to predict income brackets with real world data and different modelling approaches. We will learn a thing or two along the way, e.g. about the so-called *Accuracy-Interpretability Trade-Off*, so read on…

The data we will use is from here: [Marketing data set](http://sci2s.ugr.es/keel/dataset.php?cod=163). The description reads:

This dataset contains questions from questionnaires that were filled out by shopping mall customers in the San Francisco Bay area. The goal is to predict the Annual Income of Household from the other 13 demographics attributes.

The following extra information (or *metadata*) is provided with the data:

cat(readLines('data/marketing-names.txt'), sep = '\n')

Marketing data set

1: Description.

This dataset contains questions from questionaries that were filled out by shopping mall customers in the San Francisco Bay area. The goal is to predict the Anual Income of Household from the other 13 demographics attributes.

2: Type. Classification

3: Origin. Real world

4: Instances. 6876 (8993)

5: Features. 14

6: Classes 9

7: Missing values. Yes

8: Header.

@relation marketing

@attribute Sex integer [1, 2]

@attribute MaritalStatus integer [1, 5]

@attribute Age integer [1, 7]

@attribute Education integer [1, 6]

@attribute Occupation integer [1, 9]

@attribute YearsInSf integer [1, 5]

@attribute DualIncome integer [1, 3]

@attribute HouseholdMembers integer [1, 9]

@attribute Under18 integer [0, 9]

@attribute HouseholdStatus integer [1, 3]

@attribute TypeOfHome integer [1, 5]

@attribute EthnicClass integer [1, 8]

@attribute Language integer [1, 3]

@attribute Income {1, 2, 3, 4, 5, 6, 7, 8, 9}

@inputs Sex, MaritalStatus, Age, Education, Occupation, YearsInSf, DualIncome, HouseholdMembers, Under18, HouseholdStatus, TypeOfHome, EthnicClass, Language

@outputs Income

DATA DICTIONARY

1 ANNUAL INCOME OF HOUSEHOLD (PERSONAL INCOME IF SINGLE)

1. Less than $10,000

2. $10,000 to $14,999

3. $15,000 to $19,999

4. $20,000 to $24,999

5. $25,000 to $29,999

6. $30,000 to $39,999

7. $40,000 to $49,999

8. $50,000 to $74,999

9. $75,000 or more

2 SEX

1. Male

2. Female

3 MARITAL STATUS

1. Married

2. Living together, not married

3. Divorced or separated

4. Widowed

5. Single, never married

4 AGE

1. 14 thru 17

2. 18 thru 24

3. 25 thru 34

4. 35 thru 44

5. 45 thru 54

6. 55 thru 64

7. 65 and Over

5 EDUCATION

1. Grade 8 or less

2. Grades 9 to 11

3. Graduated high school

4. 1 to 3 years of college

5. College graduate

6. Grad Study

6 OCCUPATION

1. Professional/Managerial

2. Sales Worker

3. Factory Worker/Laborer/Driver

4. Clerical/Service Worker

5. Homemaker

6. Student, HS or College

7. Military

8. Retired

9. Unemployed

7 HOW LONG HAVE YOU LIVED IN THE SAN FRAN./OAKLAND/SAN JOSE AREA?

1. Less than one year

2. One to three years

3. Four to six years

4. Seven to ten years

5. More than ten years

8 DUAL INCOMES (IF MARRIED)

1. Not Married

2. Yes

3. No

9 PERSONS IN YOUR HOUSEHOLD

1. One

2. Two

3. Three

4. Four

5. Five

6. Six

7. Seven

8. Eight

9. Nine or more

10 PERSONS IN HOUSEHOLD UNDER 18

0. None

1. One

2. Two

3. Three

4. Four

5. Five

6. Six

7. Seven

8. Eight

9. Nine or more

11 HOUSEHOLDER STATUS

1. Own

2. Rent

3. Live with Parents/Family

12 TYPE OF HOME

1. House

2. Condominium

3. Apartment

4. Mobile Home

5. Other

13 ETHNIC CLASSIFICATION

1. American Indian

2. Asian

3. Black

4. East Indian

5. Hispanic

6. Pacific Islander

7. White

8. Other

14 WHAT LANGUAGE IS SPOKEN MOST OFTEN IN YOUR HOME?

1. English

2. Spanish

3. Other

Our task is to predict the variable “Income”.

So, let us first load the data, have a look at some of its characteristics and perform a little bit of formatting. After that we divide it into a *training* (80%) and a *test set* (20%) to account for potential *overfitting*:

data <- read.csv("data/marketing.dat")

dim(data)

## [1] 6876 14

str(data)

## 'data.frame': 6876 obs. of 14 variables:

## $ Sex : int 1 2 2 2 1 1 1 1 1 1 ...

## $ MaritalStatus : int 1 1 5 5 1 5 3 1 1 5 ...

## $ Age : int 5 3 1 1 6 2 3 6 7 2 ...

## $ Education : int 5 5 2 2 4 3 4 3 4 4 ...

## $ Occupation : int 5 1 6 6 8 9 3 8 8 9 ...

## $ YearsInSf : int 5 5 5 3 5 4 5 5 4 5 ...

## $ DualIncome : int 3 2 1 1 3 1 1 3 3 1 ...

## $ HouseholdMembers: int 5 3 4 4 2 3 1 3 2 1 ...

## $ Under18 : int 2 1 2 2 0 1 0 0 0 0 ...

## $ HouseholdStatus : int 1 2 3 3 1 2 2 2 2 2 ...

## $ TypeOfHome : int 1 3 1 1 1 3 3 3 3 3 ...

## $ EthnicClass : int 7 7 7 7 7 7 7 7 7 7 ...

## $ Language : int 1 1 1 1 1 1 1 1 1 1 ...

## $ Income : int 9 9 1 1 8 1 6 2 4 1 ...

data\_names <- names(data)

data <- cbind(data[-ncol(data)], factor(data$Income)) # make variable Income (which should be predicted) a factor

names(data) <- data\_names

set.seed(12)

random <- sample(1:nrow(data), 0.8 \* nrow(data))

data\_train <- data[random, ]

data\_test <- data[-random, ]

We start with a simple but comprehensible model, OneR (on CRAN), as a benchmark:

library(OneR)

data <- optbin(data\_train)

model <- OneR(data, verbose = TRUE)

##

## Attribute Accuracy

## 1 \* Age 28.2%

## 2 MaritalStatus 28.11%

## 3 Occupation 28.07%

## 4 HouseholdStatus 27.56%

## 5 DualIncome 27.04%

## 6 Education 25.98%

## 7 HouseholdMembers 22.51%

## 8 Under18 20.69%

## 9 TypeOfHome 19.36%

## 10 EthnicClass 19.29%

## 11 Sex 18.07%

## 12 Language 17.82%

## 13 YearsInSf 17.75%

## ---

## Chosen attribute due to accuracy

## and ties method (if applicable): '\*'

summary(model)

##

## Call:

## OneR.data.frame(x = data, verbose = TRUE)

##

## Rules:

## If Age = 1 then Income = 1

## If Age = 2 then Income = 1

## If Age = 3 then Income = 6

## If Age = 4 then Income = 8

## If Age = 5 then Income = 8

## If Age = 6 then Income = 8

## If Age = 7 then Income = 6

##

## Accuracy:

## 1551 of 5500 instances classified correctly (28.2%)

##

## Contingency table:

## Age

## Income 1 2 3 4 5 6 7 Sum

## 1 \* 421 \* 352 99 43 21 15 25 976

## 2 16 204 107 39 13 22 33 434

## 3 9 147 122 49 12 21 35 395

## 4 5 121 188 71 39 29 42 495

## 5 3 77 179 81 29 23 34 426

## 6 10 93 \* 234 156 70 56 \* 47 666

## 7 12 92 185 155 107 66 33 650

## 8 12 111 211 \* 251 \* 160 \* 86 44 875

## 9 11 76 114 187 104 69 22 583

## Sum 499 1273 1439 1032 555 387 315 5500

## ---

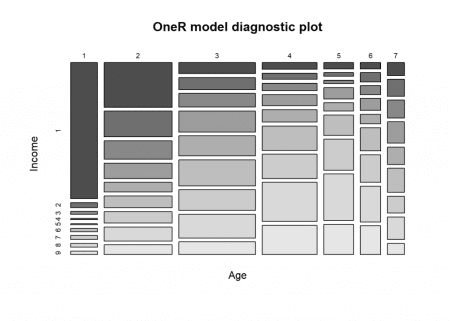
## Maximum in each column: '\*'

##

## Pearson's Chi-squared test:

## X-squared = 2671.2, df = 48, p-value < 2.2e-16

plot(model)



prediction <- predict(model, data\_test)

eval\_model(prediction, data\_test)

##

## Confusion matrix (absolute):

## Actual

## Prediction 1 2 3 4 5 6 7 8 9 Sum

## 1 232 45 46 32 33 27 19 27 24 485

## 2 0 0 0 0 0 0 0 0 0 0

## 3 0 0 0 0 0 0 0 0 0 0

## 4 0 0 0 0 0 0 0 0 0 0

## 5 0 0 0 0 0 0 0 0 0 0

## 6 31 30 44 44 41 66 44 57 50 407

## 7 0 0 0 0 0 0 0 0 0 0

## 8 16 20 20 47 27 87 71 110 86 484

## 9 0 0 0 0 0 0 0 0 0 0

## Sum 279 95 110 123 101 180 134 194 160 1376

##

## Confusion matrix (relative):

## Actual

## Prediction 1 2 3 4 5 6 7 8 9 Sum

## 1 0.17 0.03 0.03 0.02 0.02 0.02 0.01 0.02 0.02 0.35

## 2 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 3 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 4 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 5 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 6 0.02 0.02 0.03 0.03 0.03 0.05 0.03 0.04 0.04 0.30

## 7 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 8 0.01 0.01 0.01 0.03 0.02 0.06 0.05 0.08 0.06 0.35

## 9 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## Sum 0.20 0.07 0.08 0.09 0.07 0.13 0.10 0.14 0.12 1.00

##

## Accuracy:

## 0.2965 (408/1376)

##

## Error rate:

## 0.7035 (968/1376)

##

## Error rate reduction (vs. base rate):

## 0.1176 (p-value < 2.2e-16)

What can we conclude from this? First the most important feature is “Age” while “Marital Status”, “Occupation” and “Household Status” perform comparably well. The overall *accuracy* (i.e. the percentage of correctly predicted instances) is with about 30% not that great, on the other hand not that extraordinarily uncommon when dealing with real-world data. Looking at the model itself, in the form of *rules* and the *diagnostic plot*, we can see that we have *non-linear relationship* between Age and Income: the older one gets the higher the income bracket, except for people who are old enough to retire. This seems plausible.

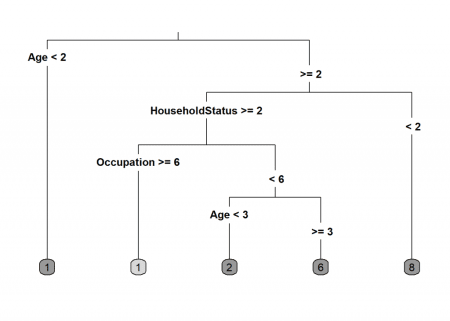
OneR is basically a one step *decision tree*, so the natural choice for our next analysis would be to have a full decision tree built (all packages are on CRAN):

library(rpart)

library(rpart.plot)

model <- rpart(Income ~., data = data\_train)

rpart.plot(model, type = 3, extra = 0, box.palette = "Grays")



prediction <- predict(model, data\_test, type = "class")

eval\_model(prediction, data\_test)

##

## Confusion matrix (absolute):

## Actual

## Prediction 1 2 3 4 5 6 7 8 9 Sum

## 1 201 36 22 13 16 12 8 15 12 335

## 2 43 25 32 22 17 12 10 14 6 181

## 3 0 0 0 0 0 0 0 0 0 0

## 4 0 0 0 0 0 0 0 0 0 0

## 5 0 0 0 0 0 0 0 0 0 0

## 6 18 24 40 50 42 68 32 33 22 329

## 7 0 0 0 0 0 0 0 0 0 0

## 8 17 10 16 38 26 88 84 132 120 531

## 9 0 0 0 0 0 0 0 0 0 0

## Sum 279 95 110 123 101 180 134 194 160 1376

##

## Confusion matrix (relative):

## Actual

## Prediction 1 2 3 4 5 6 7 8 9 Sum

## 1 0.15 0.03 0.02 0.01 0.01 0.01 0.01 0.01 0.01 0.24

## 2 0.03 0.02 0.02 0.02 0.01 0.01 0.01 0.01 0.00 0.13

## 3 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 4 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 5 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 6 0.01 0.02 0.03 0.04 0.03 0.05 0.02 0.02 0.02 0.24

## 7 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## 8 0.01 0.01 0.01 0.03 0.02 0.06 0.06 0.10 0.09 0.39

## 9 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

## Sum 0.20 0.07 0.08 0.09 0.07 0.13 0.10 0.14 0.12 1.00

##

## Accuracy:

## 0.3096 (426/1376)

##

## Error rate:

## 0.6904 (950/1376)

##

## Error rate reduction (vs. base rate):

## 0.134 (p-value < 2.2e-16)

The new model has an accuracy that is a little bit better but the interpretability is a little bit worse. You have to go through the different branches to see in which income bracket it ends. So for example when the age bracket is below 2(which means that it is 1) it predicts income bracket 1, when it is bigger than 2and the Household Status bracket is 1it predicts income income bracket 8and so on. The most important variable, as you can see is again Age (which is reassuring that OneR was on the right track) but we also see Household Status and Occupation again.

What is better than one tree? Many trees! So the next natural step is to have many trees built, while varying the features and the examples that should be included in each tree. At the end it may be that different trees give different income brackets as their respective prediction, which we solve via voting as in a good democracy. This whole method is fittingly called *Random Forests* and fortunately there are many good packages available in R. We use the randomForest package (also on CRAN) here:

library(randomForest)

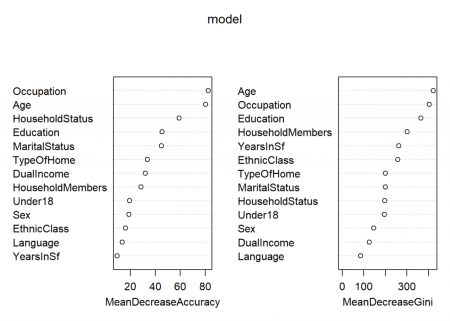
## randomForest 4.6-14

## Type rfNews() to see new features/changes/bug fixes.

set.seed(4543) # for reproducibility

model <- randomForest(Income ~., data = data\_train, importance = TRUE)

varImpPlot(model)



prediction <- predict(model, data\_test)

eval\_model(prediction, data\_test)

##

## Confusion matrix (absolute):

## Actual

## Prediction 1 2 3 4 5 6 7 8 9 Sum

## 1 223 35 26 16 19 11 9 18 16 373

## 2 24 15 12 20 7 11 1 4 1 95

## 3 9 10 11 14 9 6 3 4 2 68

## 4 5 15 25 22 10 22 6 9 5 119

## 5 2 2 8 9 6 12 6 3 1 49

## 6 3 5 15 14 19 40 23 17 15 151

## 7 8 4 7 13 14 26 25 24 5 126

## 8 3 8 5 11 13 44 49 87 68 288

## 9 2 1 1 4 4 8 12 28 47 107

## Sum 279 95 110 123 101 180 134 194 160 1376

##

## Confusion matrix (relative):

## Actual

## Prediction 1 2 3 4 5 6 7 8 9 Sum

## 1 0.16 0.03 0.02 0.01 0.01 0.01 0.01 0.01 0.01 0.27

## 2 0.02 0.01 0.01 0.01 0.01 0.01 0.00 0.00 0.00 0.07

## 3 0.01 0.01 0.01 0.01 0.01 0.00 0.00 0.00 0.00 0.05

## 4 0.00 0.01 0.02 0.02 0.01 0.02 0.00 0.01 0.00 0.09

## 5 0.00 0.00 0.01 0.01 0.00 0.01 0.00 0.00 0.00 0.04

## 6 0.00 0.00 0.01 0.01 0.01 0.03 0.02 0.01 0.01 0.11

## 7 0.01 0.00 0.01 0.01 0.01 0.02 0.02 0.02 0.00 0.09

## 8 0.00 0.01 0.00 0.01 0.01 0.03 0.04 0.06 0.05 0.21

## 9 0.00 0.00 0.00 0.00 0.00 0.01 0.01 0.02 0.03 0.08

## Sum 0.20 0.07 0.08 0.09 0.07 0.13 0.10 0.14 0.12 1.00

##

## Accuracy:

## 0.3459 (476/1376)

##

## Error rate:

## 0.6541 (900/1376)

##

## Error rate reduction (vs. base rate):

## 0.1796 (p-value < 2.2e-16)

As an aside you can see that the basic modelling workflow stayed the same – no matter what approach (OneR, decision tree or random forest) you chose. This standard is kept for most (modern) packages and one of the great strengths of R! With thousands of packages on CRAN alone there are of course sometimes differences but those are normally well documented (so the help function or the vignette are your friends!)

Now, back to the result of the last analysis: again, the overall accuracy is better but because we have hundreds of trees now the interpretability suffered a lot. This is also known under the name Accuracy-Interpretability Trade-Off. The best we can do in the case of random forests is to find out which features are the most important ones. Again Age, Occupation and Household Status show up, which is consistent with our analyses so far. Additionally, because of the many trees that had to be built, this analysis ran a lot longer than the other two.

Random forests are one of the best methods out of the box, so the accuracy of about 34% tells us that our first model (OneR) wasn’t doing too bad in the first place! Why are able to reach comparatively good results with just one feature. This is true for many real-world data sets. Sometimes simple models are not much worse than very complicated ones – you should keep that in mind!