

Predictive Analytics: Application in the Credit Risk Domain
Case Study Teaching (CST)-Vignette in cheat sheet style
("group project cover sheet")

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Contents

1 Contextualization: Credit risk management domain - Specification

1.1 Methodological and linguistic overview

1.1.1 Empirical research methodology in the credit risk management domain

Two predicting models will be of special importance, i.e. Generalized Linear Models (glm) and Score Card Models (scm). As will be shown, the scm-models add two special concepts to the glm-models, i.e. the

1. **Classing/Binning/Grouping** concept, where the predictor variables are partitioned into bins
2. **Weight-of-Evidence (woe)** concept for evaluating the predictive importance of the variables' bins (attributes)

The empirical research methodology deals with the construction, calibration and validation of credit scoring models.

Hint: “Risk Model Management” lecture at the TU Wien by Dr. Thomas Lederer, where the focus lies on the **construction, calibration and validation (CCV)** framework for predictive analytics in the risk management domain.

1.1.2 Credit risk management domain language

‘Vocabulary and Syntax’ of domain language, i.e. key domain concepts are

- Credit scoring model: **Scorecard model**, **logistic regression model**, decision tree model...
- Model **construction** step
 - Distinction between **binary response** (dependent) vs. **interval/nominal/ordinal predictor** (independent) variable
 - **Classing** predictor variables via **binning** interval (numeric) variables and **grouping** nominal (categorical/ordinal) variables
 - Using the **Weight-of-Evidence (woe)** metric in the predictor variables' classing
- Model **calibration** step: Statistical **estimation of the models parameters** and statistical **testing of the model fit** via test statistics (e.g. Akaike Information Criteria abbreviated as **AIC**)
- Model **validation** step: Statistical **testing of the fitted models prediction accuracy** via in-sample and out-of-sample forecast accuracy tests (e.g. Area Under Curve abbreviated as **AUC** and **Gini** coefficient)

1.2 Literature References

Weight-of-Evidence (woe): Origins

- ?
- ?

Scorecard Model: Up-to-date article

Yap/Ong/Husain: Using data mining to improve assessment of credit worthiness via credit scoring models, Expert Systems with Applications, 38, 2011, 13274–13283

Scorecard Model - Reference Manual: Package ‘scorecard’, April 13, 2024

- <https://cran.r-project.org/web/packages/scorecard/scorecard.pdf>

Scorecard Model - Vignette: Developing a Credit Scorecard (Shichen Xie, Michael Thomas)

- <https://cran.r-project.org/web/packages/scorecard/vignettes/demo.html>

Credit Scoring Development Using R, Ng Yong Kad, 11/9/2020:

- <https://rpubs.com/ngyongkad/scorecard>

WoE, IV and Scorecards in Credit Risk Modelling, OEB, March 2018:

- https://rstudio-pubs-static.s3.amazonaws.com/376828_032c59adbc984b0ab892ce0026370352.html

Credit scorecard using Logistic Regression on R:

- <https://stats.stackexchange.com/questions/419160/credit-scorecard-using-logistic-regression-on-r>

2 Use Case Preparation: Loading and preparing data

2.1 Loading libraries: scorecard, tidyverse, knitr

```
library(scorecard)
library(tidyverse)
library(knitr)
```

2.2 Loading external data: germancredit

The variables are distinguished among predictor (feature, independent) variables and response (label, dependent) variables.

```
data("germancredit")
```

Variables: Names

```
germancredit %>% names()

## [1] "status.of.existing.checking.account"
## [2] "duration.in.month"
## [3] "credit.history"
## [4] "purpose"
## [5] "credit.amount"
## [6] "savings.account.and.bonds"
## [7] "present.employment.since"
## [8] "installment.rate.in.percentage.of.disposable.income"
## [9] "personal.status.and.sex"
## [10] "other.debtors.or.guarantors"
## [11] "present.residence.since"
## [12] "property"
## [13] "age.in.years"
## [14] "other.installment.plans"
## [15] "housing"
## [16] "number.of.existing.credits.at.this.bank"
## [17] "job"
## [18] "number.of.people.being.liable.to.provide.maintenance.for"
## [19] "telephone"
## [20] "foreign.worker"
## [21] "creditability"
```

2.3 Selecting response and predictor variables for the use case: data.df

For demonstrating special considerations the following variables from the germancredit data are chosen:

- Response variable is (as always): **creditability** (binary)
- Five predictor variables:
 - **credit.amount** (numeric)
 - **duration.in.month** (numeric)
 - **credit.history** (factor)
 - **purpose** (character)
 - **property** (factor)

Hint: Consider the different primitive data types in R, i.e. numeric (num), factor (Factor), character (chr) and integer (int).

Selecting the response and the five predictor variables

```
data.df <- germancredit %>% select(
  creditability,
  status.of.existing.checking.account,
  duration.in.month,
  credit.history,
  savings.account.and.bonds,
  purpose
)

iv.df <- iv(data.df, y = "creditability")
```

Hint: Consider the different data types applied in R, i.e. vector, matrix, array, data frame (df) and list. These types will be indicated in the names of the variables, e.g. data.df is a data frame that contains the data.

Exemplarily showing the variables' contents

```
data.df %>%
  select(
    creditability,
    status.of.existing.checking.account,
    duration.in.month,
    credit.history,
    savings.account.and.bonds,
    purpose
  ) %>%
  head()
```

##	creditability	status.of.existing.checking.account	duration.in.month
## 1	good	... < 0 DM	6
## 2	bad	0 <= ... < 200 DM	48
## 3	good	no checking account	12
## 4	good	... < 0 DM	42
## 5	bad	... < 0 DM	24
## 6	good	no checking account	36

```
##
##                                credit.history
## 1 critical account/ other credits existing (not at this bank)
## 2                                existing credits paid back duly till now
## 3 critical account/ other credits existing (not at this bank)
## 4                                existing credits paid back duly till now
```

Table 1: data.df

creditability	status.of.existing.checking.account	duration.in.month
good	... < 0 DM	6
bad	0 <= ... < 200 DM	48
good	no checking account	12
good	... < 0 DM	42
bad	... < 0 DM	24
good	no checking account	36

```
## 5          delay in paying off in the past
## 6          existing credits paid back duly till now
## savings.account.and.bonds purpose
## 1 unknown/ no savings account radio/television
## 2          ... < 100 DM radio/television
## 3          ... < 100 DM education
## 4          ... < 100 DM furniture/equipment
## 5          ... < 100 DM car (new)
## 6 unknown/ no savings account education
```

The following chunk contains the code for generating Table ??.

```
data.df[,1:3] %>%
  head() %>%
  kable(align = 'lccc',
        digits = 2,
        caption = "data.df")
```

```
data.df %>%
  select(creditability,
         status.of.existing.checking.account) %>%
  head()
```

```
## creditability status.of.existing.checking.account
## 1 good ... < 0 DM
## 2 bad 0 <= ... < 200 DM
## 3 good no checking account
## 4 good ... < 0 DM
## 5 bad ... < 0 DM
## 6 good no checking account
```

```
data.df %>%
  select(creditability,
         duration.in.month) %>%
  head()
```

```
## creditability duration.in.month
## 1 good 6
## 2 bad 48
## 3 good 12
## 4 good 42
## 5 bad 24
## 6 good 36
```

For checking the statistical relevance of the five predictor variables in the use case their information value is calculated

```
data.df %>% iv(y="creditability")
```

```
##               variable info_value
##               <char>      <num>
## 1: status.of.existing.checking.account 0.6660115
## 2:               duration.in.month 0.3345035
## 3:               credit.history 0.2932335
## 4: savings.account.and.bonds 0.1960096
## 5:               purpose 0.1691951
```

Hint: All predictor variable have info_value > 0.02 so that they have relevance in predicting creditability

2.4 Filtering data and transforming data types: data_f.df

For filtering missing values, information values and identical values the var_filter() function is applied

```
data_f.df <- data.df %>%
  var_filter("creditability")
```

```
## v Variable filtering on 1000 rows and 5 columns in 00:00:00
## v 0 variables are removed in total
```

Exemplarily showing the variables' contents

```
data_f.df %>%
  select(
    creditability,
    status.of.existing.checking.account,
    duration.in.month,
    credit.history,
    savings.account.and.bonds,
    purpose
  ) %>%
  head()
```

```
##      creditability status.of.existing.checking.account duration.in.month
##      <int>               <fctr>                <num>
## 1:           0                ... < 0 DM                6
## 2:           1                0 <= ... < 200 DM           48
## 3:           0                no checking account         12
## 4:           0                ... < 0 DM                42
## 5:           1                ... < 0 DM                24
## 6:           0                no checking account         36
##
##                                credit.history
##                                <fctr>
## 1: critical account/ other credits existing (not at this bank)
## 2:                existing credits paid back duly till now
## 3: critical account/ other credits existing (not at this bank)
## 4:                existing credits paid back duly till now
## 5:                delay in paying off in the past
## 6:                existing credits paid back duly till now
## savings.account.and.bonds      purpose
##                                <fctr>      <char>
## 1: unknown/ no savings account  radio/television
## 2:                ... < 100 DM  radio/television
## 3:                ... < 100 DM  education
```

```
## 4:          ... < 100 DM furniture/equipment
## 5:          ... < 100 DM          car (new)
## 6: unknown/ no savings account      education
```

Hint: Consider the change of the data type of creditability from “factor” to “integer”. This is important as now the **language of data science and machine learning** is applied, where the occurrence of the event is labeled with the number “1” as positive. Think of a medical test. A positive event means that something unwanted was found, so the positive test result is interpreted as “bad”. The same reasoning applies in the credit risk context, where a positive occurrence of the default event is interpreted as “bad”.

2.5 Splitting filtered data into train and validate samples: data_f.list

For having two independent samples for training and evaluation the filtered data frame is split into a list that contains two data frames, i.e. for the train and the validate samples

```
data_f.list <- data_f.df %>%
  split_df("creditability",
    ratios = c(0.65, 0.35),
    name_dfs = c("train", "validate"))
```

Hint: For the use case the splitting is set to 65/35 % and the splitted samples are named **train** and **evaluate** instead of **test** for making clear that it belongs to the **validation step** of the risk model management process.

Hint: By default the splitting is 70/30 % for the train/validate samples, i.e. the argument is ratios=c(0.7,0.3) in the split_df() function. The standard names for the splitted samples are train and test in the function’s argument name_dfs=c(‘train’,‘test’).

Exemplarily showing the content of the data_f.list

```
data_f.list %>% class()
```

```
## [1] "list"
```

```
data_f.list %>% lapply(class)
```

```
## $train
## [1] "data.table" "data.frame"
##
## $validate
## [1] "data.table" "data.frame"
```

```
data_f.list %>% lapply(dim)
```

```
## $train
## [1] 635   6
##
## $validate
## [1] 365   6
```

```
data_f.list$train %>% str()
```

```
## Classes 'data.table' and 'data.frame':  635 obs. of  6 variables:
## $ status.of.existing.checking.account: Factor w/ 4 levels "... < 0 DM","0 <= ... < 200 DM",...: 1 1 ...
## $ duration.in.month                  : num  6 42 24 36 24 12 30 12 15 24 ...
## $ credit.history                     : Factor w/ 5 levels "no credits taken/ all credits paid back o...: 1 1 1 1 1 1 1 1 1 1 ...
## $ savings.account.and.bonds          : Factor w/ 5 levels "... < 100 DM",...: 5 1 1 5 3 4 1 1 1 5 ...
## $ purpose                           : chr  "radio/television" "furniture/equipment" "car (new)" "e...
## $ creditability                     : int   0 0 1 0 0 0 1 1 0 0 ...
```



```
## - attr(*, ".internal.selfref")=<externalptr>
```

2.6 Specifying dummy variable for credit defaults: default.list

For being able to statistically analyze and test the results from the scorecard the default.list is established that contains the default values of the response variable

```
default.list <- data_f.list %>%  
  lapply(function(x) x$creditability)
```

Hint: The default.list is needed for calculating the population stability index (PSI) with the function perf_psi() and the gains table with the function gains_table().

Exemplarily showing the content of the default.list

```
default.list %>% str()
```

```
## List of 2  
## $ train : int [1:635] 0 0 1 0 0 0 1 1 0 0 ...  
## $ validate: int [1:365] 1 0 0 1 0 1 1 1 0 0 ...
```

3 Weight-Of-Evidence (WoE)-based transformation of predictor variables

3.1 WoE-based binning of train and validate samples: bins.list

WoE-based classing, i.e. binning and grouping of predictor variables

```
bins.list <- data_f.list$train %>%
  woebin("creditability")
```

```
## v Binning on 635 rows and 6 columns in 00:00:01
```

Hint: The default binning method is method="width". Other methods are

- "frequ" that support numerical variables as well as
- "tree" and "chimerge" supporting both, i.e. numerical and categorical variables which are used in the optimal binning approach.

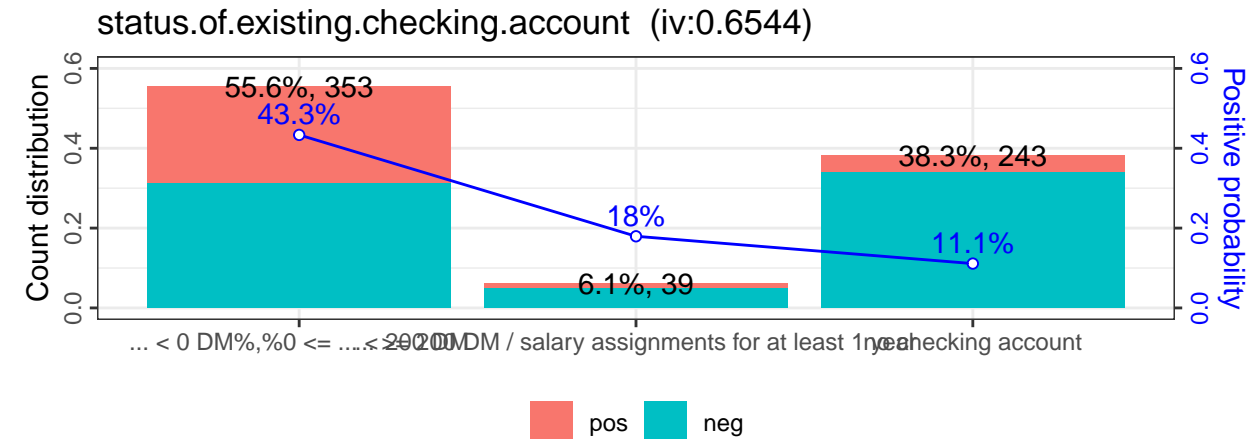
```
bins.list %>% names()
```

```
## [1] "status.of.existing.checking.account" "duration.in.month"
## [3] "credit.history"                    "savings.account.and.bonds"
## [5] "purpose"
```

Plotting the bins (including bin statistics)

```
bins.list$status.of.existing.checking.account %>%
  woebin_plot()
```

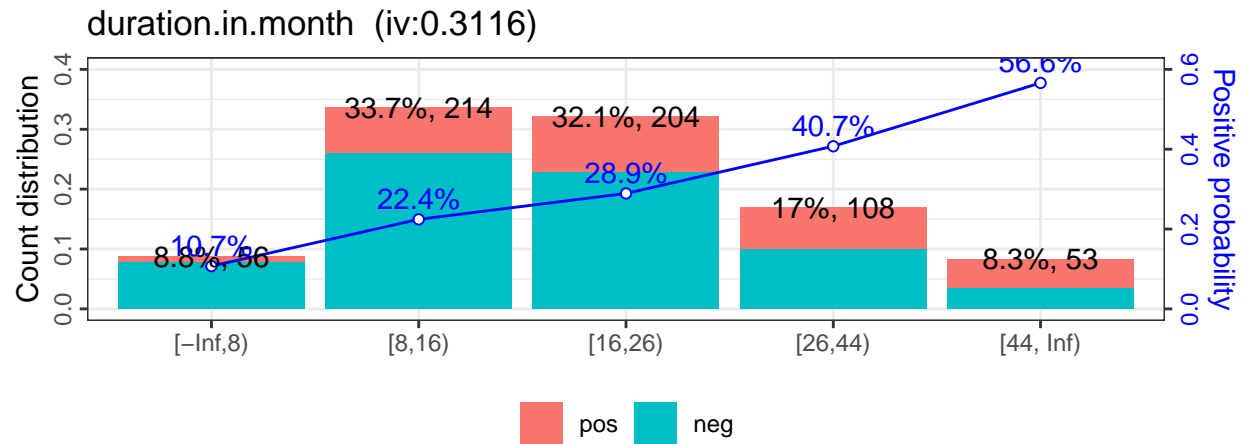
```
## $status.of.existing.checking.account
```



Hint: credit.amount does not have an acceptable structure of the default rates (positive probability) over the bins like e.g. a linear or u-curve structure; hence it should not be included in the scorecard model!

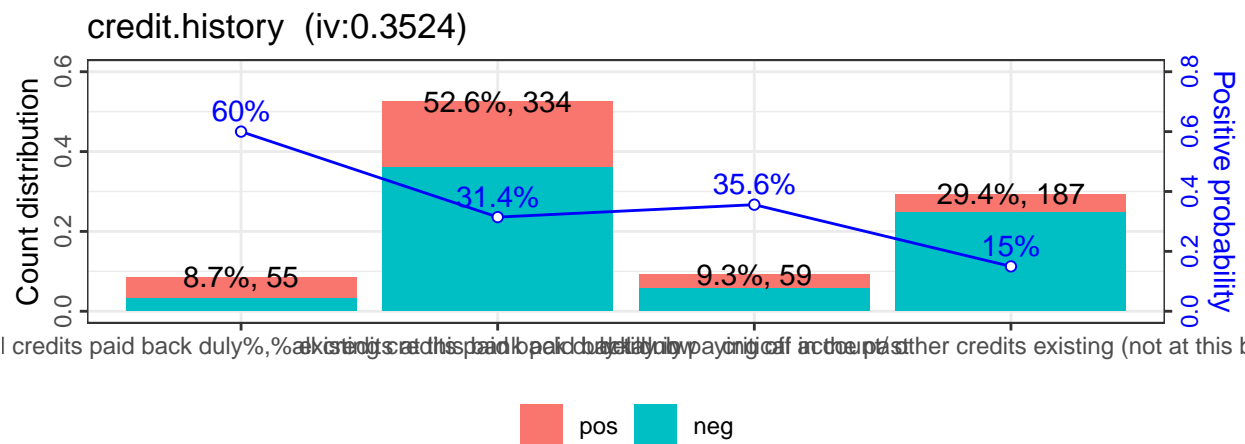
```
bins.list$duration.in.month %>%
  woebin_plot()
```

```
## $duration.in.month
```



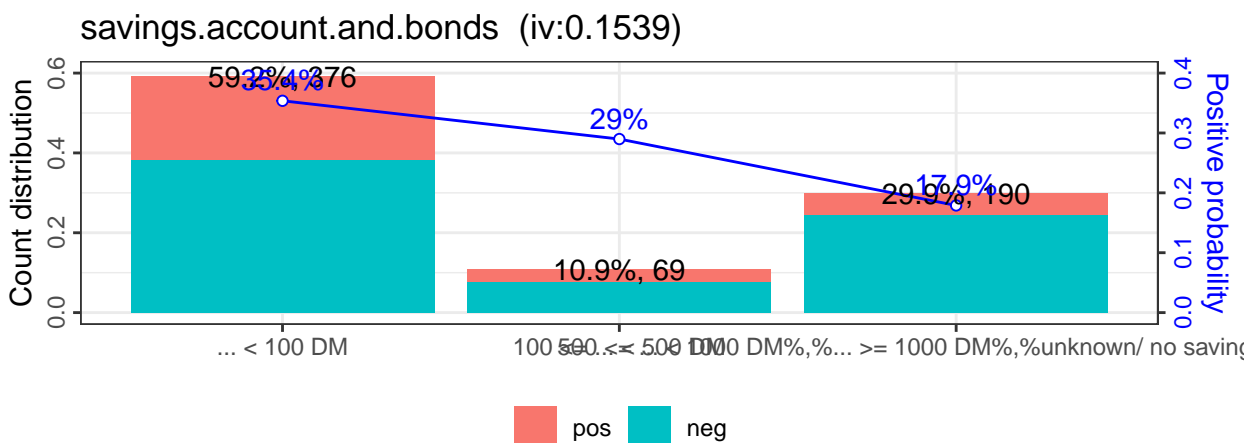
```
bins.list$credit.history %>%
  woebin_plot()
```

```
## $credit.history
```



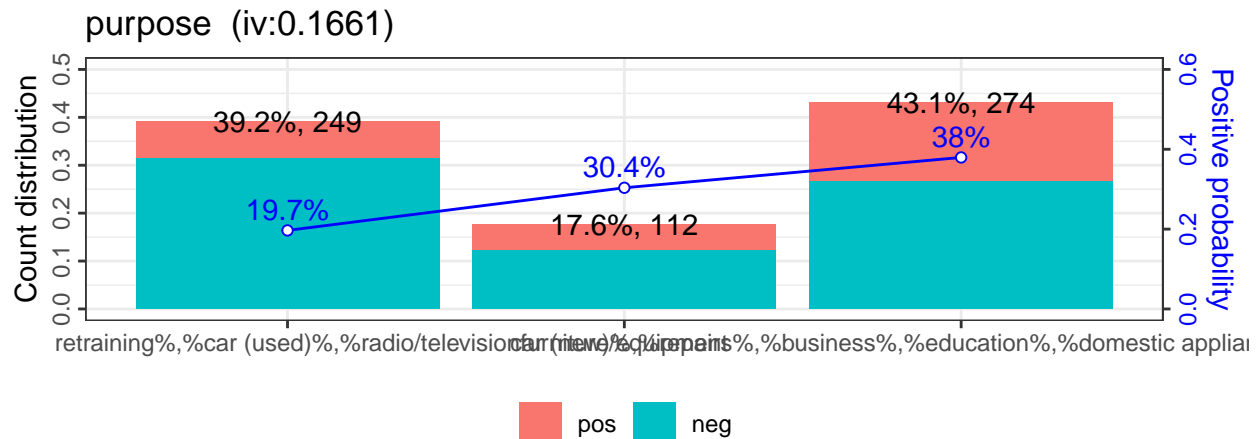
```
bins.list$savings.account.and.bonds %>%
  woebin_plot()
```

```
## $savings.account.and.bonds
```



```
bins.list$purpose %>%
  woebin_plot()
```

```
## $purpose
```



Hint: duration.in.month has linear structure of the default rates; hence it should be included in the scorecard model!

Excursion: Manual bin-adjustments

Bins can be altered manually by

1. Saving the bin list generated in the `woebin()` function via e.g. `save_as="breaks2410.list"`
2. Loading the saved R-file "breaks2410.list.R", editing the breaks as needed and storing the file
3. Sourcing the edited and stored "breaks2410.list.R" file with the `source(...)$value` function
4. Binning the data again with the `woebin()` function with the additional argument `"break_list"`

ad 1)

```
bins.list <- data_f.list$train %>%
  woebin("creditability",
    save_as = "breaks2410.list")
```

ad 3)

```
breaksList <- source("breaks2410.list.R")$value
```

ad 4)

```
bins.list <- data_f.list$train %>%
  woebin("creditability",
    breaks_list = "breaksList")
```

Hint: The above code chunks are not yet evaluated, as they are performed only when the original binning does not deliver beneficial results.

3.2 WoE-based transforming of predictor variables: data_woe.list

3.2.1 WoE-based transforming of train and validate data: data_woe.list

Transforming splitted sample: Needed for train/validate analysis

```
data_woe.list <- data_f.list %>%
  lapply(function(x) woebin_ply(x, bins.list))
```

```
## v Woe transforming on 635 rows and 5 columns in 00:00:00
```

```
## v Woe transforming on 365 rows and 5 columns in 00:00:00
```

```
data_woe.list %>% lapply(class)
```

```
## $train  
## [1] "data.table" "data.frame"  
##  
## $validate  
## [1] "data.table" "data.frame"
```

```
data_woe.list %>% lapply(dim)
```

```
## $train  
## [1] 635  6  
##  
## $validate  
## [1] 365  6
```

```
#data_woe.list$train %>%  
# select(creditability, credit.amount_woe, duration.in.month_woe) %>%  
# head()
```

4 Generalized linear model (glm): Regressing predictors against responses

4.1 Logistic regression of WoE-transformed predictors: `glm(.,data_woe.list$train)`

The WoE-based logistic regression is the preferred regression approach as it delivers the most compact regression models.

4.1.1 Constructing and calibrating the WoE-based logistic regression model

```
data_woe.glm <- glm(creditability ~ .,
                    family = binomial(),
                    data = data_woe.list$train)
```

4.1.2 Investigating the fitted regression model

```
data_woe.glm$aic
```

```
## [1] 619.9392
```

```
Summary of regression: summary()
```

```
data_woe.glm %>% summary()
```

```
##
## Call:
## glm(formula = creditability ~ ., family = binomial(), data = data_woe.list$train)
##
## Coefficients:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    -0.8628    0.1023  -8.435 < 2e-16
## status.of.existing.checking.account_woe  0.8195    0.1310   6.254 3.99e-10
## duration.in.month_woe    0.9772    0.1897   5.152 2.58e-07
## credit.history_woe       0.7643    0.1754   4.357 1.32e-05
## savings.account.and.bonds_woe  0.8944    0.2697   3.316 0.000912
## purpose_woe            0.9840    0.2506   3.927 8.59e-05
##
## (Intercept)          ***
## status.of.existing.checking.account_woe ***
## duration.in.month_woe ***
## credit.history_woe   ***
## savings.account.and.bonds_woe ***
## purpose_woe          ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##    Null deviance: 769.77  on 634  degrees of freedom
## Residual deviance: 607.94  on 629  degrees of freedom
## AIC: 619.94
##
## Number of Fisher Scoring iterations: 5
```

4.2 Logistic regression of original predictors: glm(.,data_f.list\$train)

```
#data_f.glm <- glm(creditability ~ .,  
#                  family = binomial(),  
#                  data = data_f.list$train %>%  
#                  select(creditability,  
#                          credit.amount,  
#                          duration.in.month,  
#                          credit.history))
```

Hint: For simplicity only three original predictors are included in the logistic regression model

```
#data_f.glm$aic
```

```
#data_f.glm$xlevels
```

For getting a compact summary the function `summary()` is customized and formatted

```
formatSummary <- function(model_summary) {  
  aux_coeff <- model_summary$coefficients[, 1]  
  aux_prob <- model_summary$coefficients[, 4]  
  aux_stars <- symnum(aux_prob,  
                      corr = FALSE,  
                      na = FALSE,  
                      cutpoints = c(0, 0.001, 0.01, 0.05, 0.1, 1),  
                      symbols = c("***", "**", "*", ".", " "))  
  names(aux_coeff) <- str_trunc(names(aux_coeff),  
                                width = 40)  
  aux_result <- data.frame(Estimate = aux_coeff,  
                           Prob_z = aux_prob,  
                           "Stars" = aux_stars)  
  return(aux_result)  
}
```

```
#summary(data_f.glm) %>% formatSummary()
```

5 Building scorecard-models (scm) and calculating scorepoints

Scorepoints are calculated by combining scorecard-model, which combines bin and glm information, with individual data

5.1 Building scm-models: Combining bins.list & data_woe.glm in scorecard()

Building the scorecard via bin and glm information resulting from train sample

```
scorecard.scm <- bins.list %>% scorecard(data_woe.glm)
```

```
scorecard.scm %>% names()
```

```
## [1] "basepoints"                "status.of.existing.checking.account"
## [3] "duration.in.month"         "credit.history"
## [5] "savings.account.and.bonds" "purpose"
```

Investigating the content of the “woe-based” scorecard model

```
scorecard.scm$basepoints
```

```
##      variable    bin    woe points
##      <char> <lgcl> <lgcl> <num>
## 1: basepoints    NA     NA    450
```

```
scorecard.scm$duration.in.month[,1:8]
```

```
##      variable      bin count count_distr   neg   pos   posprob
##      <char>      <char> <int>      <num> <int> <int>      <num>
## 1: duration.in.month [-Inf,8)    56 0.08818898    50    6 0.1071429
## 2: duration.in.month  [8,16)   214 0.33700787   166   48 0.2242991
## 3: duration.in.month  [16,26)   204 0.32125984   145   59 0.2892157
## 4: duration.in.month  [26,44)   108 0.17007874    64   44 0.4074074
## 5: duration.in.month [44, Inf)    53 0.08346457    23   30 0.5660377
##      woe
##      <num>
## 1: -1.24657892
## 2: -0.36710216
## 3: -0.02551168
## 4:  0.49899117
## 5:  1.13938778
```

```
scorecard.scm$duration.in.month[,c(1,9:13)]
```

```
##      variable      bin_iv total_iv breaks is_special_values points
##      <char>      <num>      <num> <char>      <lgcl>      <num>
## 1: duration.in.month 0.0991299271 0.3115523    8      FALSE      88
## 2: duration.in.month 0.0417950298 0.3115523   16      FALSE      26
## 3: duration.in.month 0.0002079889 0.3115523   26      FALSE       2
## 4: duration.in.month 0.0461252338 0.3115523   44      FALSE     -35
## 5: duration.in.month 0.1242941288 0.3115523  Inf      FALSE     -80
```

5.2 Calculating scorepoints: Combinig individual data.df & scm-model in scorecard_ply()

Generating a score list


```
score.list <- data_f.list %>%
  lapply(function(x) scorecard_ply(x, scorecard.scm))
```

Hint: The `only_total_score=TRUE` (= default argument) has to be used for providing two compatible lists for further processing. If scores to the different predictors are of interest, the two separate, i.e. train and validate samples have to be analyzed individually with the argument `only_total_score=FALSE`.

```
score.list %>% names()
```

```
## [1] "train" "validate"
```

```
score.list$train %>%
  head()
```

```
##      score
##      <num>
## 1:    630
## 2:    354
## 3:    357
## 4:    496
## 5:    557
## 6:    622
```

```
score.list$validate %>%
  head()
```

```
##      score
##      <num>
## 1:    350
## 2:    551
## 3:    395
## 4:    285
## 5:    456
## 6:    420
```

6 WoE-based predicting (forecasting) of probabilities and score-points

6.1 Predicting probabilities: Combining data_woe.list & data_woe.glm in predict()

```
predProb.list <- data_woe.list %>%  
  lapply(function(x) predict(data_woe.glm,  
                             type = 'response',  
                             x))
```

Hint: Due to the fact that the data_woe.glm was calibrated for the train sample two different types of prediction can be distinguished, i.e. the in-sample (IS) prediction by using the train sample in the predict()-function, and the out-of-sample (OoS) prediction by using the test sample in the predict()-function.

```
predProb.list %>% names()
```

```
## [1] "train" "validate"
```

```
predProb.list$train %>% head() # In-Sample prediction
```

```
##          1          2          3          4          5          6  
## 0.03390496 0.61729222 0.60866854 0.18293009 0.08764694 0.03756245
```

```
predProb.list$validate %>% head() # Out-of-Sample prediction
```

```
##          1          2          3          4          5          6  
## 0.6311053 0.0952773 0.4777985 0.8080544 0.2818604 0.3935574
```

6.2 Predicting scorepoints: Retrieving predictions from score.list generated in scorecard_ply()

The prediction of the scorepoints is already incorporated in the built scorecard.

```
score.list$train %>%  
  head()
```

```
##      score  
##      <num>  
## 1:    630  
## 2:    354  
## 3:    357  
## 4:    496  
## 5:    557  
## 6:    622
```

```
score.list$validate %>%  
  head()
```

```
##      score  
##      <num>  
## 1:    350  
## 2:    551  
## 3:    395  
## 4:    285  
## 5:    456  
## 6:    420
```

7 Scorecard Validation: Statistical testing of forecasting accuracy

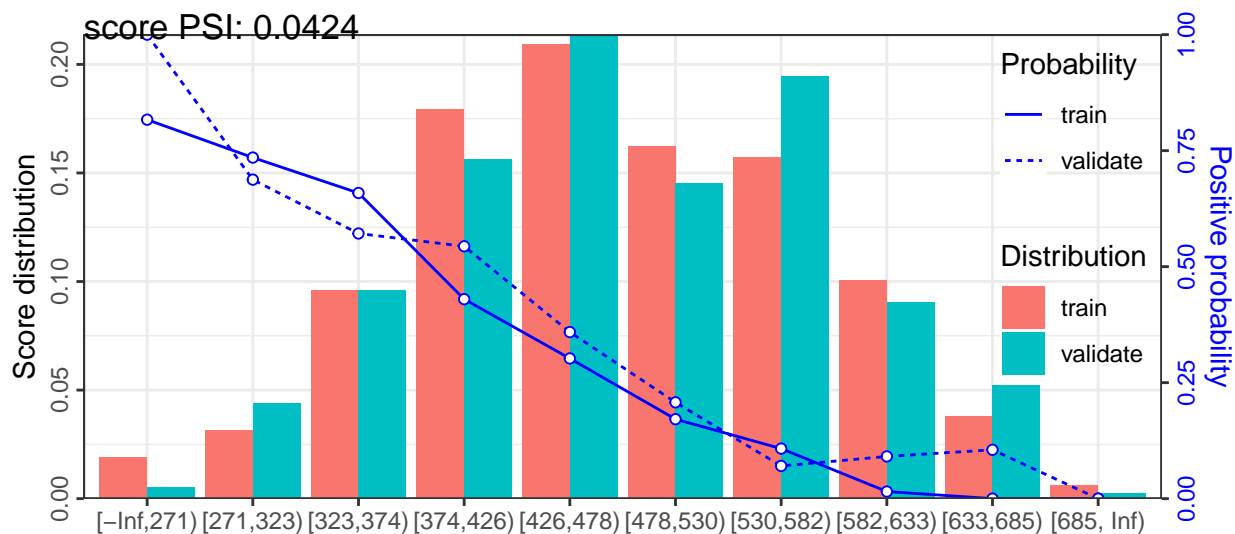
7.1 Checking stability of score and probability distributions: Population Stability Index (PSI)

```
psi.list <- perf_psi(score = score.list,
  label = default.list,
  return_distr_dat = TRUE)
```

Hint: More details of `perf_psi()` function are given @ https://www.rdocumentation.org/packages/scorecard/versions/0.1.9/topics/perf_psi

```
psi.list$pic
```

```
## $score
```



```
psi.list %>% names()
```

```
## [1] "pic" "psi" "dat"
```

```
psi.list$dat %>% names()
```

```
## [1] "score"
```

```
psi.list$dat$score[,1:9] %>% head()
```

```
## Key: <dataset>
```

	dataset	bin	count	cum_count	neg	pos	cum_neg	cum_pos	count_distr
	<fctr>	<fctr>	<int>	<int>	<int>	<int>	<int>	<int>	<num>
## 1:	train	[-Inf,271)	12	12	2	10	2	10	0.0189
## 2:	train	[271,323)	20	32	5	15	7	25	0.0315
## 3:	train	[323,374)	61	93	20	41	27	66	0.0961
## 4:	train	[374,426)	114	207	64	50	91	116	0.1795
## 5:	train	[426,478)	133	340	92	41	183	157	0.2094
## 6:	train	[478,530)	103	443	85	18	268	175	0.1622

```
psi.list$psi
```

	variable	dataset	psi
	<char>	<char>	<num>
## 1:	score	train_validate	0.04239616

```

perf_psi(score, label = NULL, title = NULL, x_limits = NULL,
  x_tick_break = 50, show_plot = TRUE, seed = 186,
  return_distr_dat = FALSE)
# e.g. # x_limits = c(250, 700),
#       # x_tick_break = 50,

```

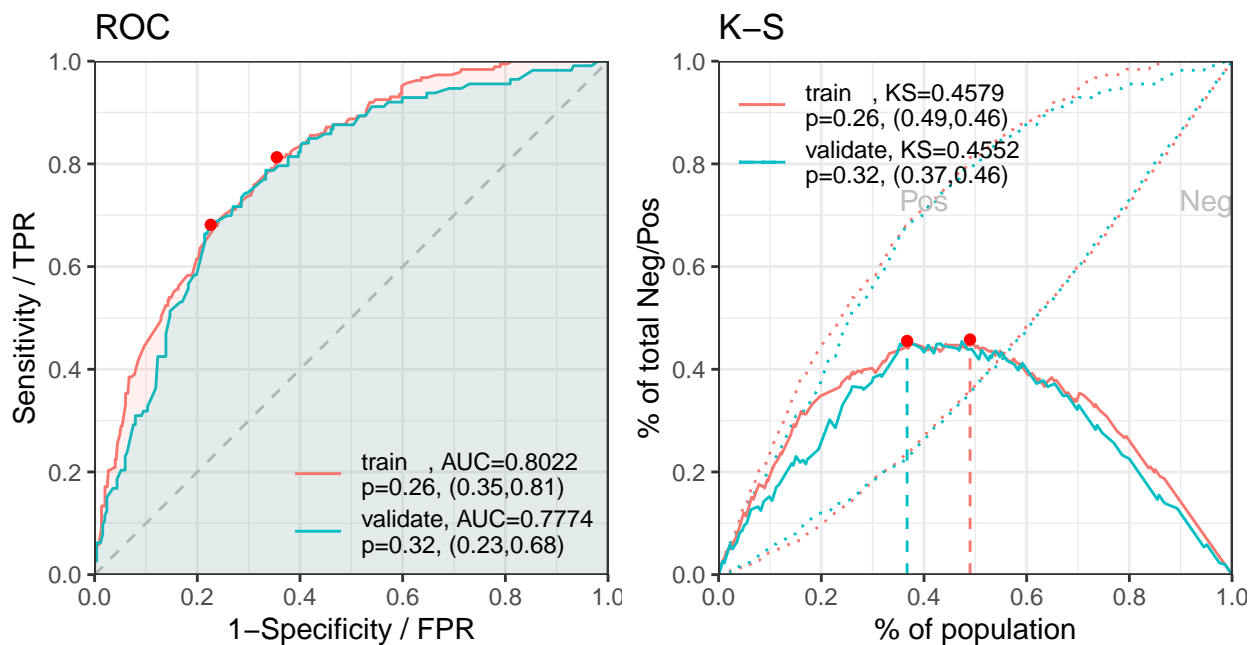
7.2 IS & OoS testing probability prediction accuracy: perf_eva(.,predProb.list)

probability prediction accuracy

```

ProbPredAccuracy <- perf_eva(pred = predProb.list,
  label = default.list,
  binomial_metric = c("rmse", "auc", "gini"),
  show_plot=c("roc", "ks"),
  confusion_matrix = TRUE)

```



```
names(ProbPredAccuracy)
```

```
## [1] "binomial_metric" "confusion_matrix" "pic"
```

```
ProbPredAccuracy$binomial_metric
```

```

## $train
##      RMSE      AUC      Gini
##      <num>    <num>    <num>
## 1: 0.3987765 0.8022465 0.6044929
##
## $validate
##      RMSE      AUC      Gini
##      <num>    <num>    <num>
## 1: 0.4153243 0.7773915 0.554783

```

```
ProbPredAccuracy$confusion_matrix
```

```
## $train
```

```
##      label pred_0 pred_1      error
##      <char> <num> <num>      <num>
## 1:      0      289      159 0.3549107
## 2:      1       35      152 0.1871658
## 3: total      324      311 0.3055118
##
## $validate
##      label pred_0 pred_1      error
##      <char> <num> <num>      <num>
## 1:      0      168       84 0.3333333
## 2:      1       25       88 0.2212389
## 3: total      193      172 0.2986301
```

Excursion

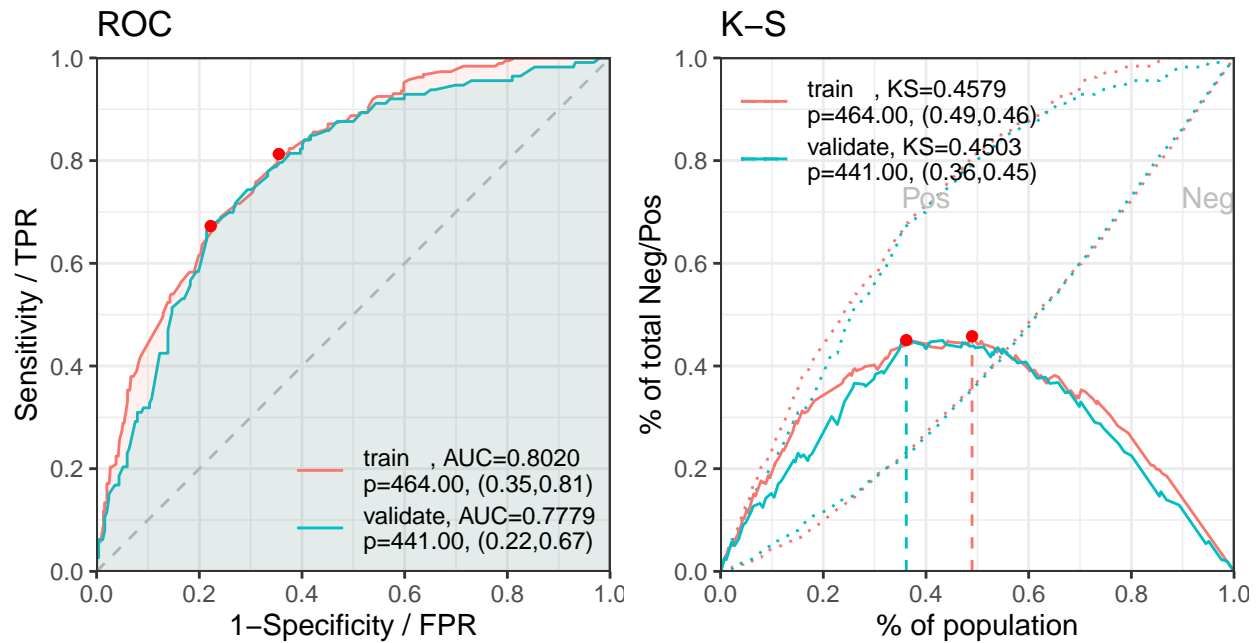
```
perf_eva(pred = predProb.list,
         label = default.list,
         binomial_metric = c("rmse","auc","gini"),
         show_plot= FALSE,
         confusion_matrix = FALSE)
```

```
## $binomial_metric
## $binomial_metric$train
##      RMSE      AUC      Gini
##      <num>      <num>      <num>
## 1: 0.3987765 0.8022465 0.6044929
##
## $binomial_metric$validate
##      RMSE      AUC      Gini
##      <num>      <num>      <num>
## 1: 0.4153243 0.7773915 0.554783
```

7.3 IS & OoS testing scorepoint prediction accuracy: perf_eva(.,score.list)

scorepoint prediction accuracy

```
ScorePredAccuracy <- perf_eva(pred = score.list,
                              label = default.list,
                              binomial_metric = c("rmse","auc","gini"),
                              show_plot=c("roc","ks"),
                              confusion_matrix = TRUE)
```



```
names(ScorePredAccuracy)
```

```
## [1] "binomial_metric" "confusion_matrix" "pic"
```

```
ScorePredAccuracy$binomial_metric
```

```
## $train
##      AUC      Gini
##    <num>  <num>
## 1: 0.801966 0.6039319
##
## $validate
##      AUC      Gini
##    <num>  <num>
## 1: 0.7779007 0.5558014
```

```
ScorePredAccuracy$confusion_matrix
```

```
## $train
##   label pred_0 pred_1  error
##   <char> <num> <num>  <num>
## 1:    0    289    159 0.3549107
## 2:    1     35    152 0.1871658
## 3: total    324    311 0.3055118
##
## $validate
##   label pred_0 pred_1  error
##   <char> <num> <num>  <num>
## 1:    0    168     84 0.3333333
## 2:    1     25     88 0.2212389
## 3: total    193    172 0.2986301
```

8 Appendix

8.1 Appendix: Essay style with formulas in LaTeX language

Group project assignment: Write a scholarly essay with full sentences, correct citations and LaTeX formulas.

Example essay style: From a statistical perspective the transition from the *MPS* to the VaR framework is related to switching the perspective from considering moments (parameters) of random variables, i.e. μ and σ , to considering the quantiles and corresponding probabilities of these variables. Specifically, the VaR measure specifies the risk of a random variable (\tilde{P}) via the threshold quantile (VaR) that is exceeded into the negative direction (i.e. $P \leq VaR$) with the loss probability (α) or respectively, is exceeded into the positive direction (i.e. $P > VaR$) with the complementary probability, i.e. the confidence level ($1 - \alpha$).

8.2 Appendix: Generating tables, figures, cross references and citations

```
data.df[1:100,2:3] %>% plot()
```

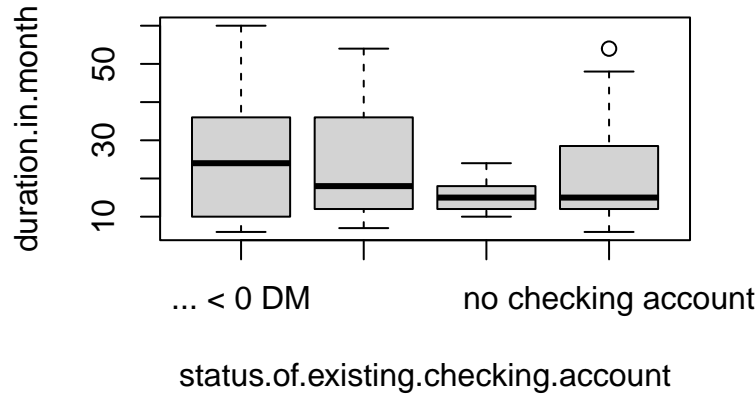


Figure 1: Amount vs. Duration

Figure ?? is a sample figure where the credit.amount is scatter plotted against the duration.in.month.

Formulas without numbering

$$\Pr\{\tilde{P} \leq VaR\} = \alpha$$

Formulas with numbering (and labeling which is needed for referencing)

$$\Pr\{\tilde{P} \leq VaR\} = \alpha \tag{1}$$

Formula (??) is a sample formula defining the Value at Risk.

Always cite original literature to avoid plagiarism: e.g. ? or (?). Don't forget to cite page numbers as well for literal citations, e.g. (?, p. 100).