Package ‘PrInDT’

May 10, 2023

Type Package

Title Prediction and Interpretation in Decision Trees for Classification and Regression

Version 1.0.1

Description Optimization of conditional inference trees from the package ‘party’ for classification and regression.

For optimization, the model space is searched for the best tree on the full sample by means of repeated subsampling. Restrictions are allowed so that only trees are accepted which do not include pre-specified uninterpretable split results (cf. Weihs & Buschfeld, 2021a).

The function PrInDT() represents the basic resampling loop for 2-class classification (cf. Weihs & Buschfeld, 2021a). The function RePrInDT() (repeated PrInDT()) allows for repeated applications of PrInDT() for different percentages of the observations of the large and the small classes (cf. Weihs & Buschfeld, 2021c). The function NesPrInDT() (nested PrInDT()) allows for an extra layer of subsampling for a specific factor variable (cf. Weihs & Buschfeld, 2021b). The functions PrInDTMulev() and PrInDTMulab() deal with multilevel and multilabel classification. In addition to these PrInDT() variants for classification, the function PrInDTreg() has been developed for regression problems. Finally, the function PostPrInDT() allows for a posterior analysis of the distribution of a specified variable in the terminal nodes of a given tree.

References are:
-- Weihs, C., Buschfeld, S. (2021a) "Combining Prediction and Interpretation in Decision Trees (PrInDT) - a Linguistic Example" <arXiv:2103.02336>;

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NeedsCompilation no

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**LazyData** true

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**data_land**

*Landscape analysis*

**Description**

The use of language(s) on public signs and categorization criteria.

**Usage**

```r
data_land
```
Format

A data frame with 149 observations and 28 columns

coder  who coded the sign: Factor (3 levels "C","E","S") (anonymized)
researcher who took a photograph of the sign: Factor (2 levels "L","S") (anonymized)
sign  where the sign was found: Factor (11 levels "digi","door","graf",....)
type.of.sign kind of sign: Factor (5 levels "com","commem","infra","reg","trans")
permanent was the sign permanent? Factor (2 levels "no","yes")
proper.noun kind of proper noun on the sign: Factor (9 levels "bn","bn+","cn",....)
no.languages number of languages on sign: Factor (4 levels "1","2","3","4+")
French French on sign? Factor (2 levels "0","1")
Dutch Dutch on sign? Factor (2 levels "0","1")
English English on sign? Factor (2 levels "0","1")
Italian Italian on sign? Factor (2 levels "0","1")
Spanish Spanish on sign? Factor (2 levels "0","1")
German German on sign? Factor (2 levels "0","1")
Indian,Mandarin,Portuguese,Libanese,Japanese,Danish,Hebrew,Catalan 8 infrequent languages: 
  Factor (2 levels "0","1")
bn.unclear brand name unclear: Factor (2 levels "0","1")
multilingual.type type of multilingualism on sign: Factor (6 levels "0","1","2","3","4","uc")
location location of sign: Factor (2 levels "M","P") (anonymized)

Source

Sarah Buschfeld, TU Dortmund

<table>
<thead>
<tr>
<th>data_speaker</th>
<th>Subject pronouns and a predictor with one very frequent level</th>
</tr>
</thead>
</table>

Description

Usage of subject pronouns and its predictors; speaker level "adult" very frequent.

Usage

data_speaker
**Format**

A data frame with 3370 observations and 6 columns

- **class** subject pronoun realized? Factor (2 levels "zero","realized")
- **AGE** age: Numerical (in months)
- **ETHN_GROUP** ethnic group: Factor (3 levels "C","I","n_a") (anonymized)
- **MLU** mean length of utterance: Factor (5 levels "1","2","3","adult","OL")
- **PRN_TYPE** pronoun type: Factor (5 levels "dem","it_con","it_ex","it_ref","refer")
- **SPEAKER** speaker: Factor (2 levels "adult","child")

**Source**

Sarah Buschfeld, TU Dortmund

---

<table>
<thead>
<tr>
<th>data_vowel</th>
<th>Vowel length</th>
</tr>
</thead>
</table>

**Description**

Vowel length and categorization criteria.

**Usage**

`data_vowel`

**Format**

A data frame with 82 observations and 22 columns

- **Nickname** nickname: Factor (43 levels "Nick1","Nick2","...","Nick43") (anonymized)
- **LiBa** linguistic background: Factor (2 levels "mono","multi")
- **MLU** mean length of utterance: Factor (3 levels "1","2","3")
- **phone_label** phone label: Factor (2 levels "fleece","kit")
- **lexeme** lexeme: Factor (14 levels "bee","cheek","cheese","chicken", ...)
- **phone_left_1_duration** duration of phone to the left of the vowel: Numerical (in msec)
- **phone_right_1_duration** duration of phone to the right of the vowel: Numerical (in msec)
- **word_duration** duration of word: Numerical (in msec)
- **vowel_minimum_pitch** minimum pitch of vowel: Numerical (in Hertz)
- **vowel_maximum_pitch** maximum pitch of vowel: Numerical (in Hertz)
- **vowel_intensity_mean** mean intensity of vowel: Numerical (in decibel)
- **f1_fifty** first formant F1 at midpoint of vowel (50%): Numerical (in Hertz)
- **f2_fifty** second formant F2 at midpoint of vowel (50%): numerical (in Hertz)
**target** vowel length: Numerical (in msec)

**cons_class_l** class of consonant to the left of the vowel: Factor (6 levels "l","r","tsh",...)

**cons_class_r** class of consonant to the right of the vowel: Factor (7 levels "?"(glottal stop),"empty","nas",...)

**ETH** ethnic group: Factor (6 levels "C1a","C1b","C1c","C2a","C2b","C2c") (anonymized)

**SEX** gender: Factor (2 levels "female","male")

**AGE** age: Numerical (in months)

**syllables** number of syllables in lexeme: integer (1,2)

**speed** speed of speech: Numerical (word duration / syllables; in msec)

**country** country: Factor (2 levels "E","S") (anonymized)

**Source**

Sarah Buschfeld, TU Dortmund

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**Description**

Usage of subject pronouns and its predictors.

**Usage**

data_zero

**Format**

A data frame with 1024 observations and 7 columns

**real** subject pronoun realized? Factor (2 levels "zero","realized")

**AGE** age: Numerical (in months)

**LiBa** linguistic background: Factor (3 levels "mono","multi", NA)

**ETH** ethnic group: Factor (6 levels "C1a","C1b","C1c","C2a","C2b","C2c") (anonymized)

**SEX** gender: Factor (2 levels "female","male")

**MLU** mean length of utterance: Factor (4 levels "1","2","3","OL")

**PRN** pronoun: Factor (7 levels "I","you_s","he","she","it","we","they")

**Source**

Sarah Buschfeld, TU Dortmund
FindSubstr

Description

Check whether one of the character strings in the vector 'ctesv' appears as a split result in the conditional inference tree 'ct'. ctesv is a vector of character strings of forbidden split results.

Example: ctesv <- rbind('variable1 == {value1, value2}','variable2 <= value3'), where character strings specified in 'value1', 'value2' are not allowed as results of a splitting operation in 'variable 1' in a tree. For restrictions of the type 'variable <= xxx', all split results in a tree are excluded with 'variable <= yyy' and yyy <= xxx.

Trees with split results specified in 'ctesv' are not accepted during optimization.

A concrete example is: 'ctesv <- rbind('ETH == {C2a, C1a}','AGE <= 20')' for variables 'ETH' and 'AGE' and values 'C2a','C1a', and '20'.

For an application, please refer to, e.g., the functions PrInDT and PrInDTreg.

If no restrictions exist, the default = NA is used.

Usage

FindSubstr(ct, ctesv)

Arguments

ct Tree to be checked
ctesv Vector with character strings of excluded split results

Value

testt TRUE if any of the split results in 'ctesv' appears in 'ct'; FALSE otherwise

NesPrInDT

Nested PrInDT with additional undersampling of a factor with two unbalanced levels

Description

Function for additional undersampling of the factor 'nesvar' with two unbalanced levels to avoid dominance of the level with higher frequency. The factor 'nesvar' is allowed not be part of the input data frame 'datain'. The data of this factor is given in the vector 'nesunder'. The observations in 'nesunder' have to represent the same cases as in 'datain' in the same ordering.

PrInDT is called 'repin' times with subsamples of the original data so that the level with the larger frequency in the vector 'nesunder' has approximately the same number of values as the level with the smaller frequency.

Only the arguments 'nesvar', 'nesunder', and 'repin' relate to the additional undersampling, all the other arguments relate to the standard PrInDT procedure.
As in PrInDT, the aim is to optimally model the relationship between the two-class factor variable 'classname' and all other factor and numerical variables in the data frame 'datain' by means of 'N' repetitions of undersampling. The trees generated by PrInDT can be restricted by excluding unacceptable trees which include split results specified in the character strings of the vector 'ctestv'. The probability threshold 'thres' for the prediction of the smaller class may be specified (default = 0.5).

Undersampling may be stratified in two ways by the feature 'strat'.

The results are evaluated on the full sample and on the subsamples of 'nesunder'.

**Reference**


**Usage**

NesPrInDT(datain, classname, ctestv=NA, N, plarge, psmall=1.0, conf.level=0.95, thres=0.5, stratvers=0, strat=NA, seedl=TRUE, nesvar, nesunder, repin)

**Arguments**

datain: Input data frame with class factor variable 'classname' and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)

classname: Name of class variable (character)

ctestv: Vector of character strings of forbidden split results; see function PrInDT for details.

If no restrictions exist, the default = NA is used.

N: Number of repetitions (integer > 0)

plarge: Undersampling percentage of larger class (numerical, > 0 and <= 1)

psmall: Undersampling percentage of smaller class (numerical, > 0 and <= 1); default = 1

conf.level: (1 - significance level) in function ctree (numerical, > 0 and <= 1); default = 0.95

thres: Probability threshold for prediction of smaller class; default = 0.5

stratvers: Version of stratification;

= 0: none (default),

= 1: stratification according to the percentages of the values of the factor variable 'strat',

> 1: stratification with minimum number 'stratvers' of observations per value of 'strat'

strat: Name of one (!) stratification variable for undersampling (character);

default = NA (no stratification)

seedl: Should the seed for random numbers be set (TRUE / FALSE)?

default = TRUE

nesvar: Name of factor to be undersampled (character)

nesunder: Data of factor to be undersampled (integer)

repin: Number of repetitions (integer) for undersampling of 'nesvar'
Details

Standard output can be produced by means of `print(name)` or just `name` as well as `plot(name)` where 'name' is the output data frame of the function.
The plot function will produce a series of more than one plot. If you use R, you might want to specify `windows(record=TRUE)` before `plot(name)` to save the whole series of plots. In R-Studio this functionality is provided automatically.

Value

- **undba**: balanced accuracies on undersamples
- **imax**: indices of best trees on undersamples
- **undba3en**: balanced accuracies of ensembles of 3 best trees on undersamples
- **accF**: balanced accuracies on full sample
- **accE**: balanced accuracy on full sample of best ensemble of 3 trees from undersampling
- **maxt**: indices of best trees on full sample
- **treesb**: 3 best trees of all undersamples of 'nesunder'; refer to an individual tree as `treesb[[k]]`, k = 1, ..., 3*repin

Examples

```r
# data input and preparation --> data frame with
# class variable, factors, and numericals (no character variables)!!
data <- PrInDT::data_speaker
data <- na.omit(data)
nesvar <- "SPEAKER"
N <- 49  # no. of repetitions in inner loop
plarge <- 0.06  # sampling percentage for larger class in nesunder-subsample
psmall <- 1  # sampling percentage for smaller class in nesunder-subsample
nesunder <- data[,nesvar] <- list(NULL)
outNes <- NesPrInDT(data,"class",ctestv=NA,N,plarge,psmall,conf.level=0.95,nesvar=nesvar, nesunder=nesunder,repin=5)
outNes
plot(outNes)
hist(outNes$undba,main="",xlab = "balanced accuracies of 3 best trees of all undersamples")
```
Description

The conditional inference tree 'ct' is analyzed according to the distribution of a variable 'var' in its terminal nodes.
In the case of a discrete variable 'var', the appearance of the different levels is considered for each terminal node.
In the case of a continuous variable 'var', means and standard deviations of 'var' or the target variable are considered for each terminal node.
In particular, this function can be used for the posterior analysis of a tree regarding the distribution of a variable not present in the tree.

Usage

PostPrInDT(datain, ct, target, var, vardata, vt)

Arguments

datain: input data frame with the observations of all variables used in the model

c: conditional inference tree to be analyzed

target: name of target variable of 'ct' (character)

var: name of variable of interest (character)

vardata: observations of 'var'

vt: type of variables: 'dd' for discrete target (classification) and discrete variable 'var', 'dc' for discrete target (classification) and continuous 'var', 'cd' for continuous target (regression) and discrete 'var', and 'cc' for continuous target (regression) and continuous 'var'.

Value

None: Relevant output is produced by the function.

Examples

data <- PrInDT::data_zero
data <- na.omit(data)
outAll <- PrInDTAll(data,"real")
PostPrInDT(data,outAll$treeAll,"real","ETH",data$ETH,vt="dd")
PostPrInDT(data,outAll$treeAll,"real","AGE",data$AGE,vt="dc")
datareg <- PrInDT::data_vowel
outregAll <- PrInDTregAll(datareg,"target")
PostPrInDT(datareg,outregAll$treeAll,"target","Nickname",datareg$Nickname,vt="cd")
PostPrInDT(datareg,outregAll$treeAll,"target","AGE",datareg$AGE,vt="cc")
The basic undersampling loop for classification

Description

The function PrInDT uses ctree (conditional inference trees from the package "party") for optimal modeling of the relationship between the two-class factor variable 'classname' and all other factor and numerical variables in the data frame 'datain' by means of 'N' repetitions of undersampling. The optimization criterion is the balanced accuracy on the full sample. The trees generated from undersampling can be restricted by not accepting trees including split results specified in the character strings of the vector 'ctestv'.

The undersampling percentages are 'percl' for the larger class and 'percs' for the smaller class (default = 1).

The probability threshold 'thres' for the prediction of the smaller class may be specified (default = 0.5).

Undersampling may be stratified in two ways by the feature 'strat'.

Usage

PrInDT(datain, classname, ctestv=NA, N, percl, percs=1, conf.level=0.95, thres=0.5, stratvers=0, strat=NA, seedl=TRUE)

Arguments

datain Input data frame with class factor variable 'classname' and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)

classname Name of class variable (character)

ctestv Vector of character strings of forbidden split results;
Example: ctestv <- rbind('variable1 == {value1, value2}','variable2 <= value3'),
where character strings specified in 'value1', 'value2' are not allowed as results of a splitting operation in variable 1 in a tree.

For restrictions of the type 'variable <= xxx', all split results in a tree are excluded with 'variable <= yyy' and yyy <= xxx.

Trees with split results specified in 'ctestv' are not accepted during optimization.

A concrete example is: 'ctestv <- rbind('ETH == {C2a, C1a}','AGE <= 20')' for variables 'ETH' and 'AGE' and values 'C2a','C1a', and '20';
If no restrictions exist, the default = NA is used.

N Number (> 2) of repetitions (integer)

percl Undersampling percentage of larger class (numerical, > 0 and <= 1)

percs Undersampling percentage of smaller class (numerical, > 0 and <= 1);
default = 1

conf.level (1 - significance level) in function ctree (numerical, > 0 and <= 1);
default = 0.95
PrInDT

thres  Probability threshold for prediction of smaller class (numerical, \( \geq 0 \) and \(< 1\));
        default = 0.5

stratvers  Version of stratification;
           = 0: none (default),
           = 1: stratification according to the percentages of the values of the factor variable 'strat',
           > 1: stratification with minimum number "stratvers" of observations per value of 'strat'

strat  Name of one (!) stratification variable for undersampling (character);
        default = NA (no stratification)

seedl  Should the seed for random numbers be set (TRUE / FALSE)?
        default = TRUE

Details

For the optimization of the trees, we employ a method we call Sumping (Subsampling umbrella of model parameters), a variant of Bumping (Bootstrap umbrella of model parameters) (Tibshirani & Knight, 1999) which use subsampling instead of bootstrapping. The aim of the optimization is to identify conditional inference trees with maximum predictive power on the full sample under interpretability restrictions.

References


Standard output can be produced by means of print(name) or just name as well as plot(name) where 'name' is the output data frame of the function.

The plot function will produce a series of more than one plot. If you use R, you might want to specify windows(record=TRUE) before plot(name) to save the whole series of plots. In R-Studio this functionality is provided automatically.

Value

tree1st  best tree on full sample

tree2nd  2nd-best tree on full sample

tree3rd  3rd-best tree on full sample

treet1st  best tree on test sample

treet2nd  2nd-best tree on test sample

treet3rd  3rd-best tree on test sample

ba1st  accuracies: largeClass, smallClass, balanced of 'tree1st', both for full and test sample

ba2nd  accuracies: largeClass, smallClass, balanced of 'tree2nd', both for full and test sample

ba3rd  accuracies: largeClass, smallClass, balanced of 'tree3rd', both for full and test sample

baen  accuracies: largeClass, smallClass, balanced of ensemble of all interpretable, 3 best acceptable, and all acceptable trees on full sample
PrInDTAll

Conditional inference tree (ctree) based on all observations

Description

ctree based on all observations. Interpretability is checked (see 'ctestv'); probability threshold can be specified.


Usage

PrInDTAll(datain, classname, ctestv=NA, conf.level=0.95, thres=0.4)
Arguments

datain Input data frame with class factor variable 'classname' and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)
classname Name of class variable (character)
ctestv Vector of character strings of forbidden split results; see function PrInDT for details. If no restrictions exist, the default = NA is used.
conf.level (1 - significance level) in function ctree (numerical, > 0 and <= 1); default = 0.95
thres Probability threshold for prediction of smaller class (numerical, >= 0 and < 1); default = 0.5

Details

Standard output can be produced by means of print(name) or just name as well as plot(name) where 'name' is the output data frame of the function.

Value

treeall ctree based on all observations
baAll balanced accuracy of 'treeall'
interpAll criterion of interpretability of 'treeall' (TRUE / FALSE)
confAll confusion matrix of 'treeall'

Examples

datastrat <- PrInDT::data_zero
data <- na.omit(datastrat)
ctestv <- rbind('ETH == {C2a,C1a}', 'MLU == {1, 3}')
conf.level <- 0.99 # 1 - significance level (mincriterion) in ctree
outAll <- PrInDTAll(data,"real",ctestv,conf.level)
print(outAll) # print model based on all observations
plot(outAll) # plot model based on all observations

PrInDTAllparts

Conditional inference trees (ctrees) based on consecutive parts of the full sample
Description

ctrees based on the full sample of the smaller class and consecutive parts of the larger class of the nesting variable 'nesvar'. The variable 'nesvar' has to be part of the data frame 'datain'. Interpretability is checked (see 'ctestv'); probability threshold can be specified.

Reference

Usage

PrInDTAllparts(datain, classname, ctestv=NA, conf.level=0.95, thres=0.5, nesvar, divt)

Arguments

datain Input data frame with class factor variable 'classname' and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)
classname Name of class variable (character)
ctestv Vector of character strings of forbidden split results; see function PrInDT for details. If no restrictions exist, the default = NA is used.
conf.level (1 - significance level) in function ctree (numerical, > 0 and <= 1); default = 0.95
thres Probability threshold for prediction of smaller class (numerical, >= 0 and < 1); default = 0.5
nesvar Name of nesting variable (character)
divt Number of parts of nesting variable nesvar for which models should be determined individually

Details

Standard output can be produced by means of print(name) or just name where 'name' is the output data frame of the function.

Value

baAll balanced accuracy of tree on full sample
nesvar name of nesting variable
divt number of consecutive parts of the sample
badiv balanced accuracy of trees on 'divt' consecutive parts of the sample
Examples

```r
data <- PrInDT::data_speaker
data <- na.omit(data)
esvar <- "SPEAKER"
outNesAll <- PrInDTAllparts(data,"class",ctestv=NA,conf.level=0.95,thres=0.5,nesvar,divt=8)
outNesAll
```

---

**PrInDTMulab**

*Multiple label classification based on resampling by PrInDT*

---

**Description**

Multiple label classification based on resampling by **PrInDT**. We consider two ways of modeling (Binary relevance modeling, dependent binary modeling) and three ways of model evaluation: single assessment, joint assessment, and true prediction (see the Value section for more information). Variables should be arranged in 'datain' according to indices specified in 'indind', 'indaddind', and 'inddep'.

Undersampling is repeated 'N' times.

Undersampling percentages 'percl' for the larger class and 'percs' for the smaller class can be specified, one each per dependent class variable.

**Reference**


**Usage**

```r
PrInDTMulab(datain, classnames, ctestv, conf.level=0.95, percl, percs=1,
N, indind, indaddind, inddep)
```

**Arguments**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>datain</td>
<td>Input data frame with class factor variable 'classname' and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)</td>
</tr>
<tr>
<td>classnames</td>
<td>names of class variables (character vector)</td>
</tr>
<tr>
<td>ctestv</td>
<td>Vector of character strings of forbidden split results; see function <strong>PrInDT</strong> for details. If no restrictions exist, the default = NA is used.</td>
</tr>
<tr>
<td>conf.level</td>
<td>(1 - significance level) in function ctree (numerical, &gt; 0 and &lt;= 1); default = 0.95</td>
</tr>
<tr>
<td>percl</td>
<td>list of undersampling percentages of larger class (numerical, &gt; 0 and &lt;= 1): one per dependent class variable</td>
</tr>
<tr>
<td>percs</td>
<td>list of undersampling percentage of smaller class (numerical, &gt; 0 and &lt;= 1): one per dependent class variable</td>
</tr>
</tbody>
</table>
PrInDTMulab

N no. of repetitions (integer > 0)
indind indices of independent variables
indaddind indices of additional independent variables used in the case of dependent binary relevance modeling
inddep indices of dependent variables

Details

Standard output can be produced by means of \texttt{print(name)} or just \texttt{name} as well as \texttt{plot(name)} where 'name' is the output data frame of the function.

The plot function will produce a series of more than one plot. If you use R, you might want to specify \texttt{windows(record=TRUE)} before \texttt{plot(name)} to save the whole series of plots. In R-Studio this functionality is provided automatically.

Value

\texttt{accebr} model errors for Binary Relevance (single assessment) - only independent predictors are used for modeling one label at a time, the other labels are not used as predictors. As the performance measure for the resulting classification rules, the balanced accuracy of the best model from PrInDT is employed for each individual label.

\texttt{errbin} combined error for Binary Relevance (joint assessment) - the best prediction models for the different labels are combined to assess the combined prediction. The 01-accuracy counts a label combination as correct only if all labels are correctly predicted. The hamming accuracy corresponds to the proportion of labels whose value is correctly predicted.

\texttt{accedbr} model errors for Dependent Binary Relevance (Extended Model) (single assessment) - each label is trained by means of an extended model which not only includes the independent predictors but also the other labels. For these labels, the truly observed values are used for estimation and prediction. In the extended model, other labels, which are not treated as dependent variables, can also be used as additional predictors.

\texttt{errext} combined errors for Dependent Binary Relevance (Extended Model) (joint assessment)

\texttt{errtrue} combined errors for Dependent Binary Relevance (True Prediction) - in the prediction phase, the values of all modeled labels are first predicted by the independent predictors only and then the predicted labels are used in the estimated extended model in a 2nd step to ultimately predict the labels.

coldata column names of input data

inddep indices of dependent variables (labels to be modeled)

\texttt{treebr} list of trees from Binary Relevance modeling, one tree for each label; refer to an individual tree as \texttt{treebr[[i]]}, i = 1, ..., no. of labels

\texttt{treedbr} list of trees from Dependent Binary Relevance modeling, one for each label; refer to an individual tree as \texttt{treedbr[[i]]}, i = 1, ..., no. of labels

Examples

data <- PrInDT::data_land # load data
dataclean <- data[,c(1:7,23:24,11:13,22,8:10)] # only relevant features
indind <- c(1:9) # original predictors
indaddind <- c(10:13) # additional predictors
inddep <- c(14:16) # dependent variables
dataclean <- na.omit(dataclean)
ctestv <- NA
N <- 21 # no. of repetitions
perc <- c(0.45, 0.05, 0.25) # percentages of observations of larger class,
# 1 per dependent class variable
perc2 <- c(0.75, 0.95, 0.75) # percentages of observations of smaller class,
# 1 per dependent class variable
## # Call PrInDT: language by language
##
outmult <- PrInDTmulab(dataclean,colnames(dataclean)[inddep],ctestv=NA,conf.level=0.95,
                         percl=perc,percs=perc2,N,indind,indaddind,inddep)
print(outmult)
plot(outmult)

---

**PrInDTmulabAll**  
*Multiple label classification based on all observations*

**Description**

Multiple label classification based on all observations. We consider two ways of modeling (Binary relevance modeling, dependent binary modeling) and three ways of model evaluation: single assessment, joint assessment, and true prediction (see the Value section for more information). Interpretability is checked (see ctestv).

Variables should be arranged in `datain` according to indices specified in `indind`, `indaddind`, and `inddep`.

**Reference**


**Usage**

`PrInDTmulabAll(datain,classnames,ctestv=NA,conf.level=0.95,indind,indaddind,inddep)`

**Arguments**

- **datain**: Input data frame with class factor variable `classname` and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)
- **classnames**: names of class variables (character vector)
- **ctestv**: Vector of character strings of forbidden split results; see function `PrInDT` for details. If no restrictions exist, the default = NA is used.
conf.level (1 - significance level) in function ctree (numerical, > 0 and <= 1); default = 0.95

indind indices of independent variables
indaddind indices of additional predictors used in the case of dependent binary relevance modeling
inddep indices of dependent variables

Details

Standard output can be produced by means of print(name) or just name as well as plot(name) where 'name' is the output data frame of the function.

The plot function will produce a series of more than one plot. If you use R, you might want to specify windows(record=TRUE) before plot(name) to save the whole series of plots. In R-Studio this functionality is provided automatically.

Value

accessr model errors for Binary Relevance (single assessment) - only independent predictors are used for modeling one label at a time, the other labels are not used as predictors. The classification rules are trained on all observations. As the performance measure for the resulting classification rules, the balanced accuracy of the models for each individual label is employed.

erabin combined error for Binary Relevance (joint assessment) - the best prediction models for the different labels are combined to assess the combined prediction. The 01-accuracy counts a label combination as correct only if all labels are correctly predicted. The hamming accuracy corresponds to the proportion of labels whose value is correctly predicted.

acceadbr model errors in Dependent Binary Relevance (Extended Model) (single assessment) - each label is trained by means of an extended model which not only includes the independent predictors but also the other labels. For these labels the truly observed values are used for estimation and prediction. In the extended model, further labels, which are not treated as dependent variables, can be used as additional predictors.

eraext combined errors for Dependent Binary Relevance (Extended Model) (joint assessment)
eratrue combined errors for Dependent Binary Relevance (True Prediction) - in the prediction phase, the values of all modeled labels are first predicted by the independent predictors only (see Binary Relevance) and then the predicted labels are used in the estimated extended model in a 2nd step to ultimately predict the labels.

coldata column names of input data
inddep indices of dependent variables (labels to be modeled)
treeabr list of trees from Binary Relevance modeling, one tree for each label; refer to an individual tree as treeabr[[i]], i = 1, ..., no. of labels
treeadbr list of trees from Dependent Binary Relevance modeling, one for each label; refer to an individual tree as treeadbr[[i]], i = 1, ..., no. of labels

Examples

data <- PrInDT::data_land # load data
dataclean <- data[,c(1:7,23:24,11:13,22,8:10)] # only relevant features
PrInDTMulev <- c(1:9) # original predictors
indaddind <- c(10:13) # additional predictors
inddep <- c(14:16) # dependent variables
dataclean <- na.omit(dataclean)
ctestv <- NA
##
# Call PrInDTAll: language by language
##
outmultAll <- PrInDTMulev(dataclean,colnames(dataclean)[inddep],ctestv,conf.level=0.95,
indind,indaddind,inddep)
outmultAll
plot(outmultAll)

---

**PrInDTMulev**

*PrInDT analysis for a classification problem with multiple classes.*

---

**Description**

PrInDT analysis for a classification problem with more than 2 classes. For each combination of one class vs. the other classes a 2-class PrInDT analysis is carried out. The percentages for undersampling of the larger class ('percl' in PrInDT) are chosen so that the resulting sizes are comparable with the size of the smaller classes for which all their observations are used in undersampling ('percs' = 1 in PrInDT). The class with the highest probability in the K (= number of classes) analyses is chosen for prediction. Interpretability is checked (see 'ctestv').

**Usage**

PrInDTMulev(datain, classname, ctestv=NA, N, conf.level=0.95)

**Arguments**

- **datain**: Input data frame with class factor variable `classname` and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors).
- **classname**: Name of class variable (character).
- **ctestv**: Vector of character strings of forbidden split results; see function PrInDT for details. If no restrictions exist, the default = NA is used.
- **N**: Number of repetitions (integer > 0).
- **conf.level**: (1 - significance level) in function ctree (numerical, > 0 and <= 1) (default = 0.95).
PrInDTMulevAll

Details

Standard output can be produced by means of print(name) or just name as well as plot(name) where 'name' is the output data frame of the function.

The plot function will produce a series of more than one plot. If you use R, you might want to specify windows(record=TRUE) before plot(name) to save the whole series of plots. In R-Studio this functionality is provided automatically.

Value

- **class**: levels of class variable
- **trees**: trees for the levels of the class variable; refer to an individual tree as trees[[k]], k = 1, ..., no. of levels
- **ba**: balanced accuracy of combined predictions
- **conf**: confusion matrix of combined predictions
- **ninterp**: no. of non-interpretable trees

Examples

```r
datastrat <- PrInDT::data_zero
data <- na.omit(datastrat)
ctestv <- NA
data$rel[data$ETH %in% c("C1a","C1b","C1c") & data$real == "zero"] <- "zero1"
data$rel[data$ETH %in% c("C2a","C2b","C2c") & data$real == "zero"] <- "zero2"
data$rel[data$real == "realized"] <- "real"
data$rel <- as.factor(data$rel) # rel is new class variable
data$real <- NULL # remove old class variable
N <- 51
conf.level <- 0.99 # 1 - significance level (mincriterion) in ctree
out <- PrInDTMulev(data,"rel",ctestv,N,conf.level)
out # print best models based on subsamples
plot(out) # corresponding plots
```

Description

 conditional inference tree (ctree) for multiple classes on all observations

tree for more than 2 classes on all observations. Interpretability is checked (see 'ctestv').

Usage

PrInDTMulevAll(datain, classname, ctestv=NA, conf.level=0.95)
Arguments

- **datain**: Input data frame with class factor variable ‘classname’ and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors).

- **classname**: Name of class variable (character).

- **ctestv**: Vector of character strings of forbidden split results; see function `PrInDT` for details. If no restrictions exist, the default = NA is used.

- **conf.level**: (1 - significance level) in function ctree (numerical, > 0 and <= 1) (default = 0.95)

Details

Standard output can be produced by means of `print(name)` or just `name` as well as `plot(name)` where ‘name’ is the output data frame of the function.

Value

- **treeall**: ctree based on all observations
- **baAll**: balanced accuracy of ‘treeall’
- **interpAll**: criterion of interpretability of ‘treeall’ (TRUE / FALSE)
- **confAll**: confusion matrix of ‘treeall’

Examples

```r
datastrat <- PrInDT::data_zero
data <- na.omit(datastrat)
ctestv <- cbind('ETH == {C2a,C1a}', 'MLU == {1, 3}')
data$rel[data$ETH %in% c("C1a","C1b","C1c") & data$real == "zero"] <- "zero1"
data$rel[data$ETH %in% c("C2a","C2b","C2c") & data$real == "zero"] <- "zero2"
data$rel[data$real == "realized"] <- "real"
data$rel <- as.factor(data$rel) # rel is new class variable
data$real <- NULL # remove old class variable
cconf.level <- 0.99 # 1 - significance level (mincriterion) in ctree
outAll <- PrInDTMulevAll(data,"rel",ctestv,conf.level)
outAll # print model based on all observations
plot(outAll)
```

---

`PrInDTreg`  
*Regression tree resampling by the PrInDT method*
Description

Regression tree optimization to identify the best interpretable tree; interpretability is checked (see `ctestv`).

The relationship between the target variable `regname` and all other factor and numerical variables in the data frame `datain` is optimally modeled by means of `N` repetitions of subsampling.

The optimization criterion is the R2 of the model on the full sample.

Multiple subsampling percentages of observations and predictors can be specified (in `pobs` and `ppre`, correspondingly).

The trees generated from undersampling can be restricted by rejecting unacceptable trees which include split results specified in the character strings of the vector `ctestv`.

Usage

`PrInDTreg(datain, regname, ctestv=NA, N, pobs, ppre, conf.level=0.95)`

Arguments

- `datain` Input data frame with class factor variable `classname` and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)
- `regname` name of regressand variable (character)
- `ctestv` Vector of character strings of forbidden split results; see function `PrInDT` for details.
  - If no restrictions exist, the default = NA is used.
- `N` Number of repetitions (integer > 0)
- `pobs` Vector of resampling percentages of observations (numerical, > 0 and <= 1)
- `ppre` Vector of resampling percentages of predictor variables (numerical, > 0 and <= 1)
- `conf.level` (1 - significance level) in function `ctree` (numerical, > 0 and <= 1);
  - default = 0.95

Details

For the optimization of the trees, we employ a method we call Sumping (Subsampling umbrella of model parameters), a variant of Bumping (Bootstrap umbrella of model parameters) (Tibshirani & Knight, 1999) which use subsampling instead of bootstrapping. The aim of the optimization is to identify conditional inference trees with maximum predictive power on the full sample under interpretability restrictions.

Reference


Standard output can be produced by means of `print(name)` or just `name` as well as `plot(name)` where 'name' is the output data frame of the function.

The plot function will produce a series of more than one plot. If you use R, you might want to specify `windows(record=TRUE)` before `plot(name)` to save the whole series of plots. In R-Studio this functionality is provided automatically.
Value

- **meanint**: Mean number of interpretable trees over the combinations of individual percentages in 'pobs' and 'ppre'
- **R2mean**: Mean R2 on test sets
- **ctmax**: Best resampled regression tree according to R2 on the full data set
- **permax**: Maximum R2 achieved for %observations
- **perfemax**: Maximum R2 achieved for %predictors
- **maxR2**: Best R2 on the full data set for resampled regression trees (for 'ctmax')
- **interpmax**: Interpretability of best tree 'ctmax'
- **ctmax2**: Second best resampled regression tree according to R2 on the full data set
- **permax2**: Second best R2 achieved for %observations
- **perfemax2**: Second best R2 achieved for %features
- **max2R2**: Second best R2 on the full data set for resampled regression trees (for 'ctmax2')
- **interp2max**: Interpretability of second-best tree 'ctmax2'

Examples

data <- PrInDT::data_vowel
data <- na.omit(data)
ctestv <- 'vowel_maximum_pitch <= 320'
N <- 30 # no. of repetitions
pobs <- c(0.70,0.60) # percentages of observations
ppre <- c(0.90,0.70) # percentages of predictors
outreg <- PrInDTreg(data,"target",ctestv,N,pobs,ppre)
outreg
plot(outreg)

Description

Regression tree based on the full sample; interpretability is checked (see 'ctestv'). The relationship between the target variable 'regname' and all other factor and numerical variables in the data frame 'datain' is modeled based on all observations.

Usage

PrInDTregAll(datain, regname, ctestv=NA, conf.level=0.95)
Arguments

datain Input data frame with class factor variable `classname` and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)
regname name of regressand variable (character)
ctestv Vector of character strings of forbidden split results; see function PrInDT for details. If no restrictions exist, the default = NA is used.
conf.level (1 - significance level) in function ctree (numerical, > 0 and <= 1); default = 0.95

Details

Standard output can be produced by means of print(name) or just name as well as plot(name) where `name` is the output data frame of the function.

Value

treeall tree based on all observations
R2All goodness of fit of `treeall` based on all observations
interpAll criterion of interpretability of `treeall` (TRUE / FALSE)

Examples

data <- PrInDT::data_vowel
data <- na.omit(data)
ctestv <- `vowel_maximum_pitch <= 320`
outreg <- PrInDTregAll(data,"target",ctestv)
outreg
plot(outreg)

RePrInDT

Repeated PrInDT for specified percentage combinations

Description

PrInDT is called repeatedly according to the percentages specified in the vectors `plarge` and `psmall`. The relationship between the two-class factor variable `classname` and all other factor and numerical variables in the data frame `datain` is optimally modeled by means of `N` repetitions of undersampling. The trees generated from undersampling can be restricted by rejecting unacceptable trees which include split results specified in the character strings of the vector `ctestv`. The probability threshold `thres` for the prediction of the smaller class may be specified (default =
0.5).
Undersampling may be stratified in two ways by the feature 'strat'.

**Reference**

**Usage**

```
RePrInDT(datain, classname, ctestv=NA, N, plarge, psmall, conf.level=0.95, thres=0.5, stratvers=0, strat=NA, seedl=TRUE)
```

**Arguments**

- **datain**: Input data frame with class factor variable ‘classname’ and the influential variables, which need to be factors or numericals (transform logicals and character variables to factors)
- **classname**: Name of class variable (character)
- **ctestv**: Vector of character strings of forbidden split results; see function PrInDT for details. If no restrictions exist, the default = NA is used.
- **N**: Number of repetitions (integer > 0)
- **plarge**: Vector of undersampling percentages of larger class (numerical, > 0 and <= 1)
- **psmall**: Vector of undersampling percentages of smaller class (numerical, > 0 and <= 1)
- **conf.level**: (1 - significance level) in function ctree (numerical, > 0 and <= 1); default = 0.95
- **thres**: Probability threshold for prediction of smaller class (numerical, >= 0 and < 1); default = 0.5
- **stratvers**: Version of stratification; = 0: none (default),
  = 1: stratification according to the percentages of the values of the factor variable 'strat',
  > 1: stratification with minimum number 'stratvers' of observations per value of 'strat'
- **strat**: Name of one (!) stratification variable for undersampling (character); default = NA (no stratification)
- **seedl**: Should the seed for random numbers be set (TRUE / FALSE)? default = TRUE

**Details**
Standard output can be produced by means of `print(name)` or just `name` as well as `plot(name)` where 'name' is the output data frame of the function.
The plot function will produce a series of more than one plot. If you use R, you might want to specify `windows(record=TRUE)` before `plot(name)` to save the whole series of plots. In R-Studio this functionality is provided automatically.
Value

treesb best trees for the different percentage combinations; refer to an individual tree as treesb[[k]], k = 1, ..., length(plarge)*length(psmall)

acc1st accuracies of best trees on full sample

acc3en accuracies of ensemble of 3 best trees on full sample

simp_m mean of permutation losses for the predictors

Examples

datastrat <- PrInDT::data_zero
data <- na.omit(datastrat) # cleaned full data: no NAs
# interpretation restrictions (split exclusions)
ctestv <- rbind('ETH == \{C2a, C1a\}', 'MLU == \{1, 3\}')
N <- 51 # no. of repetitions
conf.level <- 0.99 # 1 - significance level (mincriterion) in ctree
psmall <- c(0.95,1) # percentages of the small class
plarge <- c(0.09,0.1) # percentages of the large class
outRe <- RePrInDT(data,"real",ctestv,N,plarge,psmall,conf.level) # might take 5 minutes
outRe
plot(outRe)
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