

# Package ‘TunePareto’

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**Author** Christoph Müssel, Ludwig Lausser, Hans Kestler

**Maintainer** Hans Kestler <hans.kestler@uni-ulm.de>

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TunePareto-package      *Multi-objective parameter tuning for classifiers*

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## Description

Generic methods for parameter tuning of classification algorithms using multiple scoring functions

## Details

The methods of this package allow to assess the performance of classifiers with respect to certain parameter values and multiple scoring functions, such as the cross-validation error or the sensitivity. It provides the [tunePareto](#) function which can be configured to run most common classification methods implemented in R. Several sampling strategies for parameters are supplied, including Latin Hypercube sampling, quasi-random sequences, and evolutionary algorithms.

Classifiers are wrapped in generic `TuneParetoClassifier` objects which can be created using [tuneParetoClassifier](#). For state-of-the-art classifiers, the package includes the corresponding wrapper objects (see [tunePareto.knn](#), [tunePareto.tree](#), [tunePareto.randomForest](#), [tunePareto.svm](#), [tunePareto.NaiveBayes](#)).

The method tests combinations of the supplied classifier parameters according to the supplied scoring functions and calculates the Pareto front of optimal parameter configurations. The Pareto fronts can be visualized using [plotDominationGraph](#), [plotParetoFronts2D](#) and [plotObjectivePairs](#).

A number of predefined scoring functions are provided (see [predefinedObjectiveFunctions](#)), but the user is free to implement own scores (see [createObjective](#)).

## Author(s)

Christoph Müssel, Ludwig Lausser, Hans Kestler

Maintainer: Hans Kestler <[hans.kestler@uni-ulm.de](mailto:hans.kestler@uni-ulm.de)>

## References

Christoph Müssel, Ludwig Lausser, Markus Maucher, Hans A. Kestler (2012). Multi-Objective Parameter Selection for Classifiers. *Journal of Statistical Software*, 46(5), 1-27. DOI <https://doi.org/10.18637/jss.v046.i05>.

**Examples**

```

# optimize the 'cost' and 'kernel' parameters of an SVM according
# to CV error and CV Specificity on the 'iris' data set
# using several predefined values for the cost
r <- tunePareto(data = iris[, -ncol(iris)],
               labels = iris[, ncol(iris)],
               classifier=tunePareto.svm(),
               cost=c(0.001,0.01,0.1,1,10),
               kernel=c("linear", "polynomial",
                       "radial", "sigmoid"),
               objectiveFunctions=list(cvError(10, 10),
                                     cvSpecificity(10, 10, caseClass="setosa")))

# print Pareto-optimal solutions
print(r)

# use a continuous interval for the 'cost' parameter
# and optimize it using evolutionary algorithms and
# parallel execution with snowfall
library(snowfall)
sfInit(parallel=TRUE, cpus=2, type="SOCK")
r <- tunePareto(data = iris[, -ncol(iris)],
               labels = iris[, ncol(iris)],
               classifier = tunePareto.svm(),
               cost = as.interval(0.001,10),
               kernel = c("linear", "polynomial",
                         "radial", "sigmoid"),
               sampleType="evolution",
               numCombinations=20,
               numIterations=20,
               objectiveFunctions = list(cvError(10, 10),
                                       cvSensitivity(10, 10, caseClass="setosa"),
                                       cvSpecificity(10, 10, caseClass="setosa")),
               useSnowfall=TRUE)

sfStop()

# print Pareto-optimal solutions
print(r)

# plot the Pareto fronts
plotDominationGraph(r, legend.x="topright")

```

---

allCombinations

*Build a list of all possible combinations of parameter values*


---

**Description**

Builds a list of all possible combinations of parameter values from supplied ranges of parameter values. That is, each of the specified values is combined with all specified values for other parameters. The resulting lists can be used in the `classifierParameterCombinations` and `predictorParameterCombinations` parameters of `tunePareto`.

**Usage**

```
allCombinations(parameterRanges)
```

**Arguments**

parameterRanges

A list of lists of parameter ranges. That is, each element of the list specifies the values of a single parameter to be tested and is named according to this parameter. It is also possible to set parameters to fixed values by specifying only one value.

**Value**

Returns a list of lists, where each of the inner lists represents one parameter combination and consists of named elements for the parameters.

**See Also**

[tunePareto](#)

**Examples**

```
library(class)
# Combine only valid combinations of 'k' and 'l'
# for the k-NN classifier:
comb <- c(allCombinations(list(k=1,l=0)),
         allCombinations(list(k=3,l=0:2)),
         allCombinations(list(k=5,l=0:4)),
         allCombinations(list(k=7,l=0:6)))
print(comb)

print(tunePareto(data = iris[, -ncol(iris)],
                labels = iris[, ncol(iris)],
                classifier = tunePareto.knn(),
                parameterCombinations = comb,
                objectiveFunctions = list(cvError(10, 10),
                                       reclassError())))
```

---

as.interval

*Specify a continuous interval*

---

**Description**

Specifies a continuous interval by supplying a lower and upper bound. Such intervals can be supplied as parameter value ranges in [tunePareto](#).

**Usage**

```
as.interval(lower, upper)
```

**Arguments**

lower	The lower bound of the interval
upper	The upper bound of the interval

**Value**

A list of class `Interval` specifying the lower and upper bound.

**See Also**

[tunePareto](#)

---

createObjective	<i>Create a new objective function</i>
-----------------	--

---

**Description**

Creates a new `TuneParetoObjective` object. An objective consists of two parts: The precalculation function, which applies the classifier to the data, and the objective itself, which is calculated from the predicted class labels.

**Usage**

```
createObjective(precalculationFunction,
               precalculationParams = NULL,
               objectiveFunction,
               objectiveFunctionParams = NULL,
               direction = c("minimize", "maximize"),
               name)
```

**Arguments**

precalculationFunction	The name of the precalculation function that applies the classifiers to the data. Two predefined precalculation functions are <code>reclassification</code> and <code>crossValidation</code> .
precalculationParams	A named list of parameters for the precalculation function.
objectiveFunction	The name of the objective function that calculates the objective from the precalculated class labels.
objectiveFunctionParams	A named list of further parameters for the objective function.
direction	Specifies whether the objective is minimized or maximized.
name	A readable name of the objective.

## Details

The objective calculation is divided into a precalculation step and the objective calculation itself. The main reason for this is the possibility to aggregate precalculation across objectives. For example, if both the specificity and the sensitivity of a cross-validation (with the same parameters) are required, the cross-validation is run only once to save computational time. Afterwards, the results are passed to both objective functions.

A precalculation function has the following parameters:

**data** The data set to be used for the precalculation. This is usually a matrix or data frame with the samples in the rows and the features in the columns.

**labels** A vector of class labels for the samples in data.

**classifier** A `TuneParetoClassifier` wrapper object containing the classifier to tune. A number of state-of-the-art classifiers are included in **TunePareto** (see [predefinedClassifiers](#)). Custom classifiers can be employed using [tuneParetoClassifier](#).

**classifierParams** A named list of parameter assignments for the classifier.

**predictorParams** If the classifier has separate training and prediction functions, a named list of parameter assignments for the predictor.

Additionally, the function can have further parameters which are supplied in `precalculationParams`. To train a classifier and obtain predictions, the precalculation function can call the generic [trainTuneParetoClassifier](#) and [predict.TuneParetoModel](#) functions.

The precalculation function usually returns the predicted labels, the true labels and the model, but the only requirement of the return value is that it can be processed by the corresponding objective function. Predefined precalculation functions are [reclassification](#) and [crossValidation](#).

The objective function has a single obligatory parameter named `result` which supplies the result of the precalculation. Furthermore, optional parameters can be specified. Their values are taken from `objectiveFunctionParams`. The function either returns a single number specifying the objective value, or a list with a score component containing the objective value and a `additionalData` component that contains additional information to be stored in the `additionalData` component of the `TuneParetoResult` object (see [tunePareto](#)).

## Value

Returns an object of class `TuneParetoObjective` with the following components:

<code>precalculationFunction</code>	The supplied precalculation function
<code>precalculationParams</code>	The additional parameters to be passed to the precalculation function
<code>objectiveFunction</code>	The objective function
<code>minimize</code>	TRUE if the objective is minimized, FALSE if it is maximized.
<code>name</code>	The readable name of the objective.

## See Also

[predefinedObjectiveFunctions](#), [trainTuneParetoClassifier](#), [predict.TuneParetoModel](#)

## Examples

```
# create new objective minimizing the number of support vectors
# for a support vector machine

reclassSupportVectors <- function (saveModel = FALSE)
{
  createObjective(precalculationFunction = reclassification,
    precalculationParams = NULL, objectiveFunction =
    function(result, saveModel)
    {
      if(result$model$classifier$name != "svm")
        stop("This objective function can only be applied
          to classifiers of type tunePareto.svm()")

      res <- result$model$model$tot.nSV

      if (saveModel)
        # return a list containing the objective value as well as the model
        {
          return(list(additionalData = result$model, fitness = res))
        }
      else
        # only return the objective value
        return(res)
    },
    objectiveFunctionParams = list(saveModel = saveModel),
    direction = "minimize",
    name = "Reclass.SupportVectors")
}

# tune error vs. number of support vectors on the 'iris' data set
r <- tunePareto(data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  classifier = tunePareto.svm(),
  cost=c(0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50),
  objectiveFunctions=list(reclassError(), reclassSupportVectors()))

print(r)
```

---

generateCVRuns

*Generate cross-validation partitions*

---

## Description

This function generates a set of partitions for a cross-validation. It can be employed if the same cross-validation settings should be used in the objective functions of several experiments. The resulting fold list can be passed to the cross-validation objective functions (see [predefinedObjectiveFunctions](#)) and the internal cross-validation precalculation function [crossValidation](#).

**Usage**

```
generateCVRuns(labels,
               ntimes = 10,
               nfold = 10,
               leaveOneOut = FALSE,
               stratified = FALSE)
```

**Arguments**

labels	A vector of class labels of the data set to be used for the cross-validation.
nfold	The number of groups of the cross-validation. Ignored if leaveOneOut=TRUE.
ntimes	The number of repeated runs of the cross-validation. Ignored if leaveOneOut=TRUE.
leaveOneOut	If this is true, a leave-one-out cross-validation is performed, i.e. each sample is left out once in the training phase and used as a test sample
stratified	If set to true, a stratified cross-validation is carried out. That is, the percentage of samples from different classes in the cross-validation folds corresponds to the class sizes in the complete data set. If set to false, the folds may be unbalanced.

**Value**

A list with `ntimes` elements, each representing a cross-validation run. Each of the runs is a list of `nfold` vectors specifying the indices of the samples to be left out in the folds.

**See Also**

[predefinedObjectiveFunctions](#), [crossValidation](#)

**Examples**

```
# precalculate the cross-validation partitions
foldList <- generateCVRuns(labels = iris[, ncol(iris)],
                          ntimes = 10,
                          nfold = 10,
                          stratified=TRUE)

# build a list of objective functions
objectiveFunctions <- list(cvError(foldList=foldList),
                          cvSensitivity(foldList=foldList, caseClass="setosa"))

# pass them to tunePareto
print(tunePareto(data = iris[, -ncol(iris)],
                 labels = iris[, ncol(iris)],
                 classifier = tunePareto.knn(),
                 k = c(3,5,7,9),
                 objectiveFunctions = objectiveFunctions))
```

---

`mergeTuneParetoResults`*Calculate optimal solutions from several calls of tunePareto*

---

## Description

Merges the results of multiple `TuneParetoResult` objects as returned by `tunePareto`, and recalculates the optimal solutions for the merged solution set. All supplied `TuneParetoResult` objects must use the same objective functions.

## Usage

```
mergeTuneParetoResults(...)
```

## Arguments

... A set of `TuneParetoResult` objects to be merged.

## Value

A `TuneParetoResult` object containing the parameter configurations of all objects in the ... argument and selecting the Pareto-optimal solutions among all these configurations. For more details on the object structure, refer to `tunePareto`.

## See Also

[tunePareto](#), [recalculateParetoSet](#)

## Examples

```
# optimize an SVM with small costs on
# the 'iris' data set
r1 <- tunePareto(classifier = tunePareto.svm(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  cost=seq(0.01,0.1,0.01),
  objectiveFunctions=list(cvWeightedError(10, 10),
    cvSensitivity(10, 10, caseClass="setosa")))
print(r1)

# another call to tunePareto with higher costs
r2 <- tunePareto(classifier = tunePareto.svm(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  cost=seq(0.5,10,0.5),
  objectiveFunctions=list(cvWeightedError(10, 10),
    cvSensitivity(10, 10, caseClass="setosa")))
print(r2)
```

```
# merge the results
print(mergeTuneParetoResults(r1,r2))
```

---

plotDominationGraph     *Visualize the Pareto fronts of parameter configuration scores*

---

### Description

Draws the Pareto fronts and domination relations of tested parameter configurations in a graph. Here, the leftmost column of nodes represents the non-dominated configurations (i.e. the first Pareto front). The second column contains the second Pareto front, i.e. the configurations that are only dominated by the first Pareto front, and so on. An edge between two configurations indicate that the first configuration is dominated by the second.

### Usage

```
plotDominationGraph(tuneParetoResult,
                    transitiveReduction = TRUE,
                    drawDominatedObjectives = TRUE,
                    drawLabels = TRUE,
                    drawLegend = TRUE,
                    x.legend = "topleft",
                    cex.legend = 0.7,
                    col.indicator,
                    pch.indicator = 15,
                    cex.indicator = 0.8,
                    ...)
```

### Arguments

tuneParetoResult	An object of class TuneParetoResult as returned by <a href="#">tunePareto</a> .
transitiveReduction	If this is true, transitive edges in the graph are removed to enhance readability. That is, if configuration c1 dominates configuration c2 and c2 dominates c3, no edge from c3 to c1 is drawn.
drawDominatedObjectives	If set to true, color indicators are drawn next to the nodes. Here, each color corresponds to one objective. The color is drawn next to a node if this node has the best score in this objectives among all solutions of the same Pareto front (i.e., column of the graph).
drawLabels	Specifies whether the parameter configurations should be printed next to the corresponding edges.
drawLegend	If drawDominatedObjectives=TRUE, this specifies whether a legend with the objective colors should be drawn.

<code>x.legend</code>	The position of the legend. For details, refer to the <code>x</code> parameter of <a href="#">legend</a> .
<code>cex.legend</code>	Specifies the size of the text in the legend if <code>drawLegend</code> is true.
<code>col.indicator</code>	Specifies an optional list of colors, one for each objective function. These colors will be used for the indicators if <code>drawDominatedObjectives</code> is true. By default, a predefined set of colors is used.
<code>pch.indicator</code>	Specifies a single plotting character or a list of plotting characters for the objective functions in the indicators which is used for the indicators if <code>drawDominatedObjectives</code> is true.
<code>cex.indicator</code>	Specifies the size of the symbols in the indicators which is be used for the indicators if <code>drawDominatedObjectives</code> is true. This can also be a vector of sizes for the symbols of the objectives.
<code>...</code>	Further graphical parameters for <a href="#">plot.igraph</a> .

**Value**

Invisibly returns the `igraph` object representing the graph.

**See Also**

[tunePareto](#)

**Examples**

```
# call tunePareto using a k-NN classifier
# with different 'k' and 'l' on the 'iris' data set
x <- tunePareto(data = iris[, -ncol(iris)],
               labels = iris[, ncol(iris)],
               classifier = tunePareto.knn(),
               k = c(5,7,9),
               l = c(1,2,3),
               objectiveFunctions=list(cvError(10, 10),
                                     cvSpecificity(10, 10, caseClass="setosa")))

# plot the graph
plotDominationGraph(x)
```

---

`plotObjectivePairs`      *Plot a matrix of Pareto front panels*

---

**Description**

Plots a matrix of Pareto front panels for each pair of objectives. The plot for  $n$  objectives consists of  $n \times n$  panels, where the panel in row  $i$  and column  $j$  depicts the Pareto fronts of the  $i$ -th and the  $j$ -th objective. Each of the panels is drawn in the same way as [plotParetoFronts2D](#).

**Usage**

```
plotObjectivePairs(tuneParetoResult,
                  drawLabels = TRUE,
                  drawBoundaries = TRUE,
                  labelPos = 4,
                  fitLabels=TRUE,
                  cex.conf=0.5,
                  lty.fronts=1,
                  pch.fronts=8,
                  col.fronts,
                  ...)
```

**Arguments**

tuneParetoResult	An object of class <code>TuneParetoResult</code> as returned by <a href="#">tunePareto</a> .
drawLabels	If set to true, the descriptions of the configurations are printed next to the points in the plot.
drawBoundaries	If set to true, the upper or lower objective limits supplied in the <code>objectiveBoundaries</code> parameter of <a href="#">tunePareto</a> are drawn as horizontal and vertical lines.
labelPos	The position of the configuration labels in the plot (if <code>drawLabels</code> is true). Values of 1, 2, 3 and 4 denote positions below, to the left of, above and to the right of the points on the Pareto fronts.
fitLabels	If this parameter is true (and <code>drawLabels</code> is true), overlapping or partially hidden configuration labels are removed from the plot to improve the readability of the remaining labels.
cex.conf	The size of the configuration labels in the plots (if <code>drawLabels</code> is true).
lty.fronts	A vector of line types to use for the Pareto fronts. By default, straight lines are drawn for all fronts.
pch.fronts	A vector of symbols to use for points on the Pareto fronts. All points on the same front will have the same symbol. By default, an asterisk is used.
col.fronts	A vector of colors to use for the Pareto fronts. By default, a predefined set of colors is used.
...	Further graphical parameters to be passed to the <a href="#">plot</a> function.

**Value**

This function does not have a return value.

**See Also**

[tunePareto](#), [plotParetoFronts2D](#), [plotDominationGraph](#)

**Examples**

```
# optimize the 'cost' parameter of an SVM according
# to CV error, CV error variance, and CV Specificity
# on two classes of the 'iris' data set
r <- tunePareto(data = iris[, -ncol(iris)],
               labels = iris[, ncol(iris)],
               classifier = tunePareto.svm(),
               cost=c(0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50),
               objectiveFunctions=list(cvError(10, 10),
                                      cvErrorVariance(10, 10),
                                      cvSpecificity(10, 10, caseClass="virginica")))

# plot the matrix of Pareto fronts
plotObjectivePairs(r)
```

---

plotParetoFronts2D      *A classical 2-dimensional plot of Pareto fronts*

---

**Description**

Draws a classical Pareto front plot of 2 objectives of a parameter tuning. The first objective is on the x axis of the plot, and the second objective is on the y axis. Points on a Pareto front are connected by lines. Each Pareto front is drawn in a different color.

**Usage**

```
plotParetoFronts2D(tuneParetoResult,
                  objectives,
                  drawLabels = TRUE,
                  drawBoundaries = TRUE,
                  labelPos = 4,
                  fitLabels=TRUE,
                  cex.conf=0.5,
                  lty.fronts=1,
                  pch.fronts=8,
                  col.fronts,
                  ...)
```

**Arguments**

tuneParetoResult	An object of class <code>TuneParetoResult</code> as returned by <a href="#">tunePareto</a> .
objectives	The names or indices of the two objectives to plot. Pareto-optimality is determined only on the basis of these two objectives. Optional if the parameter tuning has exactly two objectives.
drawLabels	If set to true, the descriptions of the configurations are printed next to the points in the plot.

<code>drawBoundaries</code>	If set to true, the upper or lower objective limits supplied in the <code>objectiveBoundaries</code> parameter of <code>tunePareto</code> are drawn as horizontal and vertical lines.
<code>labelPos</code>	The position of the configuration labels in the plot (if <code>drawLabels</code> is true). Values of 1, 2, 3 and 4 denote positions below, to the left of, above and to the right of the points on the Pareto fronts.
<code>fitLabels</code>	If this parameter is true (and <code>drawLabels</code> is true), overlapping or partially hidden configuration labels are removed from the plot to improve the readability of the remaining labels.
<code>cex.conf</code>	The size of the configuration labels in the plots (if <code>drawLabels</code> is true).
<code>lty.fronts</code>	A vector of line types to use for the Pareto fronts. By default, straight lines are drawn for all fronts.
<code>pch.fronts</code>	A vector of symbols to use for points on the Pareto fronts. All points on the same front will have the same symbol. By default, an asterisk is used.
<code>col.fronts</code>	A vector of colors to use for the Pareto fronts. By default, a predefined set of colors is used.
<code>...</code>	Further graphical parameters to be passed to the <code>plot</code> function.

**Value**

This function does not have a return value.

**See Also**

[tunePareto](#), [plotDominationGraph](#)

**Examples**

```
# optimize the 'cost' parameter according
# to CV error and CV Specificity on the 'iris' data set
r <- tunePareto(data = iris[, -ncol(iris)],
               labels = iris[, ncol(iris)],
               classifier = tunePareto.svm(),
               cost=c(0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50),
               objectiveFunctions=list(cvError(10, 10),
                                     cvSpecificity(10, 10, caseClass="setosa")))

# plot the Pareto graph
plotParetoFronts2D(r)
```

**Description**

These predefined precalculation functions can be employed to create own objectives using `createObjective`. They perform a reclassification or a cross-validation and return the true labels and the predictions.

**Usage**

```

reclassification(data, labels,
                 classifier, classifierParams, predictorParams)

crossValidation(data, labels,
               classifier, classifierParams, predictorParams,
               ntimes = 10, nfold = 10,
               leaveOneOut = FALSE, stratified = FALSE,
               foldList = NULL)

```

**Arguments**

data	The data set to be used for the precalculation. This is usually a matrix or data frame with the samples in the rows and the features in the columns.
labels	A vector of class labels for the samples in data.
classifier	A TuneParetoClassifier wrapper object containing the classifier to tune. A number of state-of-the-art classifiers are included in <b>TunePareto</b> (see <a href="#">predefinedClassifiers</a> ). Custom classifiers can be employed using <a href="#">tuneParetoClassifier</a> .
classifierParams	A named list of parameter assignments for the training routine of the classifier.
predictorParams	If the classifier consists of separate training and prediction functions, a named list of parameter assignments for the predictor function.
nfold	The number of groups of the cross-validation. Ignored if leaveOneOut=TRUE.
ntimes	The number of repeated runs of the cross-validation. Ignored if leaveOneOut=TRUE.
leaveOneOut	If this is true, a leave-one-out cross-validation is performed, i.e. each sample is left out once in the training phase and used as a test sample
stratified	If set to true, a stratified cross-validation is carried out. That is, the percentage of samples from different classes in the cross-validation folds corresponds to the class sizes in the complete data set. If set to false, the folds may be unbalanced.
foldList	If this parameter is set, the other cross-validation parameters (ntimes, nfold, leaveOneOut, stratified) are ignored. Instead, the precalculated cross-validation partition supplied in foldList is used. This allows for using the same cross-validation experiment in multiple <a href="#">tunePareto</a> calls. Partitions can be generated using <a href="#">generateCVRuns</a> .

**Details**

reclassification trains the classifier with the full data set. Afterwards, the classifier is applied to the same data set.

crossValidate partitions the samples in the data set into a number of groups (depending on nfold and leaveOneOut). Each of these groups is left out once in the training phase and used for prediction. The whole procedure is repeated several times (as specified in ntimes).

**Value**

reclassification returns a list with the following components:

**trueLabels** The original labels of the dataset as supplied in labels

**predictedLabels** A vector of predicted labels of the data set

**model** The TuneParetoModel object resulting from the classifier training

crossValidation returns a nested list structure. At the top level, there is one list element for each run of the cross-validation. Each of these elements consists of a list of sub-structures for each fold. The sub-structures have the following components:

**trueLabels** The original labels of the test samples in the fold

**predictedLabels** A vector of predicted labels of the test samples in the fold

**model** The TuneParetoModel object resulting from the classifier training in the fold

That is, for a cross-validation with  $n$  runs and  $m$  folds, there are  $n$  top-level lists, each having  $m$  sub-lists comprising the true labels and the predicted labels.

**See Also**

[createObjective](#), [generateCVRuns](#).

**Examples**

```
# create new objective minimizing the
# false positives of a reclassification

cvFalsePositives <- function(nfold=10, ntimes=10, leaveOneOut=FALSE, foldList=NULL, caseClass)
{
  return(createObjective(
    precalculationFunction = "crossValidation",
    precalculationParams = list(nfold=nfold,
                                ntimes=ntimes,
                                leaveOneOut=leaveOneOut,
                                foldList=foldList),

    objectiveFunction =
    function(result, caseClass)
    {

      # take mean value over the cv runs
      return(mean(sapply(result,
                          function(run)
                          # iterate over runs of cross-validation
                          {
                            # extract all predicted labels in the folds
                            predictedLabels <-
                              unlist(lapply(run,
                                             function(fold)fold$predictedLabels))

                            # extract all true labels in the folds
                            trueLabels <-
```

```

        unlist(lapply(run,
                     function(fold)fold$trueLabels))

        # calculate number of false positives in the run
        return(sum(predictedLabels == caseClass &
                  trueLabels != caseClass))
      )))
    },
    objectiveFunctionParams = list(caseClass=caseClass,
                                   direction = "minimize",
                                   name = "CV.FalsePositives"))
  }

# use the objective in an SVM cost parameter tuning on the 'iris' data set
r <- tunePareto(data = iris[, -ncol(iris)],
               labels = iris[, ncol(iris)],
               classifier = tunePareto.svm(),
               cost = c(0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50),
               objectiveFunctions=list(cvFalsePositives(10, 10, caseClass="setosa")))
print(r)

```

---

predefinedClassifiers *TunePareto wrappers for certain classifiers*

---

## Description

Creates TunePareto classifier objects for the k-Nearest Neighbour classifier, support vector machines, and trees.

## Usage

```

tunePareto.knn()

tunePareto.svm()

tunePareto.tree()

tunePareto.randomForest()

tunePareto.NaiveBayes()

```

## Details

tunePareto.knn encapsulates a k-Nearest Neighbour classifier as defined in link[class]{knn} in package **class**. The classifier allows for supplying and tuning the following parameters of link[class]{knn}:

k, l, use.all

`tunePareto.svm` encapsulates the support vector machine `svm` classifier in package **e1071**. The classifier allows for supplying and tuning the following parameters:

`kernel`, `degree`, `gamma`, `coef0`, `cost`, `nu`, `class.weights`, `cacheSize`, `tolerance`, `epsilon`, `scale`, `shrinking`, `fitted`, `subset`, `na.action`

`tunePareto.tree` encapsulates the CART classifier `tree` in package **tree**. The classifier allows for supplying and tuning the following parameters:

`weights`, `subset`, `na.action`, `method`, `split`, `mincut`, `minsize`, `mindev`

as well as the `type` parameter of `predict.tree`.

`tunePareto.randomForest` encapsulates the `randomForest` classifier in package **randomForest**. The classifier allows for supplying and tuning the following parameters:

`subset`, `na.action`, `ntree`, `mtry`, `replace`, `classwt`, `cutoff`, `strata`, `sampsiz`, `nodesize`, `maxnodes`

`tunePareto.NaiveBayes` encapsulates the `NaiveBayes` classifier in package **klaR**. The classifier allows for supplying and tuning the following parameters:

`prior`, `usekernel`, `fL`, `subset`, `na.action`, `bw`, `adjust`, `kernel`, `weights`, `window`, `width`, `give.Rkern`, `n`, `from`, `to`, `cut`, `na.rm`

### Value

Returns objects of class `TuneParetoClassifier` as described in `tuneParetoClassifier`. These can be passed to functions like `tunePareto` or `trainTuneParetoClassifier`.

### See Also

[tuneParetoClassifier](#), [tunePareto](#), [trainTuneParetoClassifier](#)

### Examples

```
# tune a k-NN classifier with different 'k' and 'l'
# on the 'iris' data set
print(tunePareto(classifier = tunePareto.knn(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  k = c(5,7,9),
  l = c(1,2,3),
  objectiveFunctions=list(cvError(10, 10),
    cvSpecificity(10, 10, caseClass="setosa"))))

# tune an SVM with different costs on
# the 'iris' data set
# using Halton sequences for sampling
print(tunePareto(classifier = tunePareto.svm(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  cost = as.interval(0.001,10),
  sampleType = "halton",
  numCombinations=20,
  objectiveFunctions=list(cvWeightedError(10, 10),
```

```

cvSensitivity(10, 10, caseClass="setosa"))))

# tune a CART classifier with different
# splitting criteria on the 'iris' data set
print(tunePareto(classifier = tunePareto.tree(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  split = c("deviance", "gini"),
  objectiveFunctions=list(cvError(10, 10),
    cvErrorVariance(10, 10))))

# tune a Random Forest with different numbers of trees
# on the 'iris' data set
print(tunePareto(classifier = tunePareto.randomForest(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  ntree = seq(50, 300, 50),
  objectiveFunctions=list(cvError(10, 10),
    cvSpecificity(10, 10, caseClass="setosa"))))

# tune a Naive Bayes classifier with different kernels
# on the 'iris' data set
print(tunePareto(classifier = tunePareto.NaiveBayes(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  kernel = c("gaussian", "epanechnikov", "rectangular",
    "triangular", "biweight",
    "cosine", "optcosine"),
  objectiveFunctions=list(cvError(10, 10),
    cvSpecificity(10, 10, caseClass="setosa"))))

```

---

```
predefinedObjectiveFunctions
```

*Predefined objective functions for parameter tuning*

---

## Description

Predefined objective functions that calculate several performance criteria of reclassification or cross-validation experiments.

## Usage

```

reclassAccuracy(saveModel = FALSE)
reclassError(saveModel = FALSE)
reclassWeightedError(saveModel = FALSE)
reclassSensitivity(caseClass, saveModel = FALSE)
reclassRecall(caseClass, saveModel = FALSE)

```

```
reclassTruePositive(caseClass, saveModel = FALSE)
reclassSpecificity(caseClass, saveModel = FALSE)
reclassTrueNegative(caseClass, saveModel = FALSE)
reclassFallout(caseClass, saveModel = FALSE)
reclassFalsePositive(caseClass, saveModel = FALSE)
reclassMiss(caseClass, saveModel = FALSE)
reclassFalseNegative(caseClass, saveModel = FALSE)
reclassPrecision(caseClass, saveModel = FALSE)
reclassPPV(caseClass, saveModel = FALSE)
reclassNPV(caseClass, saveModel = FALSE)
reclassConfusion(trueClass, predictedClass, saveModel = FALSE)

cvAccuracy(nfold = 10, ntimes = 10,
           leaveOneOut = FALSE, stratified = FALSE,
           foldList = NULL,
           saveModel = FALSE)
cvError(nfold = 10, ntimes = 10,
        leaveOneOut = FALSE, stratified=FALSE,
        foldList=NULL,
        saveModel = FALSE)
cvErrorVariance(nfold = 10, ntimes = 10,
               leaveOneOut = FALSE, stratified=FALSE,
               foldList=NULL,
               saveModel = FALSE)
cvWeightedError(nfold = 10, ntimes = 10,
               leaveOneOut = FALSE, stratified=FALSE,
               foldList=NULL,
               saveModel = FALSE)
cvSensitivity(nfold = 10, ntimes = 10,
             leaveOneOut = FALSE, stratified=FALSE,
             foldList=NULL, caseClass,
             saveModel = FALSE)
cvRecall(nfold = 10, ntimes = 10,
        leaveOneOut = FALSE, stratified=FALSE,
        foldList=NULL, caseClass,
        saveModel = FALSE)
cvTruePositive(nfold = 10, ntimes = 10,
              leaveOneOut = FALSE, stratified=FALSE,
              foldList=NULL, caseClass,
              saveModel = FALSE)
cvSpecificity(nfold = 10, ntimes = 10,
            leaveOneOut = FALSE, stratified=FALSE,
            foldList=NULL, caseClass,
            saveModel = FALSE)
cvTrueNegative(nfold = 10, ntimes = 10,
              leaveOneOut = FALSE, stratified=FALSE,
              foldList=NULL, caseClass,
              saveModel = FALSE)
```

```

cvFallout(nfold = 10, ntimes = 10,
          leaveOneOut = FALSE, stratified=FALSE,
          foldList=NULL, caseClass,
          saveModel = FALSE)
cvFalsePositive(nfold = 10, ntimes = 10,
                leaveOneOut = FALSE, stratified=FALSE,
                foldList=NULL, caseClass,
                saveModel = FALSE)
cvMiss(nfold = 10, ntimes = 10,
        leaveOneOut = FALSE, stratified=FALSE,
        foldList=NULL, caseClass,
        saveModel = FALSE)
cvFalseNegative(nfold = 10, ntimes = 10,
                leaveOneOut = FALSE, stratified=FALSE,
                foldList=NULL, caseClass,
                saveModel = FALSE)
cvPrecision(nfold = 10, ntimes = 10,
             leaveOneOut = FALSE, stratified=FALSE,
             foldList=NULL, caseClass,
             saveModel = FALSE)
cvPPV(nfold = 10, ntimes = 10,
       leaveOneOut = FALSE, stratified=FALSE,
       foldList=NULL, caseClass,
       saveModel = FALSE)
cvNPV(nfold = 10, ntimes = 10,
       leaveOneOut = FALSE, stratified=FALSE,
       foldList=NULL, caseClass,
       saveModel = FALSE)
cvConfusion(nfold = 10, ntimes = 10,
            leaveOneOut = FALSE, stratified=FALSE,
            foldList=NULL, trueClass, predictedClass,
            saveModel = FALSE)

```

### Arguments

<code>nfold</code>	The number of groups of the cross-validation. Ignored if <code>leaveOneOut=TRUE</code> .
<code>ntimes</code>	The number of repeated runs of the cross-validation. Ignored if <code>leaveOneOut=TRUE</code> .
<code>leaveOneOut</code>	If this is true, a leave-one-out cross-validation is performed, i.e. each sample is left out once in the training phase and used as a test sample
<code>stratified</code>	If set to true, a stratified cross-validation is carried out. That is, the percentage of samples from different classes in the cross-validation folds corresponds to the class sizes in the complete data set. If set to false, the folds may be unbalanced.
<code>foldList</code>	If this parameter is set, the other cross-validation parameters ( <code>ntimes</code> , <code>nfold</code> , <code>leaveOneOut</code> , <code>stratified</code> ) are ignored. Instead, the precalculated cross-validation partition supplied in <code>foldList</code> is used. This allows for using the same cross-validation experiment in multiple <a href="#">tunePareto</a> calls. Partitions can be generated using <a href="#">generateCVRuns</a> .

caseClass	The class containing the positive samples for the calculation of specificity and sensitivity. All samples with different class labels are regarded as controls (negative samples).
trueClass	When calculating the confusion of two classes, the class to which a sample truly belongs.
predictedClass	When calculating the confusion of two classes, the class to which a sample is erroneously assigned.
saveModel	If set to true, the trained model(s) are stored to the additionalData component of the resulting TuneParetoResult objects (see <a href="#">tunePareto</a> for details). In case of a reclassification, a single model is stored. In case of a cross-validation, a list of length nruns, each containing a sub-list of nfold models, is stored. If the size of a model is large, setting saveModel = TRUE can result in a high memory consumption. As the model information is the same for all reclassification objectives or for cross-validation objectives with the same parameters, it is usually sufficient to set saveModel=TRUE for only one of the objective functions.

## Details

The functions do not calculate the objectives directly, but return a structure of class TuneParetoObjectives that provides all information on the objective function for later use in [tunePareto](#).

The behaviour of the functions in [tunePareto](#) is as follows:

The reclassification functions train the classifiers with the full data set. Afterwards, the classifiers are applied to the same data set. reclassAccuracy measures the fraction of correctly classified samples, while reclassError calculates the fraction of misclassified samples. reclassWeightedError calculates the sum of fractions of misclassified samples in each class weighted by the class size. reclassSensitivity measures the sensitivity, and reclassSpecificity measures the specificity of the reclassification experiment. reclassTruePositive and reclassRecall are aliases for reclassSensitivity, and reclassTrueNegative is an alias for reclassSpecificity. reclassFallout and its equivalent alias reclassFalsePositive give the ratio of false positives to all negative samples, and reclassMiss and its alias reclassFalseNegative measure the ratio of false negatives to all positive samples. reclassPrecision calculates the precision of the reclassification experiment, i.e. the ratio of true positives to all samples classified as positive. This is equivalent to the positive predictive value (reclassPPV). reclassNPV measures the negative predictive value, i.e. the ratio of true negatives to all samples classified as negative. reclassConfusion calculates the fraction of samples in trueClass that have been confused with predictedClass.

reclassError, reclassWeightedError, reclassFallout, reclassFalsePositive, reclassMiss, reclassFalsePositive and reclassConfusion are minimization objectives, whereas reclassAccuracy, reclassSensitivity, reclassTruePositive, reclassRecall, reclassSpecificity, reclassTrueNegative, reclassPrecision, reclassPPV and reclassNPV are maximization objectives.

The cross-validation functions partition the samples in the data set into a number of groups (depending on nfold and leaveOneOut). Each of these groups is left out once in the training phase and used for prediction. The whole procedure is usually repeated several times (as specified in ntimes), and the results are averaged. Similar to the reclassification functions, cvAccuracy calculates the fraction of correctly classified samples over the runs, cvError calculates the average fraction of misclassified samples over the runs, and cvWeightedError calculates the mean sum of fractions of misclassified samples in each class weighted by the class size. cvErrorVariance calculates the variance of the cross-validation error. cvSensitivity, cvRecall and cvTruePositive calculate

the average sensitivity, and cvSpecificity and cvTrueNegative calculate the average specificity. cvFallout and cvFalsePositive calculate the average false positive rate over the runs. cvMiss and cvFalseNegative calculate the average false negative rate over the runs. cvPrecision and cvPPV calculate the average precision/positive predictive rate. cvNPV gives the average negative predictive rate over all runs. cvConfusion calculates the average fraction of samples in trueClass that have been confused with predictedClass.

cvError, cvWeightedError, cvErrorVariance, cvFallout, cvFalsePositive, cvMiss, cvFalseNegative and cvConfusion are minimization objectives, and cvAccuracy, cvSensitivity, cvRecall, cvTruePositive, cvSpecificity, cvTrueNegative, cvPrecision, cvPPV and cvNPV are maximization objectives.

### Value

An object of class TuneParetoObjective representing the objective function. For more details, see [createObjective](#).

### See Also

[createObjective](#), [tunePareto](#), [generateCVRuns](#)

### Examples

```
# build a list of objective functions
objectiveFunctions <- list(cvError(10, 10),
                          reclassSpecificity(caseClass="setosa"),
                          reclassSensitivity(caseClass="setosa"))

# pass them to tunePareto
print(tunePareto(data = iris[, -ncol(iris)],
                 labels = iris[, ncol(iris)],
                 classifier = tunePareto.knn(),
                 k = c(3,5,7,9),
                 objectiveFunctions = objectiveFunctions))
```

---

predict.TuneParetoModel

*Prediction method for TuneParetoClassifier objects*

---

### Description

S3 method that predicts the labels of unknown samples using a trained TuneParetoModel model of a TuneParetoClassifier object.

### Usage

```
## S3 method for class 'TuneParetoModel'
predict(object, newdata, ...)
```

**Arguments**

object	A TuneParetoTraining object as returned by <a href="#">trainTuneParetoClassifier</a> .
newdata	The samples whose class labels are predicted. This is usually a matrix or data frame with the samples in the rows and the features in the columns.
...	Further parameters for the predictor. These must be defined in the predictorParamNames argument of <a href="#">tuneParetoClassifier</a> .

**Value**

Returns a vector of class labels for the samples in newdata-

**See Also**

[tuneParetoClassifier](#), [predefinedClassifiers](#), [trainTuneParetoClassifier](#)

**Examples**

```
# train an SVM classifier
cl <- tunePareto.svm()
tr <- trainTuneParetoClassifier(cl,
                               iris[,-ncol(iris)],
                               iris[,ncol(iris)],
                               cost=0.001)

# re-apply the classifier to predict the training data
print(iris[,ncol(iris)])
print(predict(tr, iris[,-ncol(iris)]))
```

---

`print.TuneParetoResult`

*Print method for objects used in TunePareto*

---

**Description**

Customized printing methods for several objects used in TunePareto: For TuneParetoResult objects, the Pareto-optimal parameter configurations are printed. For TuneParetoClassifier and TuneParetoModel objects, information on the classifier and its parameters is printed.

**Usage**

```
## S3 method for class 'TuneParetoResult'
print(x, ...)
## S3 method for class 'TuneParetoClassifier'
print(x, ...)
## S3 method for class 'TuneParetoModel'
print(x, ...)
```

**Arguments**

- x                    An object of class TuneParetoResult, TuneParetoClassifier or TuneParetoModel to be printed.
- ...                   Further parameters (currently unused).

**Value**

Invisibly returns the printed object.

**See Also**

[tunePareto](#), [tuneParetoClassifier](#), [trainTuneParetoClassifier](#)

---

rankByDesirability     *Rank results according to their desirabilities*

---

**Description**

Calculates the desirability index for each Pareto-optimal combination (or for all combinations), and ranks the combinations according to this value. The desirability index was introduced by Harrington in 1965 for multicriteria optimization. Desirability functions specify the desired values of each objective and are aggregated in a single desirability index.

**Usage**

```
rankByDesirability(tuneParetoResult,
                  desirabilityIndex,
                  optimalOnly = TRUE)
```

**Arguments**

- tuneParetoResult     A TuneParetoResult object containing the parameter configurations to be examined
- desirabilityIndex     A function accepting a vector of objective values and returning a desirability index in [0,1].
- optimalOnly           If set to true, only the Pareto-optimal solutions are ranked. Otherwise, all tested solutions are ranked. Defaults to TRUE.

**Value**

A matrix of objective values with an additional column for the desirability index. The rows of the matrix are sorted according to the index.

**Examples**

```

# optimize the 'cost' parameter of an SVM on
# the 'iris' data set
res <- tunePareto(classifier = tunePareto.svm(),
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  cost=c(0.01,0.05,0.1,0.5,1,5,10,50,100),
  objectiveFunctions=list(cvWeightedError(10, 10),
    cvSensitivity(10, 10, caseClass="setosa"),
    cvSpecificity(10, 10, caseClass="setosa")))

# create desirability functions
# aggregate functions in desirability index (e.g. harrington desirability function)
# here, for the sake of simplicity a random number generator
di <- function(x) {runif(1)}

# rank all tuning results according to their desirabilities
print(rankByDesirability(res,di,optimalOnly=FALSE))

```

---

recalculateParetoSet *Recalculate Pareto-optimal solutions*

---

**Description**

Recalculates the Pareto-optimal solutions in a `TuneParetoResult` according to the specified objectives only, and returns another `TuneParetoResult` object reduced to these objectives. This avoids time-consuming recalculations of objective values if only a subset of objectives should be considered for a previously evaluated set of parameter combinations.

**Usage**

```
recalculateParetoSet(tuneParetoResult,
  objectives)
```

**Arguments**

<code>tuneParetoResult</code>	The <code>TuneParetoResult</code> object containing the parameter configurations to be examined
<code>objectives</code>	A vector of objective function indices. The Pareto set is recalculated according to these objectives, i.e. omitting other objectives. If this argument is not supplied, all objectives are used, which usually returns a copy of the input.

**Value**

Returns a reduced TuneParetoResult object. For more details on the object structure, refer to [tunePareto](#).

**See Also**

[tunePareto](#), [mergeTuneParetoResults](#)

**Examples**

```
# optimize the 'cost' parameter of an SVM on
# the 'iris' data set
res <- tunePareto(classifier = tunePareto.svm(),
                 data = iris[, -ncol(iris)],
                 labels = iris[, ncol(iris)],
                 cost=seq(0.01,0.1,0.01),
                 objectiveFunctions=list(cvWeightedError(10, 10),
                                       cvSensitivity(10, 10, caseClass="setosa"),
                                       cvSpecificity(10, 10, caseClass="setosa")))

print(res)

# select only specificity and sensitivity
print(recalculateParetoSet(res, 2:3))
```

---

trainTuneParetoClassifier

*Train a TunePareto classifier*

---

**Description**

Trains a classifier wrapped in a TuneParetoClassifier object. The trained classifier model can then be passed to [predict.TuneParetoModel](#).

**Usage**

```
trainTuneParetoClassifier(classifier, trainData, trainLabels, ...)
```

**Arguments**

classifier	A TuneParetoClassifier object as returned by <a href="#">tuneParetoClassifier</a> or one of the predefined classification functions (see <a href="#">predefinedClassifiers</a> ).
trainData	The data set to be used for the classifier training. This is usually a matrix or data frame with the samples in the rows and the features in the columns.
trainLabels	A vector of class labels for the samples in trainData.
...	Further parameters to be passed to the classifier. These must be parameters specified in the classifierParameterNames parameter of <a href="#">tuneParetoClassifier</a> and usually correspond to the tuned parameters.

**Value**

Returns an object of class `TuneParetoModel` with the following entries

<code>classifier</code>	The classifier object supplied in the <code>classifier</code> parameter
<code>classifierParams</code>	The additional parameters supplied to the classifier in the <code>...</code> parameter
<code>trainData</code>	If <code>classifier</code> is an all-in-one classifier without a separate prediction method, this stores the input training data.
<code>trainLabels</code>	If <code>classifier</code> is an all-in-one classifier without a separate prediction method, this stores the input training labels.
<code>model</code>	If <code>classifier</code> consists of separate training and prediction methods, this contains the trained classifier model.

**See Also**

[tuneParetoClassifier](#), [predefinedClassifiers](#), [predict.TuneParetoModel](#)

**Examples**

```
# train an SVM classifier
cl <- tunePareto.svm()
tr <- trainTuneParetoClassifier(cl,
                               iris[,-ncol(iris)],
                               iris[,ncol(iris)],
                               cost=0.001)

# re-apply the classifier to predict the training data
print(iris[,ncol(iris)])
print(predict(tr, iris[,-ncol(iris)]))
```

---

tunePareto

*Generic function for multi-objective parameter tuning of classifiers*

---

**Description**

This generic function tunes parameters of arbitrary classifiers in a multi-objective setting and returns the Pareto-optimal parameter combinations.

**Usage**

```
tunePareto(..., data, labels,
           classifier, parameterCombinations,
           sampleType = c("full", "uniform",
                          "latin", "halton",
                          "niederreiter", "sobol",
                          "evolution"),
           numCombinations,
```

```
mu=10, lambda=20, numIterations=100,
objectiveFunctions, objectiveBoundaries,
keepSeed = TRUE, useSnowfall = FALSE, verbose=TRUE)
```

## Arguments

data	The data set to be used for the parameter tuning. This is usually a matrix or data frame with the samples in the rows and the features in the columns.
labels	A vector of class labels for the samples in data.
classifier	A TuneParetoClassifier wrapper object containing the classifier to tune. A number of state-of-the-art classifiers are included in <b>TunePareto</b> (see <a href="#">predefinedClassifiers</a> ). Custom classifiers can be employed using <a href="#">tuneParetoClassifier</a> .
parameterCombinations	If not all combinations of parameter ranges for the classifier are meaningful, you can set this parameter instead of specifying parameter values in the ... argument. It holds an explicit list of possible combinations, where each element of the list is a named sublist with one entry for each parameter.
sampleType	Determines the way parameter configurations are sampled. If type="full", all possible combinations are tried. This is only possible if all supplied parameter ranges are discrete or if the combinations are supplied explicitly in parameterCombinations. If type="uniform", numCombinations combinations are drawn uniformly at random. If type="latin", Latin Hypercube sampling is applied. This is particularly encouraged when tuning using continuous parameters. If type="halton", "niederreiter", "sobol", numCombinations parameter combinations are drawn on the basis of the corresponding quasi-random sequences (initialized at a random step to ensure that different values are drawn in repeated runs). This is particularly encouraged when tuning using continuous parameters. type="niederreiter" and type="sobol" require the <b>gsl</b> package to be installed. If type="evolution", an evolutionary algorithm is applied. In details, this employs mu+lambda Evolution Strategies with uncorrelated mutations and non-dominated sorting for survivor selection. This is encouraged when the space of possible parameter configurations is very large. For smaller parameter spaces, the above sampling methods may be faster.
numCombinations	If this parameter is set, at most numCombinations randomly chosen parameter configurations are tested. Otherwise, all possible combinations of the supplied parameter ranges are tested.
mu	The number of individuals used in the Evolution Strategies if type="evolution".
lambda	The number of offspring per generation in the Evolution Strategies if type="evolution".
numIterations	The number of iterations/generations the evolutionary algorithm is run if type="evolution".

objectiveFunctions	A list of objective functions used to tune the parameters. There are a number of predefined objective functions (see <a href="#">predefinedObjectiveFunctions</a> ). Custom objective functions can be created using <a href="#">createObjective</a> .
objectiveBoundaries	If this parameter is set, it specifies boundaries of the objective functions for valid solutions. That is, each element of the supplied vector specifies the upper or lower limit of an objective (depending on whether the objective is maximized or minimized). Parameter combinations that do not meet all these restrictions are not included in the result set, even if they are Pareto-optimal. If only some of the objectives should have bounds, supply NA for the remaining objectives.
keepSeed	If this is true, the random seed is reset to the same value for each of the tested parameter configurations. This is an easy way to guarantee comparability in randomized objective functions. E.g., cross-validation runs of the classifiers will all start with the same seed, which results in the same partitions. <b>Attention:</b> If you set this parameter to FALSE, you must ensure that all configuration are treated equally in the objective functions: There may be randomness in processes such as classifier training, but there should be no random difference in the rating itself. In particular, the choice of subsets for subsampling experiments should always be the same for all configurations. For example, you can provide precalculated fold lists to the cross-validation objectives in the <code>foldList</code> parameter. If parameter configurations are rated under varying conditions, this may yield over-optimistic or over-pessimistic ratings for some configurations due to outliers.
useSnowfall	If this parameter is true, the routine loads the <b>snowfall</b> package and processes the parameter configurations in parallel. Please note that the <b>snowfall</b> cluster has to be initialized properly before running the tuning function and stopped after the run.
verbose	If this parameter is true, status messages are printed. In particular, the algorithm prints the currently tested combination.
...	The parameters of the classifier and predictor functions that should be tuned. The names of the parameters must correspond to the parameters specified in <code>classifierParameterNames</code> and <code>predictorParameterNames</code> of <a href="#">tuneParetoClassifier</a> . Each supplied argument describes the possible values of a single parameter. These can be specified in two ways: Discrete parameter ranges are specified as lists of possible values. Continuous parameter ranges are specified as intervals using <a href="#">as.interval</a> . The algorithm then generates combinations of possible parameter values. Alternatively, the combinations can be defined explicitly using the <code>parameterCombinations</code> parameter.

## Details

This is a generic function that allows for parameter tuning of a wide variety of classifiers. You can either specify the values or intervals of tuned parameters in the `...` argument, or supply selected combinations of parameter values using `parameterCombinations`. In the first case, combinations of parameter values specified in the `...` argument are generated. If `sampleType="uniform"`, `sampleType="latin"`, `sampleType="halton"`, `sampleType="niederreiter"` or `sampleType="sobol"`,

a random subset of the possible combinations is drawn.

If `sampleType="evolution"`, random parameter combinations are generated and optimized using Evolution Strategies.

In the latter case, only the parameter combinations specified explicitly in `parameterCombinations` are tested. This is useful if certain parameter combinations are invalid. You can create parameter combinations by concatenating results of calls to [allCombinations](#). Only `sampleType="full"` is allowed in this mode.

For each of the combinations, the specified objective functions are calculated. This usually involves training and testing a classifier. From the resulting objective values, the non-dominated parameter configurations are calculated and returned.

The `...` argument is the first argument of `tunePareto` for technical reasons (to prevent partial matching of the supplied parameters with argument names of `tunePareto`. This requires all arguments to be named.

## Value

Returns a list of class `TuneParetoResult` with the following components:

`bestCombinations`

A list of Pareto-optimal parameter configurations. Each element of the list consists of a sub-list with named elements corresponding to the parameter values.

`bestObjectiveValues`

A matrix containing the objective function values of the Pareto-optimal configurations in `bestCombinations`. Each row corresponds to a parameter configuration, and each column corresponds to an objective function.

`testedCombinations`

A list of all tested parameter configurations with the same structure as `bestCombinations`.

`testedObjectiveValues`

A matrix containing the objective function values of all tested configurations with the same structure as `bestObjectiveValues`.

`dominationMatrix`

A Boolean matrix specifying which parameter configurations dominate each other. If a configuration `i` dominates a configuration `j`, the entry in the `i`th row and the `j`th column is `TRUE`.

`minimizeObjectives`

A Boolean vector specifying which of the objectives are minimization objectives. This is derived from the objective functions supplied to `tunePareto`.

`additionalData`

A list containing additional data that may have been returned by the objective functions. The list has one element for each tested parameter configuration, each comprising one sub-element for each objective function that returned additional data. The structure of these sub-elements depends on the corresponding objective function. For example, the predefined objective functions (see [predefinedObjectiveFunctions](#)) save the trained models here if `saveModel` is `true`.

**See Also**

[predefinedClassifiers](#), [predefinedObjectiveFunctions](#), [createObjective](#), [allCombinations](#)

**Examples**

```
# tune 'k' of a k-NN classifier
# on two classes of the 'iris' data set --
# see ?knn
print(tunePareto(data = iris[, -ncol(iris)],
                labels = iris[, ncol(iris)],
                classifier = tunePareto.knn(),
                k = c(1,3,5,7,9),
                objectiveFunctions = list(cvError(10, 10),
                                       reclassError()))))

# example using predefined parameter configurations,
# as certain combinations of k and l are invalid:
comb <- c(allCombinations(list(k=1,l=0)),
          allCombinations(list(k=3,l=0:2)),
          allCombinations(list(k=5,l=0:4)),
          allCombinations(list(k=7,l=0:6)))

print(tunePareto(data = iris[, -ncol(iris)],
                labels = iris[, ncol(iris)],
                classifier = tunePareto.knn(),
                parameterCombinations = comb,
                objectiveFunctions = list(cvError(10, 10),
                                       reclassError()))))

# tune 'cost' and 'kernel' of an SVM on
# the 'iris' data set using Latin Hypercube sampling --
# see ?svm and ?predict.svm
print(tunePareto(data = iris[, -ncol(iris)],
                labels = iris[, ncol(iris)],
                classifier = tunePareto.svm(),
                cost = as.interval(0.001,10),
                kernel = c("linear", "polynomial",
                          "radial", "sigmoid"),
                sampleType="latin",
                numCombinations=20,
                objectiveFunctions = list(cvError(10, 10),
                                       cvSensitivity(10, 10, caseClass="setosa"))))

# tune the same parameters using Evolution Strategies
print(tunePareto(data = iris[, -ncol(iris)],
                labels = iris[, ncol(iris)],
                classifier = tunePareto.svm(),
                cost = as.interval(0.001,10),
                kernel = c("linear", "polynomial",
                          "radial", "sigmoid"),
```

```

sampleType="evolution",
numCombinations=20,
numIterations=20,
objectiveFunctions = list(cvError(10, 10),
                          cvSensitivity(10, 10, caseClass="setosa"),
                          cvSpecificity(10, 10, caseClass="setosa"))))

```

---

tuneParetoClassifier *Create a classifier object*

---

### Description

Creates a wrapper object mapping all information necessary to call a classifier which can be passed to [tunePareto](#).

### Usage

```

tuneParetoClassifier(name,
                    classifier,
                    classifierParamNames = NULL,
                    predefinedClassifierParams = NULL,
                    predictor = NULL,
                    predictorParamNames = NULL,
                    predefinedPredictorParams = NULL,
                    useFormula = FALSE,
                    formulaName = "formula",
                    trainDataName = "x",
                    trainLabelName = "y",
                    testDataName = "newdata",
                    modelName = "object",
                    requiredPackages = NULL)

```

### Arguments

name	A human-readable name of the classifier
classifier	The classification function to use. If predictor is NULL, this function is an all-in-one classification method that receives both training data and test data and returns the predicted labels for the test data. If predictor is not NULL, this is the training function of the classifier that builds a model from the training data. This model is then passed to predictor along with the test data to obtain the predicted labels for the test data.
classifierParamNames	A vector of names of possible arguments for classifier.
predefinedClassifierParams	A named list of default values for the classifier parameters.

predictor	If the classification method consists of separate training and prediction functions, this points to the prediction function that receives a model and the test data as inputs and returns the predicted class labels.
predictorParamNames	If predictor != NULL, a vector of names of possible arguments for predictor.
predefinedPredictorParams	If predictor != NULL, a named list of default values for the parameters of predictor.
useFormula	Set this to true if the classifier expects a formula to describe the relation between features and class labels. The formula itself is built automatically.
formulaName	If useFormula is true, this is the name of the parameter of the classifier's training function that holds the formula.
trainDataName	The name of the parameter of the classifier's training function that holds the training data.
trainLabelName	If useFormula=FALSE, the name of the parameter of the classifier's training function that holds the training labels. Otherwise, the training labels are added to the training data and supplied in parameter trainDataName.
testDataName	If predictor=NULL, this is the name of the parameter of classifier that receives the test data. Otherwise, it is the parameter of predictor that holds the test data.
modelName	If predictor is not NULL, this is the name of the parameter of predictor that receives the training model (i.e., the return value of classifier).
requiredPackages	A vector containing the names of packages that are required to run the classifier. These packages are loaded automatically when running the classifier using <a href="#">tunePareto</a> . They are also loaded in the <b>snowfall</b> cluster if necessary.

## Details

TunePareto classifier objects are wrappers containing all information necessary to run the classifier, including the training and prediction function, the required packages, and the names of certain arguments. **TunePareto** provides a set of predefined objects for state-of-the-art classifiers (see [predefinedClassifiers](#)).

The main [tunePareto](#) routine evaluates TuneParetoClassifier objects to call the training and prediction methods. Furthermore, direct calls to the classifiers are possible using [trainTuneParetoClassifier](#) and [predict.TuneParetoModel](#).

## Value

An object of class TuneParetoClassifier with components corresponding to the above parameters.

## See Also

[trainTuneParetoClassifier](#), [predict.TuneParetoModel](#), [tunePareto](#), [predefinedClassifiers](#)

**Examples**

```
# equivalent to tunePareto.svm()
cl <- tuneParetoClassifier(name = "svm",
  classifier = svm,
  predictor = predict,
  classifierParamNames = c("kernel", "degree", "gamma",
    "coef0", "cost", "nu",
    "class.weights", "cachesize",
    "tolerance", "epsilon",
    "subset", "na.action"),
  useFormula = FALSE,
  trainDataName = "x",
  trainLabelName = "y",
  testDataName = "newdata",
  modelName = "object",
  requiredPackages="e1071")

# call TunePareto with the classifier
print(tunePareto(classifier = cl,
  data = iris[, -ncol(iris)],
  labels = iris[, ncol(iris)],
  cost = c(0.001,0.01,0.1,1,10),
  objectiveFunctions=
  list(cvError(10, 10),
    cvSpecificity(10, 10,
      caseClass="setosa"))))
```

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