

# Package ‘pROC’

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**Description** Tools for visualizing, smoothing and comparing receiver operating characteristic (ROC curves). (Partial) area under the curve (AUC) can be compared with statistical tests based on U-statistics or bootstrap. Confidence intervals can be computed for (p)AUC or ROC curves.

**License** GPL (>= 3)

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**BugReports** <https://github.com/xrobin/pROC/issues>

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pROC-package

*pROC*

---

### Description

Tools for visualizing, smoothing and comparing receiver operating characteristic (ROC curves). (Partial) area under the curve (AUC) can be compared with statistical tests based on U-statistics or bootstrap. Confidence intervals can be computed for (p)AUC or ROC curves. Sample size / power computation for one or two ROC curves are available.

### Details

The basic unit of the pROC package is the `roc` function. It will build a ROC curve, smooth it if requested (if `smooth=TRUE`), compute the AUC (if `auc=TRUE`), the confidence interval (CI) if requested (if `ci=TRUE`) and plot the curve if requested (if `plot=TRUE`).

The `roc` function will call `smooth`, `auc`, `ci` and `plot` as necessary. See these individual functions for the arguments that can be passed to them through `roc`. These function can be called separately.

Two paired (that is `roc` objects with the same response) or unpaired (with different response) ROC curves can be compared with the `roc.test` function.

### Citation

If you use pROC in published research, please cite the following paper:

Xavier Robin, Natacha Turck, Alexandre Hainard, Natalia Tiberti, Frédérique Lisacek, Jean-Charles Sanchez and Markus Müller (2011). “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **12**, p. 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277)

Type `citation("pROC")` for a BibTeX entry.

The authors would be glad to hear how pROC is employed. You are kindly encouraged to notify Xavier Robin <pROC-cran@xavier.robin.name> about any work you publish.

### Abbreviations

The following abbreviations are employed extensively in this package:

- ROC: receiver operating characteristic
- AUC: area under the ROC curve
- pAUC: partial area under the ROC curve
- CI: confidence interval
- SP: specificity
- SE: sensitivity

### Functions

<code>roc</code>	Build a ROC curve
<code>are.paired</code>	Determine if two ROC curves are paired
<code>auc</code>	Compute the area under the ROC curve
<code>ci</code>	Compute confidence intervals of a ROC curve
<code>ci.auc</code>	Compute the CI of the AUC
<code>ci.coords</code>	Compute the CI of arbitrary coordinates
<code>ci.se</code>	Compute the CI of sensitivities at given specificities
<code>ci.sp</code>	Compute the CI of specificities at given sensitivities
<code>ci.thresholds</code>	Compute the CI of specificity and sensitivity of thresholds
<code>ci.coords</code>	Compute the CI of arbitrary coordinates
<code>coords</code>	Coordinates of the ROC curve
<code>cov</code>	Covariance between two AUCs
<code>ggroc</code>	Plot a ROC curve with <b>ggplot2</b>
<code>has.partial.auc</code>	Determine if the ROC curve have a partial AUC
<code>lines.roc</code>	Add a ROC line to a ROC plot
<code>plot.ci</code>	Plot CIs
<code>plot</code>	Plot a ROC curve
<code>power.roc.test</code>	Sample size and power computation
<code>print</code>	Print a ROC curve object
<code>roc.test</code>	Compare two ROC curves
<code>smooth</code>	Smooth a ROC curve
<code>var</code>	Variance of the AUC

## Dataset

This package comes with a dataset of 141 patients with aneurysmal subarachnoid hemorrhage: [aSAH](#).

## Installing and using

To install this package, make sure you are connected to the internet and issue the following command in the R prompt:

```
install.packages("pROC")
```

To load the package in R:

```
library(pROC)
```

## Experimental: pipelines

Since version 1.15.0, the `roc` function can be used in pipelines, for instance with `dplyr` or `magrittr`. This is still a highly experimental feature and will change significantly in future versions (see [issue 54](#)). The `roc.data.frame` method supports both standard and non-standard evaluation (NSE), and the `roc_` function supports standard evaluation only.

```
library(dplyr)
aSAH %>%
  filter(gender == "Female") %>%
  roc(outcome, s100b)
```

By default it returns the `roc` object, which can then be piped to the `coords` function to extract coordinates that can be used in further pipelines.

```
aSAH %>%
  filter(gender == "Female") %>%
  roc(outcome, s100b) %>%
  coords(transpose=FALSE) %>%
  filter(sensitivity > 0.6,
         specificity > 0.6)
```

More details and use cases are available in the [roc](#) help page.

## Bootstrap

All the bootstrap operations for [significance testing](#), [confidence interval](#), [variance](#) and [covariance](#) computation are performed with non-parametric stratified or non-stratified resampling (according to the `stratified` argument) and with the percentile method, as described in Carpenter and Bithell (2000) sections 2.1 and 3.3.

Stratification of bootstrap can be controlled with `boot.stratified`. In stratified bootstrap (the default), each replicate contains the same number of cases and controls than the original sample. Stratification is especially useful if one group has only little observations, or if groups are not balanced.

The number of bootstrap replicates is controlled by `boot.n`. Higher numbers will give a more precise estimate of the significance tests and confidence intervals but take more time to compute. 2000 is recommended by Carpenter and Bithell (2000) for confidence intervals. In our experience this is sufficient for a good estimation of the first significant digit only, so we recommend the use of 10000 bootstrap replicates to obtain a good estimate of the second significant digit whenever possible.

**Progress bars:** A progressbar shows the progress of bootstrap operations. It is handled by the **plyr** package (Wickham, 2011), and is created by the `progress_*` family of functions. Sensible defaults are guessed during the package loading:

- In non-[interactive](#) mode, no progressbar is displayed.
- In embedded GNU Emacs “ESS”, a `txtProgressBar`
- In Windows, a `winProgressBar` bar.
- In Windows, a `winProgressBar` bar.
- In other systems with or without a graphical display, a `txtProgressBar`.

The default can be changed with the option “`pROCProgress`”. The option must be a list with a name item setting the type of progress bar (“none”, “win”, “tk” or “text”). Optional items of the list are “width”, “char” and “style”, corresponding to the arguments to the underlying progressbar functions. For example, to force a text progress bar:

```
options(pROCProgress = list(name = "text", width = NA, char = "=", style = 3))
```

To inhibit the progress bars completely:

```
options(pROCProgress = list(name = "none"))
```

## Handling large datasets

**Algorithms:** Over the years, a significant amount of time has been invested in making pROC run faster and faster. From the naive algorithm iterating over all thresholds implemented in the first version (`algorithm = 1`), we went to a C++ implementation (with **Rcpp**, `algorithm = 3`), and a different algorithm using cumulative sum of responses sorted by the predictor, which scales only with the number of data points, independently on the number of thresholds (`algorithm = 2`). The curves themselves are identical, but computation time has been decreased massively.

Since version 1.12, pROC was able to automatically select the fastest algorithm for your dataset based on the number of thresholds of the ROC curve. Initially this number was around 1500 thresholds, above which algorithm 3 was selected. But with pROC 1.15 additional code profiling enabled us implement additional speedups that brought this number down to less than 100

thresholds. As the detection of the number of thresholds itself can have a large impact comparatively (up to 10% now), a new `algorithm = 6` was implemented, which assumes that `ordered` datasets should have relatively few levels, and hence thresholds. These predictors are processed with `algorithm = 3`. Any numeric dataset is now assumed to have a sufficient number of thresholds to be processed with `algorithm = 2` efficiently. In the off-chance that you have a very large numeric dataset with very few thresholds, `algorithm = 3` can be selected manually (in the call to `roc`). For instance with 5 thresholds you can expect a speedup of around to 3 times. This effect disappears altogether as soon as the curve gets to 50-100 thresholds.

This simple selection should work in most cases. However if you are unsure or want to test it for yourself, use `algorithm=0` to run a quick benchmark between 2 and 3. Make sure **microbenchmark** is installed. Beware, this is very slow as it will repeat the computation 10 times to obtain a decent estimate of each algorithm speed.

```
if (!requireNamespace("microbenchmark")) install.packages("microbenchmark")

# First a ROC curve with many thresholds. Algorithm 2 is much faster.
response <- rbinom(5E3, 1, .5)
predictor <- rnorm(5E3)
rocobj <- roc(response, predictor, algorithm = 0)

# Next a ROC curve with few thresholds but more data points
response <- rbinom(1E6, 1, .5)
predictor <- rpois(1E6, 1)
rocobj <- roc(response, predictor, algorithm = 0)
```

Other functions have been optimized too, and bottlenecks removed. In particular, the `coords` function is orders of magnitude faster in pROC 1.15. The DeLong algorithm has been improved in versions 1.6, 1.7 and 1.9.1, and currently uses a much more efficient algorithm, both in computation time and memory footprint. We will keep working on improvements to make pROC more suited to large datasets in the future.

**Bootstrap:** Bootstrap is typically slow because it involves repeatedly computing the ROC curve (or a part of it).

Some bootstrap functions are faster than others. Typically, `ci.thresholds` is the fastest, and `ci.coords` the slowest. Use `ci.coords` only if the CI you need cannot be computed by the specialized CI functions `ci.thresholds`, `ci.se` and `ci.sp`. Note that `ci.auc` cannot be replaced anyway.

A naive way to speed-up the bootstrap is by removing the progress bar:

```
rocobj <- roc(response, round(predictor))
system.time(ci(rocobj))
system.time(ci(rocobj, progress = "none"))
```

It is of course possible to reduce the number of bootstrap iterations. See the `boot.n` argument to `ci`. This will reduce the precision of the bootstrap estimate.

*Parallel processing:* Bootstrap operations can be performed in parallel. The backend provided by the **plyr** package is used, which in turn relies on the **foreach** package. To enable parallel processing, you first need to load an adaptor for the **foreach** package (**doMC**, **doMPI**, **doParallel**, **doRedis**, **doRNG** or **doSNOW**), register the backend, and set `parallel=TRUE`.

```
library(doParallel)
registerDoParallel(cl <- makeCluster(getOption("mc.cores", 2)))
ci(rocobj, method="bootstrap", parallel=TRUE)
stopCluster(cl)
```

Progress bars are not available when parallel processing is enabled.

**Using DeLong instead of bootstrap:** DeLong is an asymptotically exact method to evaluate the uncertainty of an AUC (DeLong *et al.* (1988)). Since version 1.9, pROC uses the algorithm proposed by Sun and Xu (2014) which has an  $O(N \log N)$  complexity and is always faster than bootstrapping. By default, pROC will choose the DeLong method whenever possible.

```
rocobj <- roc(response, round(predictor), algorithm=3)
system.time(ci(rocobj, method="delong"))
system.time(ci(rocobj, method="bootstrap", parallel = TRUE))
```

## Author(s)

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## References

- James Carpenter and John Bithell (2000) “Bootstrap condence intervals: when, which, what? A practical guide for medical statisticians”. *Statistics in Medicine* **19**, 1141–1164. DOI: doi: [10.1002/\(SICI\)10970258\(20000515\)19:9<1141::AIDSIM479>3.0.CO;2F](https://doi.org/10.1002/(SICI)10970258(20000515)19:9<1141::AIDSIM479>3.0.CO;2F).
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## See Also

CRAN packages **ROCR**, **verification** or Bioconductor's **roc** for ROC curves.

CRAN packages **plyr**, **MASS** and **logcondens** employed in this package.

## Examples

```
data(aSAH)

## Build a ROC object and compute the AUC ##
roc1 <- roc(aSAH$outcome, aSAH$s100b)
print(roc1)

# With a formula
roc(outcome ~ s100b, aSAH)
# With pipes, dplyr-style:
## Not run:
library(dplyr)
aSAH %>% roc(outcome, s100b)
## End(Not run)

# Create a few more curves for the next examples
roc2 <- roc(aSAH$outcome, aSAH$wfns)
roc3 <- roc(aSAH$outcome, aSAH$ndka)

## AUC ##
auc(roc1, partial.auc = c(1, .9))

## Smooth ROC curve ##
smooth(roc1)

## Summary statistics
var(roc1)
cov(roc1, roc3)

## Plot the curve ##
plot(roc1)

# More plotting options, CI and plotting
# with all-in-one syntax:
roc4 <- roc(aSAH$outcome,
            aSAH$s100b, percent=TRUE,
            # arguments for auc
            partial.auc=c(100, 90), partial.auc.correct=TRUE,
            partial.auc.focus="sens",
            # arguments for ci
            ci=TRUE, boot.n=100, ci.alpha=0.9, stratified=FALSE,
            # arguments for plot
            plot=TRUE, auc.polygon=TRUE, max.auc.polygon=TRUE, grid=TRUE,
```



```
        print.auc=TRUE, show.thres=TRUE)

# Add to an existing plot. Beware of 'percent' specification!
roc5 <- roc(aSAH$outcome, aSAH$wfns,
           plot=TRUE, add=TRUE, percent=roc4$percent)

## With ggplot2 ##
if (require(ggplot2)) {
# Create multiple curves to plot
rocs <- roc(outcome ~ wfns + s100b + ndka, data = aSAH)
ggroc(rocs)
}

## Coordinates of the curve ##
coords(roc1, "best", ret=c("threshold", "specificity", "1-npv"))
coords(roc2, "local maximas", ret=c("threshold", "sens", "spec", "ppv", "npv"))

## Confidence intervals ##

# CI of the AUC
ci(roc2)

## Not run:
# CI of the curve
sens.ci <- ci.se(roc1, specificities=seq(0, 100, 5))
plot(sens.ci, type="shape", col="lightblue")
plot(sens.ci, type="bars")
## End(Not run)

# need to re-add roc2 over the shape
plot(roc2, add=TRUE)

## Not run:
# CI of thresholds
plot(ci.thresholds(roc2))
## End(Not run)

# In parallel
if (require(doParallel)) {
  registerDoParallel(cl <- makeCluster(getOption("mc.cores", 2L)))
  ## Not run: ci(roc2, method="bootstrap", parallel=TRUE)

  stopCluster(cl)
}

## Comparisons ##

# Test on the whole AUC
roc.test(roc1, roc2, reuse.auc=FALSE)
```

```

## Not run:
# Test on a portion of the whole AUC
roc.test(roc1, roc2, reuse.auc=FALSE, partial.auc=c(100, 90),
         partial.auc.focus="se", partial.auc.correct=TRUE)

# With modified bootstrap parameters
roc.test(roc1, roc2, reuse.auc=FALSE, partial.auc=c(100, 90),
         partial.auc.correct=TRUE, boot.n=1000, boot.stratified=FALSE)
## End(Not run)

## Power & sample size ##

# Power
# 1 curve
power.roc.test(roc1)
# 2 curves
power.roc.test(roc3, roc2)

# Sample size
# 1 curve
power.roc.test(roc3, power = 0.9)
# 2 curves
power.roc.test(roc1, roc2, power = 0.9)

# Also without ROC objects.
# For instance what AUC would be significantly different from 0.5?
power.roc.test(ncases=41, ncontrols=72, sig.level=0.05, power=0.95)

```

---

are.paired

*Are two ROC curves paired?*


---

## Description

This function determines if two ROC curves can be paired.

## Usage

```

are.paired(...)
## S3 method for class 'auc'
are.paired(roc1, roc2, ...)
## S3 method for class 'smooth.roc'
are.paired(roc1, roc2, ...)
## S3 method for class 'roc'
are.paired(roc1, roc2, return.paired.rocs=FALSE,
           reuse.auc = TRUE, reuse.ci = FALSE, reuse.smooth=TRUE, ...)

```

**Arguments**

`roc1`, `roc2` the two ROC curves to compare. Either “`roc`”, “`auc`” or “`smooth.roc`” objects (types can be mixed).

`return.paired.rocs` if TRUE and the ROC curves can be paired, the two paired ROC curves with NAs removed will be returned.

`reuse.auc`, `reuse.ci`, `reuse.smooth` if `return.paired.rocs=TRUE`, determines if `auc`, `ci` and `smooth` should be re-computed (with the same parameters than the original ROC curves)

... additional arguments for `are.paired.roc`. Ignored in `are.paired.roc`

**Details**

Two ROC curves are paired if they are built on two variables observed on the same sample.

In practice, the paired status is granted if the response and levels vector of both ROC curves are **identical**. If the responses are different, this can be due to missing values differing between the curves. In this case, the function will strip all NAs in both curves and check for identity again.

It can raise false positives if the responses are identical but correspond to different patients.

**Value**

TRUE if `roc1` and `roc2` are paired, FALSE otherwise.

In addition, if TRUE and `return.paired.rocs=TRUE`, the following attributes are defined:

`roc1`, `roc2` the two ROC curve with all NAs values removed in both curves.

**See Also**

[roc](#), [roc.test](#)

**Examples**

```
data(aSAH)
aSAH.copy <- aSAH

# artificially insert NAs for demonstration purposes
aSAH.copy$outcome[42] <- NA
aSAH.copy$s100b[24] <- NA
aSAH.copy$ndka[1:10] <- NA

# Call roc() on the whole data
roc1 <- roc(aSAH.copy$outcome, aSAH.copy$s100b)
roc2 <- roc(aSAH.copy$outcome, aSAH.copy$ndka)
# are.paired can still find that the curves were paired
are.paired(roc1, roc2) # TRUE

# Removing the NAs manually before passing to roc() un-pairs the ROC curves
nas <- is.na(aSAH.copy$outcome) | is.na(aSAH.copy$ndka)
roc2b <- roc(aSAH.copy$outcome[!nas], aSAH.copy$ndka[!nas])
```

```
are.paired(roc1, roc2b) # FALSE

# Getting the two paired ROC curves with additional smoothing and ci options
roc2$ci <- ci(roc2)
paired <- are.paired(smooth(roc1), roc2, return.paired.rocs=TRUE, reuse.ci=TRUE)
paired.roc1 <- attr(paired, "roc1")
paired.roc2 <- attr(paired, "roc2")
```

---

aSAH

*Subarachnoid hemorrhage data*

---

## Description

This dataset summarizes several clinical and one laboratory variable of 113 patients with an aneurysmal subarachnoid hemorrhage.

## Usage

aSAH

## Format

A data.frame containing 113 observations of 7 variables.

## Source

Natacha Turck, Laszlo Vutskits, Paola Sanchez-Pena, Xavier Robin, Alexandre Hainard, Marianne Gex-Fabry, Catherine Fouda, Hadiji Bassem, Markus Mueller, Frédérique Lisacek, Louis Puybasset and Jean-Charles Sanchez (2010) “A multiparameter panel method for outcome prediction following aneurysmal subarachnoid hemorrhage”. *Intensive Care Medicine* **36**(1), 107–115. DOI: doi: [10.1007/s001340091641y](https://doi.org/10.1007/s001340091641y).

## See Also

Other examples can be found in all the documentation pages of this package: [roc](#), [auc](#), [ci](#), [ci.auc](#), [ci.se](#), [ci.sp](#), [ci.thresholds](#), [coords](#), [plot.ci](#), [plot.roc](#), [print.roc](#), [roc.test](#) and [smooth](#).

An example analysis with pROC is shown in:

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277)

**Examples**

```
# load the dataset
data(aSAH)

# Gender, outcome and set
with(aSAH, table(gender, outcome))

# Age
with(aSAH, by(age, outcome, mean))
with(aSAH, by(age, outcome,
  function(x) sprintf("mean: %.1f (+/- %.1f), median: %.1f (%i-%i)",
    mean(x), sd(x), median(x), min(x), max(x))))))

# WFNS score
with(aSAH, table(wfns=ifelse(wfns<=2, "1-2", "3-4-5"), outcome))
```

auc

*Compute the area under the ROC curve***Description**

This function computes the numeric value of area under the ROC curve (AUC) with the trapezoidal rule. Two syntaxes are possible: one object of class “roc”, or either two vectors (response, predictor) or a formula (response~predictor) as in the `roc` function. By default, the total AUC is computed, but a portion of the ROC curve can be specified with `partial.auc`.

**Usage**

```
auc(...)
## S3 method for class 'roc'
auc(roc, partial.auc=FALSE, partial.auc.focus=c("specificity",
"sensitivity"), partial.auc.correct=FALSE,
allow.invalid.partial.auc.correct = FALSE, ...)
## S3 method for class 'smooth.roc'
auc(smooth.roc, ...)
## S3 method for class 'multiclass.roc'
auc(multiclass.roc, ...)
## S3 method for class 'formula'
auc(formula, data, ...)
## Default S3 method:
auc(response, predictor, ...)
```

**Arguments**

roc, smooth.roc, multiclass.roc

a “roc” object from the `roc` function, a “smooth.roc” object from the `smooth` function, or a “multiclass.roc” or “mv.multiclass.roc” from the `multiclass.roc` function.

response, predictor	arguments for the <code>roc</code> function.
formula, data	a formula (and possibly a data object) of type response~predictor for the <code>roc</code> function.
partial.auc	either FALSE (default: consider total area) or a numeric vector of length 2: boundaries of the AUC to consider in [0,1] (or [0,100] if percent is TRUE).
partial.auc.focus	if partial.auc is not FALSE and a partial AUC is computed, specifies if partial.auc specifies the bounds in terms of specificity (default) or sensitivity. Can be shortened to spec/sens or even sp/se. Ignored if partial.auc=FALSE.
partial.auc.correct	logical indicating if the correction of AUC must be applied in order to have a maximal AUC of 1.0 and a non-discriminant AUC of 0.5 whatever the partial.auc defined. Ignored if partial.auc=FALSE. Default: FALSE.
allow.invalid.partial.auc.correct	logical indicating if the correction must return NA (with a <code>warning</code> ) when attempting to correct a pAUC below the diagonal. Set to TRUE to return a (probably invalid) corrected AUC. This is useful especially to avoid introducing a bias against low pAUCs in bootstrap operations.
...	further arguments passed to or from other methods, especially arguments for <code>roc</code> when calling <code>auc.default</code> , <code>auc.formula</code> , <code>auc.smooth.roc</code> . Note that the <code>auc</code> argument of <code>roc</code> is not allowed. Unused in <code>auc.roc</code> .

## Details

This function is typically called from `roc` when `auc=TRUE` (default). It is also used by `ci`. When it is called with two vectors (response, predictor) or a formula (response~predictor) arguments, the `roc` function is called and only the AUC is returned.

By default the total area under the curve is computed, but a partial AUC (pAUC) can be specified with the `partial.auc` argument. It specifies the bounds of specificity or sensitivity (depending on `partial.auc.focus`) between which the AUC will be computed. As it specifies specificities or sensitivities, you must adapt it in relation to the 'percent' specification (see details in `roc`).

`partial.auc.focus` is ignored if `partial.auc=FALSE` (default). If a partial AUC is computed, `partial.auc.focus` specifies if the bounds specified in `partial.auc` must be interpreted as sensitivity or specificity. Any other value will produce an error. It is recommended to `plot` the ROC curve with `auc.polygon=TRUE` in order to make sure the specification is correct.

If a pAUC is defined, it can be standardized (corrected). This correction is controlled by the `partial.auc.correct` argument. If `partial.auc.correct=TRUE`, the correction by McClish will be applied:

$$\frac{1 + \frac{auc - min}{max - min}}{2}$$

where `auc` is the uncorrected pAUC computed in the region defined by `partial.auc`, `min` is the value of the non-discriminant AUC (with an AUC of 0.5 or 50 in the region and `max` is the maximum possible AUC in the region. With this correction, the AUC will be 0.5 if non discriminant and 1.0 if maximal, whatever the region defined. This correction is fully compatible with percent.

Note that this correction is undefined for curves below the diagonal ( $auc < min$ ). Attempting to correct such an AUC will return NA with a warning.

### Value

The numeric AUC value, of class `c("auc", "numeric")` (or `c("multiclass.auc", "numeric")` or `c("mv.multiclass.auc", "numeric")` if a “multiclass.roc” was supplied), in fraction of the area or in percent if `percent=TRUE`, with the following attributes:

<code>partial.auc</code>	if the AUC is full (FALSE) or partial (and in this case the bounds), as defined in argument.
<code>partial.auc.focus</code>	only for a partial AUC, if the bound specifies the sensitivity or specificity, as defined in argument.
<code>partial.auc.correct</code>	only for a partial AUC, was it corrected? As defined in argument.
<code>percent</code>	whether the AUC is given in percent or fraction.
<code>roc</code>	the original ROC curve, as a “roc”, “smooth.roc” or “multiclass.roc” object.

### Smoothed ROC curves

There is no difference in the computation of the area under a smoothed ROC curve, except for curves smoothed with `method="binomial"`. In this case and only if a full AUC is requested, the classical binormal AUC formula is applied:

$$auc = \phi \frac{a}{\sqrt{1 + b^2}}.$$

If the ROC curve is smoothed with any other method or if a partial AUC is requested, the empirical AUC described in the previous section is applied.

### Multi-class AUCs

With an object of class “multiclass.roc”, a multi-class AUC is computed as an average AUC as defined by Hand and Till (equation 7).

$$auc = \frac{2}{c(c-1)} \sum aucs$$

with `aucs` all the pairwise roc curves.

### References

Tom Fawcett (2006) “An introduction to ROC analysis”. *Pattern Recognition Letters* **27**, 861–874. DOI: doi: [10.1016/j.patrec.2005.10.010](https://doi.org/10.1016/j.patrec.2005.10.010).

David J. Hand and Robert J. Till (2001). A Simple Generalisation of the Area Under the ROC Curve for Multiple Class Classification Problems. *Machine Learning* **45**(2), p. 171–186. DOI: doi: [10.1023/A:1010920819831](https://doi.org/10.1023/A:1010920819831).

Donna Katzman McClish (1989) “Analyzing a Portion of the ROC Curve”. *Medical Decision Making* **9**(3), 190–195. DOI: doi: [10.1177/0272989X8900900307](https://doi.org/10.1177/0272989X8900900307).

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

## See Also

[roc](#), [ci.auc](#)

## Examples

```
# Create a ROC curve:
data(aSAH)
roc.s100b <- roc(aSAH$outcome, aSAH$s100b)

# Get the full AUC
auc(roc.s100b)

# Get the partial AUC:
auc(roc.s100b, partial.auc=c(1, .8), partial.auc.focus="se", partial.auc.correct=TRUE)
```

---

ci

*Compute the confidence interval of a ROC curve*

---

## Description

This function computes the confidence interval (CI) of a ROC curve. The `of` argument controls the type of CI that will be computed. By default, the 95% CI are computed with 2000 stratified bootstrap replicates.

## Usage

```
ci(...)
## S3 method for class 'roc'
ci(roc, of = c("auc", "thresholds", "sp", "se", "coords"), ...)
## S3 method for class 'smooth.roc'
ci(smooth.roc, of = c("auc", "sp", "se", "coords"), ...)
## S3 method for class 'multiclass.roc'
ci(multiclass.roc, of = "auc", ...)
## S3 method for class 'multiclass.auc'
ci(multiclass.auc, of = "auc", ...)
## S3 method for class 'formula'
ci(formula, data, ...)
## Default S3 method:
ci(response, predictor, ...)
```



## Arguments

roc, smooth.roc	a “roc” object from the <code>roc</code> function, or a “smooth.roc” object from the <code>smooth</code> function.
multiclass.roc, multiclass.auc	not implemented.
response, predictor	arguments for the <code>roc</code> function.
formula, data	a formula (and possibly a data object) of type response~predictor for the <code>roc</code> function.
of	The type of confidence interval. One of “auc”, “thresholds”, “sp”, “se” or “coords”. Note that confidence interval on “thresholds” are not available for smoothed ROC curves.
...	further arguments passed to or from other methods, especially <code>auc</code> , <code>roc</code> , and the specific ci functions <code>ci.auc</code> , <code>ci.se</code> , <code>ci.sp</code> and <code>ci.thresholds</code> .

## Details

`ci.formula` and `ci.default` are convenience methods that build the ROC curve (with the `roc` function) before calling `ci.roc`. You can pass them arguments for both `roc` and `ci.roc`. Simply use `ci` that will dispatch to the correct method.

This function is typically called from `roc` when `ci=TRUE` (not by default). Depending on the `of` argument, the specific ci functions `ci.auc`, `ci.thresholds`, `ci.sp`, `ci.se` or `ci.coords` are called.

When the ROC curve has an `auc` of 1 (or 100%), the confidence interval will always be null (there is no interval). This is true for both “delong” and “bootstrap” methods that can not properly assess the variance in this case. This result is misleading, as the variance is of course not null. A `warning` will be displayed to inform of this condition, and of the misleading output.

CI of multiclass ROC curves and AUC is not implemented yet. Attempting to call these methods returns an error.

## Value

The return value of the specific ci functions `ci.auc`, `ci.thresholds`, `ci.sp`, `ci.se` or `ci.coords`, depending on the `of` argument.

## References

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

## See Also

`roc`, `auc`, `ci.auc`, `ci.thresholds`, `ci.sp`, `ci.se`, `ci.coords`

**Examples**

```

# Create a ROC curve:
data(aSAH)
roc1 <- roc(aSAH$outcome, aSAH$s100b)

## AUC ##
ci(roc1)
# this is equivalent to:
ci(roc1, of = "auc")
# or:
ci.auc(roc1)

## Coordinates ##
## Not run:
# Thresholds
ci(roc1, of = "thresholds")
ci(roc1, of = "thresholds", thresholds = "all")
ci(roc1, of = "thresholds", thresholds = 0.51)
# equivalent to:
ci.thresholds(roc1, thresholds = 0.51)

# SE/SP
ci(roc1, of = "sp", sensitivities = c(.95, .9, .85))
ci.sp(roc1)
ci(roc1, of = "se")
ci.se(roc1)

# Arbitrary coordinates
ci(roc1, of = "coords", "best")
ci.coords(roc1, 0.51, "threshold")
## End(Not run)

```

---

ci.auc

---

*Compute the confidence interval of the AUC*


---

**Description**

This function computes the confidence interval (CI) of an area under the curve (AUC). By default, the 95% CI is computed with 2000 stratified bootstrap replicates.

**Usage**

```

# ci.auc(...)
## S3 method for class 'roc'
ci.auc(roc, conf.level=0.95, method=c("delong",

```

```

"bootstrap"), boot.n = 2000, boot.stratified = TRUE, reuse.auc=TRUE,
progress = getOption("pROCProgress")$name, parallel=FALSE, ...)
## S3 method for class 'smooth.roc'
ci.auc(smooth.roc, conf.level=0.95, boot.n=2000,
boot.stratified=TRUE, reuse.auc=TRUE,
progress=getOption("pROCProgress")$name, parallel=FALSE, ...)
## S3 method for class 'auc'
ci.auc(auc, ...)
## S3 method for class 'multiclass.roc'
ci.auc(multiclass.roc, ...)
## S3 method for class 'multiclass.auc'
ci.auc(multiclass.auc, ...)
## S3 method for class 'auc'
ci.auc(auc, ...)
## S3 method for class 'formula'
ci.auc(formula, data, ...)
## Default S3 method:
ci.auc(response, predictor, ...)

```

### Arguments

roc, smooth.roc	a “roc” object from the <a href="#">roc</a> function, or a “smooth.roc” object from the <a href="#">smooth</a> function.
auc	an “auc” object from the <a href="#">auc</a> function.
multiclass.roc, multiclass.auc	not implemented.
response, predictor	arguments for the <a href="#">roc</a> function.
formula, data	a formula (and possibly a data object) of type response~predictor for the <a href="#">roc</a> function.
conf.level	the width of the confidence interval as [0,1], never in percent. Default: 0.95, resulting in a 95% CI.
method	the method to use, either “delong” or “bootstrap”. The first letter is sufficient. If omitted, the appropriate method is selected as explained in details.
boot.n	the number of bootstrap replicates. Default: 2000.
boot.stratified	should the bootstrap be stratified (default, same number of cases/controls in each replicate than in the original sample) or not.
reuse.auc	if TRUE (default) and the “roc” object contains an “auc” field, re-use these specifications for the test. If false, use optional . . . arguments to <a href="#">auc</a> . See details.
progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <a href="#">create_progress_bar</a> for more information), but a list as returned by <a href="#">create_progress_bar</a> is also accepted. See also the “Progress bars” section of <a href="#">this package’s documentation</a> .

<code>parallel</code>	if TRUE, the bootstrap is processed in parallel, using parallel backend provided by <code>plyr</code> ( <code>foreach</code> ).
<code>...</code>	further arguments passed to or from other methods, especially arguments for <code>roc</code> and <code>roc.test.roc</code> when calling <code>roc.test.default</code> or <code>roc.test.formula</code> . Arguments for <code>auc</code> and <code>txtProgressBar</code> (only <code>char</code> and <code>style</code> ) if applicable.

## Details

This function computes the CI of an AUC. Two methods are available: “`delong`” and “`bootstrap`” with the parameters defined in “`roc$auc`” to compute a CI. When it is called with two vectors (response, predictor) or a formula (response~predictor) arguments, the `roc` function is called to build the ROC curve first.

The default is to use “`delong`” method except for comparison of partial AUC and smoothed curves, where `bootstrap` is used. Using “`delong`” for partial AUC and smoothed ROCs is not supported.

With `method="bootstrap"`, the function calls `auc boot.n` times. For more details about the bootstrap, see the Bootstrap section in [this package's documentation](#).

For [smoothed ROC curves](#), smoothing is performed again at each bootstrap replicate with the parameters originally provided. If a density smoothing was performed with user-provided `density.cases` or `density.controls` the bootstrap cannot be performed and an error is issued.

With `method="delong"`, the variance of the AUC is computed as defined by DeLong *et al.* (1988) using the algorithm by Sun and Xu (2014) and the CI is deduced with `qnorm`.

CI of multiclass ROC curves and AUC is not implemented yet. Attempting to call these methods returns an error.

## Value

A numeric vector of length 3 and class “`ci.auc`”, “`ci`” and “`numeric`” (in this order), with the lower bound, the median and the upper bound of the CI, and the following attributes:

<code>conf.level</code>	the width of the CI, in fraction.
<code>method</code>	the method employed.
<code>boot.n</code>	the number of bootstrap replicates.
<code>boot.stratified</code>	whether or not the bootstrapping was stratified.
<code>auc</code>	an object of class “ <code>auc</code> ” stored for reference about the computed AUC details (partial, percent, ...)

The `aucs` item is not included in this list since version 1.2 for consistency reasons.

## AUC specification

The comparison of the CI needs a specification of the AUC. This allows to compute the CI for full or partial AUCs. The specification is defined by:

1. the “`auc`” field in the “`roc`” object if `reuse.auc` is set to TRUE (default). It is naturally inherited from any call to `roc` and fits most cases.

2. passing the specification to `auc` with ... (arguments `partial.auc`, `partial.auc.correct` and `partial.auc.focus`). In this case, you must ensure either that the `roc` object do not contain an `auc` field (if you called `roc` with `auc=FALSE`), or set `reuse.auc=FALSE`.

If `reuse.auc=FALSE` the `auc` function will always be called with ... to determine the specification, even if the “`roc`” object do contain an `auc` field.

As well if the “`roc`” object do not contain an `auc` field, the `auc` function will always be called with ... to determine the specification.

Warning: if the `roc` object passed to `ci` contains an `auc` field and `reuse.auc=TRUE`, `auc` is not called and arguments such as `partial.auc` are silently ignored.

### Warnings

If `method="delong"` and the AUC specification specifies a partial AUC, the warning “Using DeLong’s test for partial AUC is not supported. Using bootstrap test instead.” is issued. The `method` argument is ignored and “`bootstrap`” is used instead.

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, or that there are not enough points for smoothing, producing a NA area. The warning “NA value(s) produced during bootstrap were ignored.” will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

### Errors

If `density.cases` and `density.controls` were provided for smoothing, the error “Cannot compute the statistic on ROC curves smoothed with `density.controls` and `density.cases`.” is issued.

### References

James Carpenter and John Bithell (2000) “Bootstrap condence intervals: when, which, what? A practical guide for medical statisticians”. *Statistics in Medicine* **19**, 1141–1164. DOI: doi: [10.1002/\(SICI\)10970258\(20000515\)19:9<1141::AIDSIM479>3.0.CO;2F](https://doi.org/10.1002/(SICI)10970258(20000515)19:9<1141::AIDSIM479>3.0.CO;2F).

Elisabeth R. DeLong, David M. DeLong and Daniel L. Clarke-Pearson (1988) “Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach”. *Biometrics* **44**, 837–845.

Xu Sun and Weichao Xu (2014) “Fast Implementation of DeLongs Algorithm for Comparing the Areas Under Correlated Receiver Operating Characteristic Curves”. *IEEE Signal Processing Letters*, **21**, 1389–1393. DOI: doi: [10.1109/LSP.2014.2337313](https://doi.org/10.1109/LSP.2014.2337313).

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

Hadley Wickham (2011) “The Split-Apply-Combine Strategy for Data Analysis”. *Journal of Statistical Software*, **40**, 1–29. URL: doi: [10.18637/jss.v040.i01](https://doi.org/10.18637/jss.v040.i01).

### See Also

[roc](#), [auc](#), [ci](#)

## Examples

```

# Create a ROC curve:
data(aSAH)
roc1 <- roc(aSAH$outcome, aSAH$s100b)

## Basic example ##
ci.auc(roc1)

# You can also write:
ci(roc1)
ci(auc(roc1))

## More options ##
# Partial AUC and customized bootstrap:
## Not run:
ci.auc(roc1,
      conf.level=0.9,
      partial.auc=c(1, .8), partial.auc.focus="se", partial.auc.correct=TRUE,
      boot.n=10000, stratified=FALSE)
## End(Not run)

# Note that the following will NOT give a CI of the partial AUC:
## Not run:
ci.auc(roc1,
      partial.auc=c(1, .8), partial.auc.focus="se", partial.auc.correct=FALSE)
## End(Not run)
# This is because rocobj$auc is not a partial AUC and reuse.auc = TRUE by default.
# You can overcome this problem by passing an AUC instead:
auc1 <- auc(roc1, partial.auc=c(1, .8), partial.auc.focus="se",
           partial.auc.correct=FALSE)
## Not run:
ci.auc(auc1)
## End(Not run)

## On smoothed ROC curves with bootstrap ##
## Not run:
ci.auc(smooth(roc1, method="density"))
## End(Not run)

```

---

ci.coords

---

*Compute the confidence interval of arbitrary coordinates*


---

## Description

This function computes the confidence interval (CI) of the coordinates of a ROC curves with the `coords` function. By default, the 95% CI are computed with 2000 stratified bootstrap replicates.

**Usage**

```

# ci.coords(...)
## S3 method for class 'roc'
ci.coords(roc, x,
input=c("threshold", "specificity", "sensitivity"),
ret=c("threshold", "specificity", "sensitivity"),
best.method=c("youden", "closest.topleft"), best.weights=c(1, 0.5),
best.policy = c("stop", "omit", "random"),
conf.level=0.95, boot.n=2000,
boot.stratified=TRUE,
progress=getOption("pROCProgress")$name, ...)
## S3 method for class 'formula'
ci.coords(formula, data, ...)
## S3 method for class 'smooth.roc'
ci.coords(smooth.roc, x,
input=c("specificity", "sensitivity"), ret=c("specificity", "sensitivity"),
best.method=c("youden", "closest.topleft"), best.weights=c(1, 0.5),
best.policy = c("stop", "omit", "random"),
conf.level=0.95, boot.n=2000,
boot.stratified=TRUE,
progress=getOption("pROCProgress")$name, ...)
## Default S3 method:
ci.coords(response, predictor, ...)

```

**Arguments**

roc, smooth.roc	a “roc” object from the <a href="#">roc</a> function, or a “smooth.roc” object from the <a href="#">smooth</a> function.
response, predictor	arguments for the <a href="#">roc</a> function.
formula, data	a formula (and possibly a data object) of type response~predictor for the <a href="#">roc</a> function.
x, input, ret, best.method, best.weights	Arguments passed to <a href="#">coords</a> . See there for more details. The only difference is on the x argument which cannot be “all” or “local maximas”.
best.policy	The policy follow when multiple “best” thresholds are returned by <a href="#">coords</a> . “stop” will abort the processing with <a href="#">stop</a> (default), “omit” will ignore the sample (as in <a href="#">NA</a> ) and “random” will select one of the threshold randomly.
conf.level	the width of the confidence interval as [0,1], never in percent. Default: 0.95, resulting in a 95% CI.
boot.n	the number of bootstrap replicates. Default: 2000.
boot.stratified	should the bootstrap be stratified (default, same number of cases/controls in each replicate than in the original sample) or not.
progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <a href="#">create_progress_bar</a> for more information), but a list

as returned by `create_progress_bar` is also accepted. See also the “Progress bars” section of [this package’s documentation](#).

... further arguments passed to or from other methods, especially arguments for `roc` and `ci.coords.roc` when calling `ci.coords.default` or `ci.coords.formula`. Arguments for `txtProgressBar` (only `char` and `style`) if applicable.

## Details

`ci.coords.formula` and `ci.coords.default` are convenience methods that build the ROC curve (with the `roc` function) before calling `ci.coords.roc`. You can pass them arguments for both `roc` and `ci.coords.roc`. Simply use `ci.coords` that will dispatch to the correct method.

This function creates `boot.n` bootstrap replicate of the ROC curve, and evaluates the coordinates specified by the `x`, `input`, `ret`, `best.method` and `best.weights` arguments. Then it computes the confidence interval as the percentiles given by `conf.level`.

When `x="best"`, the best threshold is determined at each bootstrap iteration, effectively assessing the confidence interval of choice of the "best" threshold itself. This differs from the behavior of [ci.thresholds](#), where the "best" threshold is assessed on the given ROC curve before resampling.

For more details about the bootstrap, see the Bootstrap section in [this package’s documentation](#).

## Value

**Note:** changed in version 1.16.

A list of the same length as `ret` and named as `ret`, and of class “ci.thresholds”, “ci” and “list” (in this order).

Each element of the list is a matrix of the confidence intervals with rows given by `x` and with 3 columns, the lower bound of the CI, the median, and the upper bound of the CI.

Additionally, the list has the following attributes:

<code>conf.level</code>	the width of the CI, in fraction.
<code>boot.n</code>	the number of bootstrap replicates.
<code>boot.stratified</code>	whether or not the bootstrapping was stratified.
<code>input</code>	the input coordinate, as given in argument.
<code>x</code>	the coordinates used to calculate the CI, as given in argument.
<code>ret</code>	the return values, as given in argument or substituted by <code>link{coords}</code> .
<code>roc</code>	the object of class “roc” that was used to compute the CI.

## Warnings

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, producing a NA area. The warning “NA value(s) produced during bootstrap were ignored.” will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

This warning will also be displayed if you chose `best.policy = "omit"` and a ROC curve with multiple “best” threshold was generated during at least one of the replicates.



## References

James Carpenter and John Bithell (2000) “Bootstrap condence intervals: when, which, what? A practical guide for medical statisticians”. *Statistics in Medicine* **19**, 1141–1164. DOI: doi: [10.1002/\(SICI\)10970258\(20000515\)19:9<1141::AIDSIM479>3.0.CO;2F](https://doi.org/10.1002/(SICI)10970258(20000515)19:9<1141::AIDSIM479>3.0.CO;2F).

Tom Fawcett (2006) “An introduction to ROC analysis”. *Pattern Recognition Letters* **27**, 861–874. DOI: doi: [10.1016/j.patrec.2005.10.010](https://doi.org/10.1016/j.patrec.2005.10.010).

Hadley Wickham (2011) “The Split-Apply-Combine Strategy for Data Analysis”. *Journal of Statistical Software*, **40**, 1–29. URL: doi: [10.18637/jss.v040.i01](https://doi.org/10.18637/jss.v040.i01).

## See Also

[roc](#), [coords](#), [ci](#)

CRAN package **plyr**, employed in this function.

## Examples

```
# Create a ROC curve:
data(aSAH)
roc1 <- roc(aSAH$outcome, aSAH$s100b)

## Basic example ##
## Not run:
ci.coords(roc1, x="best", input = "threshold",
          ret=c("specificity", "ppv", "tp"))

## More options ##
ci.coords(roc1, x=0.9, input = "sensitivity", ret="specificity")
ci.coords(roc1, x=0.9, input = "sensitivity", ret=c("specificity", "ppv", "tp"))
ci.coords(roc1, x=c(0.1, 0.5, 0.9), input = "sensitivity", ret="specificity")
ci.coords(roc1, x=c(0.1, 0.5, 0.9), input = "sensitivity", ret=c("specificity", "ppv", "tp"))

# Return everything we can:
rets <- c("threshold", "specificity", "sensitivity", "accuracy", "tn", "tp", "fn", "fp", "npv",
         "ppv", "1-specificity", "1-sensitivity", "1-accuracy", "1-npv", "1-ppv")
ci.coords(roc1, x="best", input = "threshold", ret=rets)
## End(Not run)

## On smoothed ROC curves with bootstrap ##
## Not run:
ci.coords(smooth(roc1), x=0.9, input = "sensitivity", ret=c("specificity", "ppv", "tp"))
## End(Not run)
```

## Description

This function computes the confidence interval (CI) of the sensitivity at the given specificity points. By default, the 95% CI are computed with 2000 stratified bootstrap replicates.

## Usage

```
# ci.se(...)
## S3 method for class 'roc'
ci.se(roc, specificities = seq(0, 1, .1) * ifelse(roc$percent,
100, 1), conf.level=0.95, boot.n=2000, boot.stratified=TRUE,
progress=getOption("pROCProgress")$name, parallel=FALSE, ...)
## S3 method for class 'smooth.roc'
ci.se(smooth.roc, specificities = seq(0, 1, .1) *
ifelse(smooth.roc$percent, 100, 1), conf.level=0.95, boot.n=2000,
boot.stratified=TRUE, progress=getOption("pROCProgress")$name,
parallel=FALSE, ...)
## S3 method for class 'formula'
ci.se(formula, data, ...)
## Default S3 method:
ci.se(response, predictor, ...)
```

## Arguments

roc, smooth.roc	a “roc” object from the <a href="#">roc</a> function, or a “smooth.roc” object from the <a href="#">smooth</a> function.
response, predictor	arguments for the <a href="#">roc</a> function.
formula, data	a formula (and possibly a data object) of type response~predictor for the <a href="#">roc</a> function.
specificities	on which specificities to evaluate the CI.
conf.level	the width of the confidence interval as [0,1], never in percent. Default: 0.95, resulting in a 95% CI.
boot.n	the number of bootstrap replicates. Default: 2000.
boot.stratified	should the bootstrap be stratified (default, same number of cases/controls in each replicate than in the original sample) or not.
progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <a href="#">create_progress_bar</a> for more information), but a list as returned by <a href="#">create_progress_bar</a> is also accepted. See also the “Progress bars” section of <a href="#">this package’s documentation</a> .

<code>parallel</code>	if TRUE, the bootstrap is processed in parallel, using parallel backend provided by <code>plyr</code> ( <code>foreach</code> ).
<code>...</code>	further arguments passed to or from other methods, especially arguments for <code>roc</code> and <code>ci.se.roc</code> when calling <code>ci.se.default</code> or <code>ci.se.formula</code> . Arguments for <code>txtProgressBar</code> (only <code>char</code> and <code>style</code> ) if applicable.

## Details

`ci.se.formula` and `ci.se.default` are convenience methods that build the ROC curve (with the `roc` function) before calling `ci.se.roc`. You can pass them arguments for both `roc` and `ci.se.roc`. Simply use `ci.se` that will dispatch to the correct method.

The `ci.se.roc` function creates `boot.n` bootstrap replicate of the ROC curve, and evaluates the sensitivity at specificities given by the `specificities` argument. Then it computes the confidence interval as the percentiles given by `conf.level`.

For more details about the bootstrap, see the Bootstrap section in [this package's documentation](#).

For [smoothed ROC curves](#), smoothing is performed again at each bootstrap replicate with the parameters originally provided. If a density smoothing was performed with user-provided `density.cases` or `density.controls` the bootstrap cannot be performed and an error is issued.

## Value

A matrix of class "ci.se", "ci" and "matrix" (in this order) containing the given sensitivities. Row (names) are the specificities, the first column the lower bound, the 2nd column the median and the 3rd column the upper bound.

Additionally, the list has the following attributes:

<code>conf.level</code>	the width of the CI, in fraction.
<code>boot.n</code>	the number of bootstrap replicates.
<code>boot.stratified</code>	whether or not the bootstrapping was stratified.
<code>specificities</code>	the specificities as given in argument.
<code>roc</code>	the object of class " <code>roc</code> " that was used to compute the CI.

## Warnings

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, or that there are not enough points for smoothing, producing a NA area. The warning "NA value(s) produced during bootstrap were ignored." will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

## Errors

If `density.cases` and `density.controls` were provided for smoothing, the error "Cannot compute the statistic on ROC curves smoothed with `density.controls` and `density.cases`." is issued.

## References

James Carpenter and John Bithell (2000) “Bootstrap condence intervals: when, which, what? A practical guide for medical statisticians”. *Statistics in Medicine* **19**, 1141–1164. DOI: doi: [10.1002/\(SICI\)10970258\(20000515\)19:9<1141::AIDSIM479>3.0.CO;2F](https://doi.org/10.1002/(SICI)10970258(20000515)19:9<1141::AIDSIM479>3.0.CO;2F).

Tom Fawcett (2006) “An introduction to ROC analysis”. *Pattern Recognition Letters* **27**, 861–874. DOI: doi: [10.1016/j.patrec.2005.10.010](https://doi.org/10.1016/j.patrec.2005.10.010).

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

Hadley Wickham (2011) “The Split-Apply-Combine Strategy for Data Analysis”. *Journal of Statistical Software*, **40**, 1–29. URL: doi: [10.18637/jss.v040.i01](https://doi.org/10.18637/jss.v040.i01).

## See Also

[roc](#), [ci](#), [ci.sp](#), [plot.ci](#)

## Examples

```
# Create a ROC curve:
data(aSAH)
roc1 <- roc(aSAH$outcome, aSAH$s100b)

## Basic example ##
## Not run:
ci.se(roc1)
## End(Not run)

## More options ##
# Customized bootstrap and specificities:
## Not run:
ci.se(roc1, c(.95, .9, .85), boot.n=10000, conf.level=0.9, stratified=FALSE)
## End(Not run)

## Plotting the CI ##
ci1 <- ci.se(roc1, boot.n = 10)
plot(roc1)
plot(ci1)

## On smoothed ROC curves with bootstrap ##
## Not run:
ci.se(smooth(roc1, method="density"))
## End(Not run)
```

---

ci.sp

---

*Compute the confidence interval of specificities at given sensitivities*


---

### Description

This function computes the confidence interval (CI) of the specificity at the given sensitivity points. By default, the 95% CI are computed with 2000 stratified bootstrap replicates.

### Usage

```
# ci.sp(...)
## S3 method for class 'roc'
ci.sp(roc, sensitivities = seq(0, 1, .1) * ifelse(roc$percent,
100, 1), conf.level=0.95, boot.n=2000, boot.stratified=TRUE,
progress=getOption("pROCProgress")$name, parallel=FALSE, ...)
## S3 method for class 'smooth.roc'
ci.sp(smooth.roc, sensitivities = seq(0, 1, .1) *
ifelse(smooth.roc$percent, 100, 1), conf.level=0.95, boot.n=2000,
boot.stratified=TRUE, progress=getOption("pROCProgress")$name, parallel=FALSE, ...)
## S3 method for class 'formula'
ci.sp(formula, data, ...)
## Default S3 method:
ci.sp(response, predictor, ...)
```

### Arguments

roc, smooth.roc	a “roc” object from the <a href="#">roc</a> function, or a “smooth.roc” object from the <a href="#">smooth</a> function.
response, predictor	arguments for the <a href="#">roc</a> function.
formula, data	a formula (and possibly a data object) of type response~predictor for the <a href="#">roc</a> function.
sensitivities	on which sensitivities to evaluate the CI.
conf.level	the width of the confidence interval as [0,1], never in percent. Default: 0.95, resulting in a 95% CI.
boot.n	the number of bootstrap replicates. Default: 2000.
boot.stratified	should the bootstrap be stratified (default, same number of cases/controls in each replicate than in the original sample) or not.
progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <a href="#">create_progress_bar</a> for more information), but a list as returned by <a href="#">create_progress_bar</a> is also accepted. See also the “Progress bars” section of <a href="#">this package’s documentation</a> .

`parallel` if TRUE, the bootstrap is processed in parallel, using parallel backend provided by `plyr` (`foreach`).

... further arguments passed to or from other methods, especially arguments for `roc` and `ci.sp.roc` when calling `ci.sp.default` or `ci.sp.formula`. Arguments for `txtProgressBar` (only `char` and `style`) if applicable.

### Details

`ci.sp.formula` and `ci.sp.default` are convenience methods that build the ROC curve (with the `roc` function) before calling `ci.sp.roc`. You can pass them arguments for both `roc` and `ci.sp.roc`. Simply use `ci.sp` that will dispatch to the correct method.

The `ci.sp.roc` function creates `boot.n` bootstrap replicate of the ROC curve, and evaluates the specificity at sensitivities given by the `sensitivities` argument. Then it computes the confidence interval as the percentiles given by `conf.level`.

For more details about the bootstrap, see the Bootstrap section in [this package's documentation](#).

For [smoothed ROC curves](#), smoothing is performed again at each bootstrap replicate with the parameters originally provided. If a density smoothing was performed with user-provided `density.cases` or `density.controls` the bootstrap cannot be performed and an error is issued.

### Value

A matrix of class “ci.sp”, “ci” and “matrix” (in this order) containing the given specificities. Row (names) are the sensitivities, the first column the lower bound, the 2nd column the median and the 3rd column the upper bound.

Additionally, the list has the following attributes:

`conf.level` the width of the CI, in fraction.

`boot.n` the number of bootstrap replicates.

`boot.stratified` whether or not the bootstrapping was stratified.

`sensitivities` the sensitivities as given in argument.

`roc` the object of class “`roc`” that was used to compute the CI.

### Warnings

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, or that there are not enough points for smoothing, producing a NA area. The warning “NA value(s) produced during bootstrap were ignored.” will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

### Errors

If `density.cases` and `density.controls` were provided for smoothing, the error “Cannot compute the statistic on ROC curves smoothed with `density.controls` and `density.cases`.” is issued.

## References

James Carpenter and John Bithell (2000) “Bootstrap condence intervals: when, which, what? A practical guide for medical statisticians”. *Statistics in Medicine* **19**, 1141–1164. DOI: doi: [10.1002/\(SICI\)10970258\(20000515\)19:9<1141::AIDSIM479>3.0.CO;2F](https://doi.org/10.1002/(SICI)10970258(20000515)19:9<1141::AIDSIM479>3.0.CO;2F).

Tom Fawcett (2006) “An introduction to ROC analysis”. *Pattern Recognition Letters* **27**, 861–874. DOI: doi: [10.1016/j.patrec.2005.10.010](https://doi.org/10.1016/j.patrec.2005.10.010).

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

Hadley Wickham (2011) “The Split-Apply-Combine Strategy for Data Analysis”. *Journal of Statistical Software*, **40**, 1–29. URL: doi: [10.18637/jss.v040.i01](https://doi.org/10.18637/jss.v040.i01).

## See Also

[roc](#), [ci](#), [ci.se](#), [plot.ci](#)

## Examples

```
# Create a ROC curve:
data(aSAH)
roc1 <- roc(aSAH$outcome, aSAH$s100b)

## Basic example ##
## Not run:
ci.sp(roc1)
## End(Not run)

## More options ##
# Customized bootstrap and sensitivities:
## Not run:
ci.sp(roc1, c(.95, .9, .85), boot.n=10000, conf.level=0.9, stratified=FALSE)
## End(Not run)

## Plotting the CI ##
ci1 <- ci.sp(roc1, boot.n = 10)
plot(roc1)
plot(ci1)

## On smoothed ROC curves with bootstrap ##
## Not run:
ci.sp(smooth(roc1, method="density"))
## End(Not run)
```

---

ci.thresholds                      *Compute the confidence interval of thresholds*

---

### Description

This function computes the confidence interval (CI) of the sensitivity and specificity of the thresholds given in argument. By default, the 95% CI are computed with 2000 stratified bootstrap replicates.

### Usage

```
# ci.thresholds(...)
## S3 method for class 'roc'
ci.thresholds(roc, conf.level=0.95, boot.n=2000,
boot.stratified=TRUE, thresholds = "local maximas",
progress=getOption("pROCProgress")$name, parallel=FALSE, ...)
## S3 method for class 'formula'
ci.thresholds(formula, data, ...)
## S3 method for class 'smooth.roc'
ci.thresholds(smooth.roc, ...)
## Default S3 method:
ci.thresholds(response, predictor, ...)
```

### Arguments

roc	a “roc” object from the <a href="#">roc</a> function.
smooth.roc	not available for <a href="#">smoothed</a> ROC curves, available only to catch the error and provide a clear error message.
response, predictor	arguments for the <a href="#">roc</a> function.
formula, data	a formula (and possibly a data object) of type response~predictor for the <a href="#">roc</a> function.
conf.level	the width of the confidence interval as [0,1], never in percent. Default: 0.95, resulting in a 95% CI.
boot.n	the number of bootstrap replicates. Default: 2000.
boot.stratified	should the bootstrap be stratified (default, same number of cases/controls in each replicate than in the original sample) or not.
thresholds	on which thresholds to evaluate the CI. Either the numeric values of the thresholds, a logical vector (as index of roc\$thresholds) or a character “all”, “local maximas” or “best” that will be used to determine the threshold(s) on the supplied curve with <a href="#">coords</a> (not on the resampled curves).
progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <a href="#">create_progress_bar</a> for more information), but a list as returned by <a href="#">create_progress_bar</a> is also accepted. See also the “Progress bars” section of <a href="#">this package’s documentation</a> .



parallel	if TRUE, the bootstrap is processed in parallel, using parallel backend provided by plyr (foreach).
...	further arguments passed to or from other methods, especially arguments for <code>roc</code> and <code>ci.thresholds.roc</code> when calling <code>ci.thresholds.default</code> or <code>ci.thresholds.formula</code> . Arguments for <code>txtProgressBar</code> (only <code>char</code> and <code>style</code> ) if applicable. Arguments <code>best.method</code> and <code>best.weights</code> to <code>coords</code> .

## Details

`ci.thresholds.formula` and `ci.thresholds.default` are convenience methods that build the ROC curve (with the `roc` function) before calling `ci.thresholds.roc`. You can pass them arguments for both `roc` and `ci.thresholds.roc`. Simply use `ci.thresholds` that will dispatch to the correct method.

This function creates `boot.n` bootstrap replicate of the ROC curve, and evaluates the sensitivity and specificity at thresholds given by the `thresholds` argument. Then it computes the confidence interval as the percentiles given by `conf.level`.

A threshold given as a logical vector or character is converted to the corresponding numeric vector once *using the supplied ROC curve*, and not at each bootstrap iteration. See `ci.coords` for the latter behaviour.

For more details about the bootstrap, see the Bootstrap section in [this package's documentation](#).

## Value

A list of length 2 and class "ci.thresholds", "ci" and "list" (in this order), with the confidence intervals of the CI and the following items:

specificity	a matrix of CI for the specificity. Row (names) are the thresholds, the first column the lower bound, the 2nd column the median and the 3rd column the upper bound.
sensitivity	same than specificity.

Additionally, the list has the following attributes:

<code>conf.level</code>	the width of the CI, in fraction.
<code>boot.n</code>	the number of bootstrap replicates.
<code>boot.stratified</code>	whether or not the bootstrapping was stratified.
<code>thresholds</code>	the thresholds, as given in argument.
<code>roc</code>	the object of class "roc" that was used to compute the CI.

## Warnings

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, producing a NA area. The warning "NA value(s) produced during bootstrap were ignored." will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

## References

James Carpenter and John Bithell (2000) “Bootstrap condence intervals: when, which, what? A practical guide for medical statisticians”. *Statistics in Medicine* **19**, 1141–1164. DOI: doi: [10.1002/\(SICI\)10970258\(20000515\)19:9<1141::AIDSIM479>3.0.CO;2F](https://doi.org/10.1002/(SICI)10970258(20000515)19:9<1141::AIDSIM479>3.0.CO;2F).

Tom Fawcett (2006) “An introduction to ROC analysis”. *Pattern Recognition Letters* **27**, 861–874. DOI: doi: [10.1016/j.patrec.2005.10.010](https://doi.org/10.1016/j.patrec.2005.10.010).

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

Hadley Wickham (2011) “The Split-Apply-Combine Strategy for Data Analysis”. *Journal of Statistical Software*, **40**, 1–29. URL: doi: [10.18637/jss.v040.i01](https://doi.org/10.18637/jss.v040.i01).

## See Also

[roc](#), [ci](#)

## Examples

```
data(aSAH)

# Create a ROC curve:
data(aSAH)
roc1 <- roc(aSAH$outcome, aSAH$s100b)

## Basic example ##
# Compute CI of all local maxima thresholds
## Not run:
ci.thresholds(roc1)
## End(Not run)

## More options ##
# Customized bootstrap and thresholds:
## Not run:
ci.thresholds(roc1,
  thresholds=c(0.5, 1, 2),
  boot.n=10000, conf.level=0.9, stratified=FALSE)
## End(Not run)

## Plotting the CI ##
## Not run:
ci1 <- ci.thresholds(roc1)
## End(Not run)
plot(roc1)
plot(ci1)
```

---

coords	<i>Coordinates of a ROC curve</i>
--------	-----------------------------------

---

## Description

This function returns the coordinates of the ROC curve at one or several specified point(s).

## Usage

```
coords(...)
## S3 method for class 'roc'
coords(roc, x, input="threshold", ret=c("threshold",
"specificity", "sensitivity"),
as.list=FALSE, drop=TRUE, best.method=c("youden", "closest.topleft"),
best.weights=c(1, 0.5), transpose = FALSE, as.matrix=FALSE, ...)
## S3 method for class 'smooth.roc'
coords(smooth.roc, x, input, ret=c("specificity",
"sensitivity"), as.list=FALSE, drop=TRUE, best.method=c("youden",
"closest.topleft"), best.weights=c(1, 0.5), transpose = FALSE,
as.matrix=FALSE, ...)
```

## Arguments

roc, smooth.roc	a “roc” object from the <a href="#">roc</a> function, or a “smooth.roc” object from the <a href="#">smooth</a> function.
x	the coordinates to look for. Numeric (if so, their meaning is defined by the input argument) or one of “all” (all the points of the ROC curve), “local maximas” (the local maximas of the ROC curve) or “best” (see <code>best.method</code> argument). If missing or NULL, defaults to “all”.
input	If x is numeric, the kind of input coordinate (x). Typically one of “threshold”, “specificity” or “sensitivity”, but can be any of the monotone coordinate available, see the “Valid input” column under “Available coordinates”. Can be shortened like <code>ret</code> . Defaults to “threshold”. Note that “threshold” is not allowed in <code>coords.smooth.roc</code> and that the argument is ignored when x is a character.
ret	The coordinates to return. See “Available coordinates” section below. Alternatively, the single value “all” can be used to return every coordinate available.
as.list	DEPRECATED. If the returned object must be a list. Will be removed in a future version.
drop	If TRUE the result is coerced to the lowest possible dimension, as per <a href="#">Extract</a> . By default only drops if <code>transpose = TRUE</code> and either <code>ret</code> or x is of length 1.
best.method	if x=“best”, the method to determine the best threshold. Defaults to “youden”. See details in the ‘Best thresholds’ section.
best.weights	if x=“best”, the weights to determine the best threshold. See details in the ‘Best thresholds’ section.

<code>transpose</code>	whether to return the thresholds in columns (TRUE) or rows (FALSE). Since pROC 1.16 the default value is FALSE. See <code>coords_transpose</code> for more details the change.
<code>as.matrix</code>	if <code>transpose</code> is FALSE, whether to return a <code>matrix</code> (TRUE) or a <code>data.frame</code> (FALSE, the default). A <code>data.frame</code> is more convenient and flexible to use, but incurs a slight speed penalty. Consider setting this argument to TRUE if you are calling the function repeatedly.
<code>...</code>	further arguments passed from other methods. Ignored.

## Details

This function takes a “roc” or “smooth.roc” object as first argument, on which the coordinates will be determined. The coordinates are defined by the `x` and `input` arguments. “threshold” coordinates cannot be determined in a smoothed ROC.

If `input="threshold"`, the coordinates for the threshold are reported, even if the exact threshold do not define the ROC curve. The following convenience characters are allowed: “all”, “local maximas” and “best”. They will return all the thresholds, only the thresholds defining local maximas (upper angles of the ROC curve), or only the threshold(s) corresponding to the best sum of sensitivity + specificity respectively. Note that “best” can return more than one threshold. If `x` is a character, the coordinates are limited to the thresholds within the partial AUC if it has been defined, and not necessarily to the whole curve.

For `input="specificity"` and `input="sensitivity"`, the function checks if the specificity or sensitivity is one of the points of the ROC curve (in `roc$sensitivities` or `roc$specificities`). More than one point may match (in *step* curves), then only the upper-left-most point coordinates are returned. Otherwise, the specificity and sensitivity of the point is interpolated and NA is returned as `threshold`.

The `coords` function in this package is a generic, but it might be superseded by functions in other packages such as **colorspace** or **spatstat** if they are loaded after **pROC**. In this case, call the `pROC::coords` explicitly.

**Best thresholds:** If `x="best"`, the `best.method` argument controls how the optimal threshold is determined.

**“youden”** Youden’s J statistic (Youden, 1950) is employed (default). The optimal cut-off is the threshold that maximizes the distance to the identity (diagonal) line. Can be shortened to “y”. The optimality criterion is:

$$\max(sensitivities + specificities)$$

**“closest.topleft”** The optimal threshold is the point closest to the top-left part of the plot with perfect sensitivity or specificity. Can be shortened to “c” or “t”.

The optimality criterion is:

$$\min((1 - sensitivities)^2 + (1 - specificities)^2)$$

In addition, weights can be supplied if false positive and false negative predictions are not equivalent: a numeric vector of length 2 to the `best.weights` argument. The elements define

1. the relative cost of of a false negative classification (as compared with a false positive classification)
2. the prevalence, or the proportion of cases in the population ( $\frac{n_{cases}}{n_{controls} + n_{cases}}$ ).

The optimality criteria are modified as proposed by Perkins and Schisterman:

“youden”

$$\max(\text{sensitivities} + r * \text{specificities})$$

“closest.topleft”

$$\min((1 - \text{sensitivities})^2 + r * (1 - \text{specificities})^2)$$

with

$$r = \frac{1 - \text{prevalence}}{\text{cost} * \text{prevalence}}$$

By default, prevalence is 0.5 and cost is 1 so that no weight is applied in effect.

Note that several thresholds might be equally optimal.

**Available coordinates:**

The following table lists the coordinates that are available in the ret and input arguments.

Value	Description	Formula	Synonyms	Value
threshold	The threshold value	-	-	Value
tn	True negative count	-	-	Yes
tp	True positive count	-	-	Yes
fn	False negative count	-	-	Yes
fp	False positive count	-	-	Yes
specificity	Specificity	tn / (tn + fp)	tnr	Yes
sensitivity	Sensitivity	tp / (tp + fn)	recall, tpr	Yes
accuracy	Accuracy	(tp + tn) / N	-	No
npv	Negative Predictive Value	tn / (tn + fn)	-	No
ppv	Positive Predictive Value	tp / (tp + fp)	precision	No
precision	Precision	tp / (tp + fp)	ppv	No
recall	Recall	tp / (tp + fn)	sensitivity, tpr	Yes
tpr	True Positive Rate	tp / (tp + fn)	sensitivity, recall	Yes
fpr	False Positive Rate	fp / (tn + fp)	1-specificity	Yes
tnr	True Negative Rate	tn / (tn + fp)	specificity	Yes
fnr	False Negative Rate	fn / (tp + fn)	1-sensitivity	Yes
fdr	False Discovery Rate	fp / (tp + fp)	1-ppv	No
youden	Youden Index	se + r * sp	-	No
closest.topleft	Distance to the top left corner of the ROC space	-((1 - se)^2 + r * (1 - sp)^2)	-	No

The value “threshold” is not allowed in coords.smooth.roc.

Values can be shortened (for example to “thr”, “sens” and “spec”, or even to “se”, “sp” or “1-np”). In addition, some values can be prefixed with 1- to get their complement: 1-specificity, 1-sensitivity, 1-accuracy, 1-npv, 1-ppv.

The values npe and ppe are automatically replaced with 1-npv and 1-ppv, respectively (and will therefore not appear as is in the output, but as 1-npv and 1-ppv instead). These must be used verbatim in ROC curves with percent=TRUE (ie. “100-ppv” is never accepted).

The “youden” and “closest.topleft” are weighted with r, according to the value of the best.weights

argument. See the “Best thresholds” section above for more details.  
 For `ret`, the single value “all” can be used to return every coordinate available.

### Value

Depending on the length of `x` and `as.list` argument.

	<code>length(x) == 1</code> or <code>length(ret) == 1</code>
<code>as.list=TRUE</code>	a list of the length of, in the order of, and named after, <code>ret</code> .
<code>as.list=FALSE</code>	a numeric vector of the length of, in the order of, and named after, <code>ret</code> (if <code>length(x) == 1</code> ) or a numeric vector

In all cases if `input="specificity"` or `input="sensitivity"` and interpolation was required, `threshold` is returned as `NA`.

Note that if giving a character as `x` (“all”, “local maximas” or “best”), you cannot predict the dimension of the return value unless `drop=FALSE`. Even “best” may return more than one value (for example if the ROC curve is below the identity line, both extreme points).

`coords` may also return `NULL` when there a partial area is defined but no point of the ROC curve falls within the region.

### References

- Neil J. Perkins, Enrique F. Schisterman (2006) “The Inconsistency of “Optimal” Cutpoints Obtained using Two Criteria based on the Receiver Operating Characteristic Curve”. *American Journal of Epidemiology* **163**(7), 670–675. DOI: doi: [10.1093/aje/kwj063](https://doi.org/10.1093/aje/kwj063).
- Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).
- W. J. Youden (1950) “Index for rating diagnostic tests”. *Cancer*, **3**, 32–35. DOI: doi: [10.1002/10970142\(1950\)3:1<32::AIDCNCR2820030106>3.0.CO;23](https://doi.org/10.1002/10970142(1950)3:1<32::AIDCNCR2820030106>3.0.CO;23).

### See Also

[roc](#), [ci](#), [coords](#)

### Examples

```
# Create a ROC curve:
data(aSAH)
roc.s100b <- roc(aSAH$outcome, aSAH$s100b, percent = TRUE)

# Get the coordinates of S100B threshold 0.55
coords(roc.s100b, 0.55, transpose = FALSE)

# Get the coordinates at 50% sensitivity
coords(roc=roc.s100b, x=50, input="sensitivity", transpose = FALSE)
# Can be abbreviated:
coords(roc.s100b, 50, "se", transpose = FALSE)
```

```

# Works with smoothed ROC curves
coords(smooth(roc.s100b), 90, "specificity", transpose = FALSE)

# Get the sensitivities for all thresholds
cc <- coords(roc.s100b, "all", ret="sensitivity", transpose = FALSE)
print(cc$sensitivity)

# Get the best threshold
coords(roc.s100b, "best", ret="threshold", transpose = FALSE)

# Get the best threshold according to different methods
roc.ndka <- roc(aSAH$outcome, aSAH$ndka, percent=TRUE)
coords(roc.ndka, "best", ret="threshold", transpose = FALSE,
      best.method="youden") # default
coords(roc.ndka, "best", ret="threshold", transpose = FALSE,
      best.method="closest.topleft")

# and with different weights
coords(roc.ndka, "best", ret="threshold", transpose = FALSE,
      best.method="youden", best.weights=c(50, 0.2))
coords(roc.ndka, "best", ret="threshold", transpose = FALSE,
      best.method="closest.topleft", best.weights=c(5, 0.2))

# This is available with the plot.roc function too:
plot(roc.ndka, print.thres="best", print.thres.best.method="youden",
     print.thres.best.weights=c(50, 0.2))

# Return more values:
coords(roc.s100b, "best", ret=c("threshold", "specificity", "sensitivity", "accuracy",
                              "precision", "recall"), transpose = FALSE)

# Return all values
coords(roc.s100b, "best", ret = "all", transpose = FALSE)

# You can use coords to plot for instance a sensitivity + specificity vs. cut-off diagram
plot(specificity + sensitivity ~ threshold,
     coords(roc.ndka, "all", transpose = FALSE),
     type = "l", log="x",
     subset = is.finite(threshold))

# Plot the Precision-Recall curve
plot(precision ~ recall,
     coords(roc.ndka, "all", ret = c("recall", "precision"), transpose = FALSE),
     type="l", ylim = c(0, 100))

# Alternatively plot the curve with TPR and FPR instead of SE/SP
# (identical curve, only the axis change)
plot(tpr ~ fpr,
     coords(roc.ndka, "all", ret = c("tpr", "fpr"), transpose = FALSE),
     type="l")

```

---

coords\_transpose      *Transposing the output of coords*

---

## Description

This help page describes recent and upcoming changes in the return values of the `coords` function.

## Background information

Until the release of pROC 1.16, the `coords` function was returning a matrix with thresholds in columns, and the coordinate variables in rows.

```
data(aSAH)
rocobj <- roc(aSAH$outcome, aSAH$s100b)
coords(rocobj, c(0.05, 0.2, 0.5))
#           0.05         0.2         0.5
# threshold 0.05000000 0.2000000 0.5000000
# specificity 0.06944444 0.8055556 0.9722222
# sensitivity 0.97560976 0.6341463 0.2926829
```

This format didn't conform to the grammar of the **tidyverse** which has become prevalent in modern R language.

In addition, the dropping of dimensions by default makes it difficult to guess what type of data `coords` is going to return.

```
coords(rocobj, "best")
# threshold specificity sensitivity
# 0.2050000 0.8055556 0.6341463
# A numeric vector
```

Although it is possible to pass `drop = FALSE`, the fact that it is not the default makes the behaviour unintuitive.

In pROC version 1.16, this was changed and `coords` now returns a `data.frame` with the thresholds in rows and measurement in columns by default.

```
coords(rocobj, c(0.05, 0.2, 0.5), transpose = FALSE)
#   threshold specificity sensitivity
# 0.05      0.05 0.06944444 0.9756098
# 0.2      0.20 0.80555556 0.6341463
# 0.5      0.50 0.97222222 0.2926829
```

## Changes in 1.15

1. Addition of the `transpose` argument.
2. Display a warning if `transpose` is missing. Pass `transpose` explicitly to silence the warning.
3. Deprecation of `as.list`.



**Changes in 1.16**

1. Change of the default transpose to TRUE.

THIS CHANGE IS BACKWARDS INCOMPATIBLE AND IS EXPECTED TO BREAK LEGACY CODE.

**Changes in 1.17**

1. Dropped the warning if transpose is missing.

**Changes in future versions**

1. Support for the `as.list` argument might be dropped in the future. This is still under consideration.
2. The `transpose` and `drop` arguments might be deprecated in the future, but will remain available for a few additional major versions.

**Related changes in ci.coords**

In version 1.16, the format of the `ci.coords` return value was changed from a matrix-like object with mixed `x` and `ret` in rows and 3 columns, into a list-like object which should be easier to use programatically.

**Recommendations**

If you are writing a new script calling the `coords` function, set `transpose = FALSE` to silence the warning and benefit from the latest improvements in `pROC` and obtain a tidy data.

**See also**

[The GitHub issue tracking the changes described in this manual page.](#)

---

 cov.roc

*Covariance of two paired ROC curves*


---

**Description**

This function computes the covariance between the AUC of two correlated (or paired) ROC curves.

**Usage**

```
cov(...)
## Default S3 method:
cov(...)
## S3 method for class 'auc'
cov(roc1, roc2, ...)
## S3 method for class 'smooth.roc'
cov(roc1, roc2, ...)
```

```
## S3 method for class 'roc'
cov(roc1, roc2, method=c("delong", "bootstrap", "obuchowski"),
    reuse.auc=TRUE, boot.n=2000, boot.stratified=TRUE, boot.return=FALSE,
    progress=getOption("pROCprogress")$name, parallel=FALSE, ...)
```

## Arguments

roc1, roc2	the two ROC curves on which to compute the covariance. Either “roc”, “auc” or “smooth.roc” objects (types can be mixed as long as the original ROC curve are paired).
method	the method to use, either “delong” or “bootstrap”. The first letter is sufficient. If omitted, the appropriate method is selected as explained in details.
reuse.auc	if TRUE (default) and the “roc” objects contain an “auc” field, re-use these specifications for the test. See details.
boot.n	for method=“bootstrap” only: the number of bootstrap replicates or permutations. Default: 2000.
boot.stratified	for method=“bootstrap” only: should the bootstrap be stratified (same number of cases/controls in each replicate than in the original sample) or not. Default: TRUE.
boot.return	if TRUE and method=“bootstrap”, also return the bootstrapped values. See the “Value” section for more details.
progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <a href="#">create_progress_bar</a> for more information), but a list as returned by <a href="#">create_progress_bar</a> is also accepted. See also the “Progress bars” section of <a href="#">this package’s documentation</a> .
parallel	if TRUE, the bootstrap is processed in parallel, using parallel backend provided by plyr (foreach).
...	further arguments passed to or from other methods, especially arguments for cov.roc when calling cov, cov.auc or cov.smooth.roc. Arguments for auc (if reuse.auc=FALSE) and txtProgressBar (only char and style) if applicable.

## Details

This function computes the covariance between the AUC of two correlated (or paired, according to the detection of [are.paired](#)) ROC curves. It is typically called with the two roc objects of interest. Two methods are available: “delong” and “bootstrap” (see “Computational details” section below).

The default is to use “delong” method except with partial AUC and smoothed curves where “bootstrap” is employed. Using “delong” for partial AUC and smoothed ROCs is not supported.

For [smoothed ROC curves](#), smoothing is performed again at each bootstrap replicate with the parameters originally provided. If a density smoothing was performed with user-provided density.cases or density.controls the bootstrap cannot be performed and an error is issued.

cov.default forces the usage of the cov function in the stats package, so that other code relying on cov should continue to function normally.

**Value**

The numeric value of the covariance.

If `boot.return=TRUE` and `method="bootstrap"`, an attribute `resampled.values` is set with the resampled (bootstrapped) values. It contains a matrix with the columns representing the two ROC curves, and the rows the `boot.n` bootstrap replicates.

**AUC specification**

To compute the covariance of the AUC of the ROC curves, `cov` needs a specification of the AUC. The specification is defined by:

1. the "auc" field in the "roc" objects if `reuse.auc` is set to `TRUE` (default)
2. passing the specification to `auc` with ... (arguments `partial.auc`, `partial.auc.correct` and `partial.auc.focus`). In this case, you must ensure either that the `roc` object do not contain an `auc` field (if you called `roc` with `auc=FALSE`), or set `reuse.auc=FALSE`.

If `reuse.auc=FALSE` the `auc` function will always be called with ... to determine the specification, even if the "roc" objects do contain an `auc` field.

As well if the "roc" objects do not contain an `auc` field, the `auc` function will always be called with ... to determine the specification.

Warning: if the `roc` object passed to `roc.test` contains an `auc` field and `reuse.auc=TRUE`, `auc` is not called and arguments such as `partial.auc` are silently ignored.

**Computation details**

With `method="bootstrap"`, the processing is done as follow:

1. `boot.n` bootstrap replicates are drawn from the data. If `boot.stratified` is `TRUE`, each replicate contains exactly the same number of controls and cases than the original sample, otherwise if `FALSE` the numbers can vary.
2. for each bootstrap replicate, the AUC of the two ROC curves are computed and stored.
3. the variance (as per `var.roc`) of the resampled AUCs and their covariance are assessed in a single bootstrap pass.
4. The following formula is used to compute the final covariance:  $Var[AUC1] + Var[AUC2] - 2cov[AUC1, AUC2]$

With `method="deLong"`, the processing is done as described in Hanley and Hajian-Tilaki (1997) using the algorithm by Sun and Xu (2014).

With `method="obuchowski"`, the processing is done as described in Obuchowski and McClish (1997), Table 1 and Equation 5, p. 1531. The computation of  $g$  for partial area under the ROC curve is modified as:

$$expr1 * (2 * pi * expr2)^{(-1)} * (-expr4) - A * B * expr1 * (2 * pi * expr2^3)^{(-1/2)} * expr3$$

### Binormality assumption

The “obuchowski” method makes the assumption that the data is binormal. If the data shows a deviation from this assumption, it might help to normalize the data first (that is, before calling `roc`), for example with quantile normalization:

```
norm.x <- qnorm(rank(x)/(length(x)+1))
cov(roc(response, norm.x, ...), ...)
```

“delong” and “bootstrap” methods make no such assumption.

### Errors

If `density.cases` and `density.controls` were provided for smoothing, the error “Cannot compute the covariance on ROC curves smoothed with `density.controls` and `density.cases`.” is issued.

### Warnings

If “auc” specifications are different in both roc objects, the warning “Different AUC specifications in the ROC curves. Enforcing the inconsistency, but unexpected results may be produced.” is issued. Unexpected results may be produced.

If one or both ROC curves are “smooth.roc” objects with different smoothing specifications, the warning “Different smoothing parameters in the ROC curves. Enforcing the inconsistency, but unexpected results may be produced.” is issued. This warning can be benign, especially if ROC curves were generated with `roc(..., smooth=TRUE)` with different arguments to other functions (such as `plot`), or if you really want to compare two ROC curves smoothed differently.

If `method="delong"` and the AUC specification specifies a partial AUC, the warning “Using DeLong for partial AUC is not supported. Using bootstrap test instead.” is issued. The `method` argument is ignored and “bootstrap” is used instead.

If `method="delong"` and the ROC curve is smoothed, the warning “Using DeLong for smoothed ROCs is not supported. Using bootstrap instead.” is issued. The `method` argument is ignored and “bootstrap” is used instead.

DeLong ignores the direction of the ROC curve so that if two ROC curves have a different direction, the warning “DeLong should not be applied to ROC curves with a different direction.” is printed. However, the spurious computation is enforced.

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, or that there are not enough points for smoothing, producing a NA area. The warning “NA value(s) produced during bootstrap were ignored.” will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

When both ROC curves have an `auc` of 1 (or 100%), their covariance will always be null. This is true for both “delong” and “bootstrap” methods. This result is misleading, as the covariance is of course not null. A `warning` will be displayed to inform of this condition, and of the misleading output.

## Messages

The covariance can only be computed on paired data. This assumption is enforced by `are.paired`. If the ROC curves are not paired, the covariance is  $\emptyset$  and the message “ROC curves are unpaired.” is printed. If your ROC curves are paired, make sure they fit `are.paired` criteria.

## References

Elisabeth R. DeLong, David M. DeLong and Daniel L. Clarke-Pearson (1988) “Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach”. *Biometrics* **44**, 837–845.

James A. Hanley and Karim O. Hajian-Tilaki (1997) “Sampling variability of nonparametric estimates of the areas under receiver operating characteristic curves: An update”. *Academic Radiology* **4**, 49–58. DOI: doi: [10.1016/S10766332\(97\)801614](https://doi.org/10.1016/S10766332(97)801614).

Nancy A. Obuchowski, Donna K. McClish (1997). “Sample size determination for diagnostic accuracy studies involving binormal ROC curve indices”. *Statistics in Medicine*, **16**(13), 1529–1542. DOI: doi: [10.1002/\(SICI\)10970258\(19970715\)16:13<1529::AID-SIM565>3.0.CO;2H](https://doi.org/10.1002/(SICI)10970258(19970715)16:13<1529::AID-SIM565>3.0.CO;2H).

Xu Sun and Weichao Xu (2014) “Fast Implementation of DeLongs Algorithm for Comparing the Areas Under Correlated Receiver Operating Characteristic Curves”. *IEEE Signal Processing Letters*, **21**, 1389–1393. DOI: doi: [10.1109/LSP.2014.2337313](https://doi.org/10.1109/LSP.2014.2337313).

Hadley Wickham (2011) “The Split-Apply-Combine Strategy for Data Analysis”. *Journal of Statistical Software*, **40**, 1–29. URL: doi: [10.18637/jss.v040.i01](https://doi.org/10.18637/jss.v040.i01).

## See Also

`roc`, `var.roc`

CRAN package `plyr`, employed in this function.

## Examples

```
data(aSAH)

# Basic example with 2 roc objects
roc1 <- roc(aSAH$outcome, aSAH$s100b)
roc2 <- roc(aSAH$outcome, aSAH$wfns)
cov(roc1, roc2)

## Not run:
# The latter used DeLong. To use bootstrap:
cov(roc1, roc2, method="bootstrap")
# Decrease boot.n for a faster execution:
cov(roc1, roc2, method="bootstrap", boot.n=1000)

## End(Not run)

# To use Obuchowski:
cov(roc1, roc2, method="obuchowski")

## Not run:
# Comparison can be done on smoothed ROCs
```

```

# Smoothing is re-done at each iteration, and execution is slow
cov(smooth(roc1), smooth(roc2))

## End(Not run)
# or from an AUC (no smoothing)
cov(auc(roc1), roc2)

## Not run:
# With bootstrap and return.values, one can compute the variances of the
# ROC curves in one single bootstrap run:
cov.rocs <- cov(roc1, roc2, method="bootstrap", boot.return=TRUE)
# var(roc1):
var(attr(cov.rocs, "resampled.values")[,1])
# var(roc2):
var(attr(cov.rocs, "resampled.values")[,2])

## End(Not run)

## Not run:
# Covariance of partial AUC:
roc3 <- roc(aSAH$outcome, aSAH$s100b, partial.auc=c(1, 0.8), partial.auc.focus="se")
roc4 <- roc(aSAH$outcome, aSAH$wfns, partial.auc=c(1, 0.8), partial.auc.focus="se")
cov(roc3, roc4)
# This is strictly equivalent to:
cov(roc3, roc4, method="bootstrap")

# Alternatively, we could re-use roc1 and roc2 to get the same result:
cov(roc1, roc2, reuse.auc=FALSE, partial.auc=c(1, 0.8), partial.auc.focus="se")

## End(Not run)

# Spurious use of DeLong's test with different direction:
roc5 <- roc(aSAH$outcome, aSAH$s100b, direction="<")
roc6 <- roc(aSAH$outcome, aSAH$s100b, direction=">")
cov(roc5, roc6, method="delong")

## Test data from Hanley and Hajian-Tilaki, 1997
disease.present <- c("Yes", "No", "Yes", "No", "No", "Yes", "Yes", "No",
                    "No", "Yes", "No", "No", "Yes", "No", "No")
field.strength.1 <- c(1, 2, 5, 1, 1, 1, 2, 1, 2, 2, 1, 1, 5, 1, 1)
field.strength.2 <- c(1, 1, 5, 1, 1, 1, 4, 1, 2, 2, 1, 1, 5, 1, 1)
roc7 <- roc(disease.present, field.strength.1)
roc8 <- roc(disease.present, field.strength.2)
# Assess the covariance:
cov(roc7, roc8)

## Not run:
# With bootstrap:
cov(roc7, roc8, method="bootstrap")

## End(Not run)

```

---

`ggroc.roc`*Plot a ROC curve with ggplot2*

---

## Description

This function plots a ROC curve with ggplot2.

## Usage

```
## S3 method for class 'roc'  
ggroc(data, legacy.axes = FALSE, ...)  
## S3 method for class 'smooth.roc'  
ggroc(data, legacy.axes = FALSE, ...)  
## S3 method for class 'list'  
ggroc(data, aes = c("colour", "alpha", "linetype", "linewidth", "size", "group"),  
       legacy.axes = FALSE, ...)
```

## Arguments

<code>data</code>	a roc object from the <a href="#">roc</a> function, or a list of roc objects.
<code>aes</code>	the name(s) of the aesthetics for <a href="#">geom_line</a> to map to the different ROC curves supplied.
<code>legacy.axes</code>	a logical indicating if the specificity axis (x axis) must be plotted as as decreasing “specificity” (FALSE, the default) or increasing “1 - specificity” (TRUE) as in most legacy software.
<code>...</code>	additional aesthetics for <a href="#">geom_line</a> to set: <code>alpha</code> , <code>colour</code> , <code>linetype</code> , <code>linewidth</code> (new in ggplot2 3.4.0), and <code>size</code> (before ggplot2 3.4.0). The <code>group</code> aesthetic is always active since version 1.18.5 and is kept for backwards compatibility.

## Details

This function initializes a ggplot object from a ROC curve (or multiple if a list is passed). It returns the ggplot with a line layer on it. You can print it directly or add your own layers and theme elements.

## See Also

[roc](#), [plot.roc](#), [ggplot2](#)

## Examples

```
# Create a basic roc object  
data(aSAH)  
rocobj <- roc(aSAH$outcome, aSAH$s100b)  
rocobj2 <- roc(aSAH$outcome, aSAH$wfns)  
  
if (require(ggplot2)) {
```

```

g <- ggroc(rocobj)
g
# with additional aesthetics:
ggroc(rocobj, alpha = 0.5, colour = "red", linetype = 2, size = 2)

# You can then your own theme, etc.
g + theme_minimal() + ggtitle("My ROC curve") +
  geom_segment(aes(x = 1, xend = 0, y = 0, yend = 1), color="grey", linetype="dashed")

# And change axis labels to FPR/FPR
g1 <- ggroc(rocobj, legacy.axes = TRUE)
g1
g1 + xlab("FPR") + ylab("TPR") +
  geom_segment(aes(x = 0, xend = 1, y = 0, yend = 1), color="darkgrey", linetype="dashed")

# Multiple curves:
g2 <- ggroc(list(s100b=rocobj, wfns=rocobj2, ndka=roc(aSAH$outcome, aSAH$ndka)))
g2

# This is equivalent to using roc.formula:
roc.list <- roc(outcome ~ s100b + ndka + wfns, data = aSAH)
g.list <- ggroc(roc.list)
g.list

# You can change the aesthetics as you normally would with ggplot2:
g.list + scale_colour_brewer(palette="RdGy")
g.list + scale_colour_manual(values = c("red", "blue", "black"))

# with additional aesthetics:
g3 <- ggroc(roc.list, linetype=2)
g3
g4 <- ggroc(roc.list, aes="linetype", color="red")
g4
# changing multiple aesthetics:
g5 <- ggroc(roc.list, aes=c("linetype", "color"))
g5

# OR faceting
g.list + facet_grid(.~name) + theme(legend.position="none")
}

```

## Description

Redefine **base** groupGeneric functions to handle **auc** and **ci** objects properly on operations and mathematical operations. Attributes are dropped so that the AUC/CI behaves as a numeric value/matrix, respectively. In the case of AUC, all attributes are dropped, while in CI only the CI-specific attributes are, keeping those necessary for the matrices.



**Usage**

```
Math(x, ...)  
Ops(e1, e2)
```

**Arguments**

```
x, e1, e2      auc objects, or mixed numerics and auc objects.  
...           further arguments passed to other Math methods.
```

**See Also**

[groupGeneric](#), [auc](#)

**Examples**

```
data(aSAH)  
  
# Create a roc object:  
aucobj1 <- auc(roc(aSAH$outcome, aSAH$s100b))  
aucobj2 <- auc(roc(aSAH$outcome, aSAH$wfns))  
  
# Math  
sqrt(aucobj1)  
round(aucobj2, digits=1)  
  
# Ops  
aucobj1 * 2  
2 * aucobj2  
aucobj1 + aucobj2  
  
# With CI  
ciaucobj <- ci(aucobj1)  
ciaucobj * 2  
sqrt(ciaucobj)
```

---

has.partial.auc

*Does the ROC curve have a partial AUC?*

---

**Description**

This function determines if the ROC curve has a partial AUC.

**Usage**

```
has.partial.auc(roc)
## S3 method for class 'auc'
has.partial.auc(roc)
## S3 method for class 'smooth.roc'
has.partial.auc(roc)
## S3 method for class 'roc'
has.partial.auc(roc)
```

**Arguments**

roc                    the ROC curve to check.

**Value**

TRUE if the AUC is a partial AUC, FALSE otherwise.

If the AUC is not defined (i. e. if roc was called with AUC=FALSE), returns NULL.

**See Also**

[auc](#)

**Examples**

```
data(aSAH)

# Full AUC
roc1 <- roc(aSAH$outcome, aSAH$s100b)
has.partial.auc(roc1)
has.partial.auc(auc(roc1))
has.partial.auc(smooth(roc1))

# Partial AUC
roc2 <- roc(aSAH$outcome, aSAH$s100b, partial.auc = c(1, 0.9))
has.partial.auc(roc2)
has.partial.auc(smooth(roc2))

# No AUC
roc3 <- roc(aSAH$outcome, aSAH$s100b, auc = FALSE)
has.partial.auc(roc3)
```

---

lines.roc

*Add a ROC line to a ROC plot*

---

**Description**

This convenience function adds a ROC line to a ROC curve.

**Usage**

```
## S3 method for class 'roc'
lines(x, ...)
## S3 method for class 'smooth.roc'
lines(x, ...)
## S3 method for class 'roc'
lines.roc(x, lwd=2, ...)
## S3 method for class 'formula'
lines.roc(x, data, subset, na.action, ...)
## Default S3 method:
lines.roc(x, predictor, ...)
## S3 method for class 'smooth.roc'
lines.roc(x, ...)
```

**Arguments**

x	a roc object from the <a href="#">roc</a> function (for <code>plot.roc.roc</code> ), a formula (for <code>plot.roc.formula</code> ) or a response vector (for <code>plot.roc.default</code> ).
predictor, data	arguments for the <a href="#">roc</a> function.
subset, na.action	arguments for <a href="#">model.frame</a>
lwd	line width (see <a href="#">par</a> ).
...	graphical parameters for <a href="#">lines</a> , and especially type (see <a href="#">plot.default</a> ) and arguments for <a href="#">par</a> such as col (color), lty (line type) or line characteristics lend, ljoin and lmitre.

**Value**

This function returns a list of class “roc” invisibly. See [roc](#) for more details.

**See Also**

[roc](#), [plot.roc](#)

**Examples**

```
# Create a few ROC curves:
data(aSAH)
roc.s100b <- roc(aSAH$outcome, aSAH$s100b)
roc.wfns <- roc(aSAH$outcome, aSAH$wfns)

# We need a plot to be ready
plot(roc.s100b, type = "n") # but don't actually plot the curve

# Add the line
lines(roc.s100b, type="b", pch=21, col="blue", bg="grey")
```

```
# Add the line of an other ROC curve
lines(roc.wfns, type="o", pch=19, col="red")

# Without using 'lines':
rocobj <- plot.roc(aSAH$outcome, aSAH$s100b, type="b", pch=21, col="blue", bg="grey")
```

---

multiclass.roc

*Multi-class AUC*


---

### Description

This function builds multiple ROC curve to compute the multi-class AUC as defined by Hand and Till.

### Usage

```
multiclass.roc(...)
## S3 method for class 'formula'
multiclass.roc(formula, data, ...)
## Default S3 method:
multiclass.roc(response, predictor,
  levels=base::levels(as.factor(response)),
  percent=FALSE, direction = c("auto", "<", ">"), ...)
```

### Arguments

response	a factor, numeric or character vector of responses (true class), typically encoded with 0 (controls) and 1 (cases), as in <a href="#">roc</a> .
predictor	either a numeric vector, containing the value of each observation, as in <a href="#">roc</a> , or, a matrix giving the decision value (e.g. probability) for each class.
formula	a formula of the type response~predictor.
data	a matrix or data.frame containing the variables in the formula. See <a href="#">model.frame</a> for more details.
levels	the value of the response for controls and cases respectively. In contrast with levels argument to <a href="#">roc</a> , all the levels are used and <a href="#">combined</a> to compute the multiclass AUC.
percent	if the sensitivities, specificities and AUC must be given in percent (TRUE) or in fraction (FALSE, default).
direction	in which direction to make the comparison? "auto" (default for univariate curves): automatically define in which group the median is higher and take the direction accordingly. Not available for multivariate curves. ">" (default for multivariate curves): if the predictor values for the control group are higher than the values

of the case group (controls > t >= cases). “<”: if the predictor values for the control group are lower or equal than the values of the case group (controls < t <= cases).

... further arguments passed to `roc`.

### Details

This function performs multiclass AUC as defined by Hand and Till (2001). A multiclass AUC is a mean of several `auc` and cannot be plotted. Only AUCs can be computed for such curves. Confidence intervals, standard deviation, smoothing and comparison tests are not implemented.

The `multiclass.roc` function can handle two types of datasets: uni- and multi-variate. In the univariate case, a single predictor vector is passed and all the combinations of responses are assessed. In the multivariate case, a `matrix` or `data.frame` is passed as predictor. The columns must be named according to the levels of the response.

This function has been much less tested than the rest of the package and is more subject to bugs. Please report them if you find one.

### Value

If predictor is a vector, a list of class “multiclass.roc” (univariate) or “mv.multiclass.roc” (multivariate), with the following fields:

<code>auc</code>	if called with <code>auc=TRUE</code> , a numeric of class “auc” as defined in <code>auc</code> . Note that this is not the standard AUC but the multi-class AUC as defined by Hand and Till.
<code>ci</code>	if called with <code>ci=TRUE</code> , a numeric of class “ci” as defined in <code>ci</code> .
<code>response</code>	the response vector as passed in argument. If NA values were removed, a <code>na.action</code> attribute similar to <code>na.omit</code> stores the row numbers.
<code>predictor</code>	the predictor vector as passed in argument. If NA values were removed, a <code>na.action</code> attribute similar to <code>na.omit</code> stores the row numbers.
<code>levels</code>	the levels of the response as defined in argument.
<code>percent</code>	if the sensitivities, specificities and AUC are reported in percent, as defined in argument.
<code>call</code>	how the function was called. See <code>match.call</code> for more details.

### Warnings

If response is an ordered factor and one of the levels specified in `levels` is missing, a warning is issued and the level is ignored.

### References

David J. Hand and Robert J. Till (2001). A Simple Generalisation of the Area Under the ROC Curve for Multiple Class Classification Problems. *Machine Learning* **45**(2), p. 171–186. DOI: doi: [10.1023/A:1010920819831](https://doi.org/10.1023/A:1010920819831).

**See Also**[auc](#)**Examples**

```
#####
# Examples for a univariate decision value
#####
data(aSAH)

# Basic example
multiclass.roc(aSAH$gos6, aSAH$s100b)
# Produces an innocuous warning because one level has no observation

# Select only 3 of the aSAH$gos6 levels:
multiclass.roc(aSAH$gos6, aSAH$s100b, levels=c(3, 4, 5))

# Give the result in percent
multiclass.roc(aSAH$gos6, aSAH$s100b, percent=TRUE)

#####
# Examples for multivariate decision values (e.g. class probabilities)
#####

## Not run:
# Example with a multinomial log-linear model from nnet
# We use the iris dataset and split into a training and test set
requireNamespace("nnet")
data(iris)
iris.sample <- sample(1:150)
iris.train <- iris[iris.sample[1:75],]
iris.test <- iris[iris.sample[76:150],]
mn.net <- nnet::multinom(Species ~ ., iris.train)

# Use predict with type="prob" to get class probabilities
iris.predictions <- predict(mn.net, newdata=iris.test, type="prob")
head(iris.predictions)

# This can be used directly in multiclass.roc:
multiclass.roc(iris.test$Species, iris.predictions)

## End(Not run)

# Let's see an other example with an artificial dataset
n <- c(100, 80, 150)
responses <- factor(c(rep("X1", n[1]), rep("X2", n[2]), rep("X3", n[3])))
# construct prediction matrix: one column per class

preds <- lapply(n, function(x) runif(x, 0.4, 0.6))
predictor <- as.matrix(data.frame(
  "X1" = c(preds[[1]], runif(n[2] + n[3], 0, 0.7)),
```

```

      "X2" = c(runif(n[1], 0.1, 0.4), preds[[2]], runif(n[3], 0.2, 0.8)),
      "X3" = c(runif(n[1] + n[2], 0.3, 0.7), preds[[3]])
    ))
  multiclass.roc(responses, predictor)

  # One can change direction , partial.auc, percent, etc:
  multiclass.roc(responses, predictor, direction = ">")
  multiclass.roc(responses, predictor, percent = TRUE,
  partial.auc = c(100, 90), partial.auc.focus = "se")

  # Limit set of levels
  multiclass.roc(responses, predictor, levels = c("X1", "X2"))
  # Use with formula. Here we need a data.frame to store the responses as characters
  data <- cbind(as.data.frame(predictor), "response" = responses)
  multiclass.roc(response ~ X1+X3, data)

```

---

 plot.ci

*Plot confidence intervals*


---

## Description

This function adds confidence intervals to a ROC curve plot, either as bars or as a confidence shape.

## Usage

```

## S3 method for class 'ci.thresholds'
plot(x, length=.01*ifelse(attr(x,
  "roc")$percent, 100, 1), col=par("fg"), ...)
## S3 method for class 'ci.sp'
plot(x, type=c("bars", "shape"), length=.01*ifelse(attr(x,
  "roc")$percent, 100, 1), col=ifelse(type=="bars", par("fg"),
  "gainsboro"), no.roc=FALSE, ...)
## S3 method for class 'ci.se'
plot(x, type=c("bars", "shape"), length=.01*ifelse(attr(x,
  "roc")$percent, 100, 1), col=ifelse(type=="bars", par("fg"),
  "gainsboro"), no.roc=FALSE, ...)

```

## Arguments

x	a confidence interval object from the functions <a href="#">ci.thresholds</a> , <a href="#">ci.se</a> or <a href="#">ci.sp</a> .
type	type of plot, "bars" or "shape". Can be shortened to "b" or "s". "shape" is only available for <a href="#">ci.se</a> and <a href="#">ci.sp</a> , not for <a href="#">ci.thresholds</a> .
length	the length (as plot coordinates) of the bar ticks. Only if type="bars".
no.roc	if FALSE, the ROC line is re-added over the shape. Otherwise if TRUE, only the shape is plotted. Ignored if type="bars"
col	color of the bars or shape.
...	further arguments for <a href="#">segments</a> (if type="bars") or <a href="#">polygon</a> (if type="shape").

## Details

This function adds confidence intervals to a ROC curve plot, either as bars or as a confidence shape, depending on the state of the `type` argument. The shape is plotted over the ROC curve, so that the curve is re-plotted unless `no.roc=TRUE`.

Graphical functions are called with [suppressWarnings](#).

## Value

This function returns the confidence interval object invisibly.

## Warnings

With `type="shape"`, the warning “Low definition shape” is issued when the shape is defined by less than 15 confidence intervals. In such a case, the shape is not well defined and the ROC curve could pass outside the shape. To get a better shape, increase the number of intervals, for example with:

```
plot(ci.sp(rocobj, sensitivities=seq(0, 1, .01)), type="shape")
```

## References

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, 7, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

## See Also

[plot.roc](#), [ci.thresholds](#), [ci.sp](#), [ci.se](#)

## Examples

```
data(aSAH)
## Not run:
# Start a ROC plot
rocobj <- plot.roc(aSAH$outcome, aSAH$s100b)
plot(rocobj)
# Thresholds
ci.thresholds.obj <- ci.thresholds(rocobj)
plot(ci.thresholds.obj)
# Specificities
plot(rocobj) # restart a new plot
ci.sp.obj <- ci.sp(rocobj, boot.n=500)
plot(ci.sp.obj)
# Sensitivities
plot(rocobj) # restart a new plot
ci.se.obj <- ci(rocobj, of="se", boot.n=500)
plot(ci.se.obj)

# Plotting a shape. We need more
ci.sp.obj <- ci.sp(rocobj, sensitivities=seq(0, 1, .01), boot.n=100)
```



```

plot(rocobj) # restart a new plot
plot(ci.sp.obj, type="shape", col="blue")

# Direct syntax (response, predictor):
plot.roc(aSAH$outcome, aSAH$s100b,
         ci=TRUE, of="thresholds")

## End(Not run)

```

---

plot.roc

*Plot a ROC curve*


---

### Description

This function plots a ROC curve. It can accept many arguments to tweak the appearance of the plot. Two syntaxes are possible: one object of class “roc”, or either two vectors (response, predictor) or a formula (response~predictor) as in the [roc](#) function.

### Usage

```

## S3 method for class 'roc'
plot(x, ...)
## S3 method for class 'smooth.roc'
plot(x, ...)
## S3 method for class 'roc'
plot.roc(x, add=FALSE, reuse.auc=TRUE,
         axes=TRUE, legacy.axes=FALSE,
         # Generic arguments for par:
         xlim=if(x$percent){c(100, 0)} else{c(1, 0)},
         ylim=if(x$percent){c(0, 100)} else{c(0, 1)},
         xlab=ifelse(x$percent, ifelse(legacy.axes, "100 - Specificity (%)", "Specificity (%)",
                                     ifelse(legacy.axes, "1 - Specificity", "Specificity")),
         ylab=ifelse(x$percent, "Sensitivity (%)", "Sensitivity"),
         asp=1,
         mar=c(4, 4, 2, 2)+.1,
         mgp=c(2.5, 1, 0),
         # col, lty and lwd for the ROC line only
         col=par("col"),
         lty=par("lty"),
         lwd=2,
         type="l",
         # Identity line
         identity=!add,
         identity.col="darkgrey",
         identity.lty=1,
         identity.lwd=1,
         # Print the thresholds on the plot
         print.thres=FALSE,

```

```

print.thres.pch=20,
print.thres.adj=c(-.05,1.25),
print.thres.col="black",
print.thres.pattern=ifelse(x$percent, "%.1f (%.1f%%, %.1f%%)", "%.3f (%.3f, %.3f)"),
print.thres.cex=par("cex"),
print.thres.pattern.cex=print.thres.cex,
print.thres.best.method=NULL,
print.thres.best.weights=c(1, 0.5),
# Print the AUC on the plot
print.auc=FALSE,
print.auc.pattern=NULL,
print.auc.x=ifelse(x$percent, 50, .5),
print.auc.y=ifelse(x$percent, 50, .5),
print.auc.adj=c(0,1),
print.auc.col=col,
print.auc.cex=par("cex"),
# Grid
grid=FALSE,
grid.v={if(is.logical(grid) && grid[1]==TRUE)
  {seq(0, 1, 0.1) * ifelse(x$percent, 100, 1)}
  else if(is.numeric(grid))
  {seq(0, ifelse(x$percent, 100, 1), grid[1])} else {NULL}},
grid.h={if (length(grid) == 1) {grid.v}
  else if (is.logical(grid) && grid[2]==TRUE)
  {seq(0, 1, 0.1) * ifelse(x$percent, 100, 1)}
  else if(is.numeric(grid))
  {seq(0, ifelse(x$percent, 100, 1), grid[2])} else {NULL}},
grid.lty=3,
grid.lwd=1,
grid.col="#DDDDDD",
# Polygon for the AUC
auc.polygon=FALSE,
auc.polygon.col="gainsboro",
auc.polygon.lty=par("lty"),
auc.polygon.density=NULL,
auc.polygon.angle=45,
auc.polygon.border=NULL,
# Polygon for the maximal AUC possible
max.auc.polygon=FALSE,
max.auc.polygon.col="#EEEEEE",
max.auc.polygon.lty=par("lty"),
max.auc.polygon.density=NULL,
max.auc.polygon.angle=45,
max.auc.polygon.border=NULL,
# Confidence interval
ci=!is.null(x$ci),
ci.type=c("bars", "shape", "no"),
ci.col=ifelse(ci.type=="bars", par("fg"), "gainsboro"),

```

```

... )
## S3 method for class 'formula'
plot.roc(x, data, subset, na.action, ...)
## Default S3 method:
plot.roc(x, predictor, ...)
## S3 method for class 'smooth.roc'
plot.roc(x, ...)

```

## Arguments

**x** a roc object from the [roc](#) function (for `plot.roc.roc`), a formula (for `plot.roc.formula`) or a response vector (for `plot.roc.default`).

**predictor, data** arguments for the [roc](#) function.

**subset, na.action** arguments for [model.frame](#)

**add** if TRUE, the ROC curve will be added to an existing plot. If FALSE (default), a new plot will be created.

**reuse.auc** if TRUE (default) and the “roc” object contains an “auc” field, re-use these specifications for the plot (specifically `print.auc`, `auc.polygon` and `max.auc.polygon` arguments). See details.

**axes** a logical indicating if the plot axes must be drawn.

**legacy.axes** a logical indicating if the specificity axis (x axis) must be plotted as as decreasing “specificity” (FALSE, the default) or increasing “1 - specificity” (TRUE) as in most legacy software. This affects only the axis, not the plot coordinates.

**xlim, ylim, xlab, ylab, asp, mar, mgp** Generic arguments for the plot. See [plot](#) and [plot.window](#) for more details. Only used if `add=FALSE`.

**col, lty, lwd** color, line type and line width for the ROC curve. See [par](#) for more details.

**type** type of plotting as in [plot](#).

**identity** logical: whether or not the identity line (no discrimination line) must be displayed. Default: only on new plots.

**identity.col, identity.lty, identity.lwd** color, line type and line width for the identity line. Used only if `identity=TRUE`. See [par](#) for more details.

**print.thres** Should a selected set of thresholds be displayed on the ROC curve? FALSE, NULL or “no”: no threshold is displayed. TRUE or “best”: the threshold with the highest sum sensitivity + specificity is plotted (this might be more than one threshold). “all”: all the points of the ROC curve. “local maximas”: all the local maximas. Numeric vector: direct definition of the thresholds to display. Note that on a smoothed ROC curve, only “best” is supported.

**print.thres.pch, print.thres.adj, print.thres.col, print.thres.cex** the plotting character (`pch`), text string adjustment (`adj`), color (`col`) and character expansion factor (`cex`) parameters for the printing of the thresholds. See [points](#) and [par](#) for more details.

`print.thres.pattern` the text pattern for the thresholds, as a [sprintf](#) format. Three numerics are passed to `sprintf`: `threshold`, `specificity`, `sensitivity`.

`print.thres.pattern.cex` the character expansion factor (`cex`) for the threshold text pattern. See [par](#) for more details.

`print.thres.best.method`, `print.thres.best.weights` if `print.thres="best"` or `print.thres=TRUE`, what method must be used to determine which threshold is the best. See argument `best.method` and `best.weights` to [coords](#) for more details.

`print.auc` boolean. Should the numeric value of AUC be printed on the plot?

`print.auc.pattern` the text pattern for the AUC, as a [sprintf](#) format. If `NULL`, a reasonable value is computed that takes partial AUC, CI and percent into account. If the CI of the AUC was computed, three numerics are passed to `sprintf`: AUC, lower CI bound, higher CI bound. Otherwise, only AUC is passed.

`print.auc.x`, `print.auc.y` x and y position for the printing of the AUC.

`print.auc.adj`, `print.auc.cex`, `print.auc.col` the text adjustment, character expansion factor and color for the printing of the AUC. See [par](#) for more details.

`grid` boolean or numeric vector of length 1 or 2. Should a background grid be added to the plot? Numeric: show a grid with the specified interval between each line; Logical: show the grid or not. Length 1: same values are taken for horizontal and vertical lines. Length 2: grid value for vertical (`grid[1]`) and horizontal (`grid[2]`). Note that these values are used to compute `grid.v` and `grid.h`. Therefore if you specify a `grid.h` and `grid.v`, it will be ignored.

`grid.v`, `grid.h` numeric. The x and y values at which a vertical or horizontal line (respectively) must be drawn. `NULL` if no line must be added.

`grid.lty`, `grid.lwd`, `grid.col` the line type (`lty`), line width (`lwd`) and color (`col`) of the lines of the grid. See [par](#) for more details. Note that you can pass vectors of length 2, in which case it specifies the vertical (1) and horizontal (2) lines.

`auc.polygon` boolean. Whether or not to display the area as a polygon.

`auc.polygon.col`, `auc.polygon.lty`, `auc.polygon.density`, `auc.polygon.angle`, `auc.polygon.border` color (`col`), line type (`lty`), density, angle and border for the AUC polygon. See [polygon](#) and [par](#) for more details.

`max.auc.polygon` boolean. Whether or not to display the maximal possible area as a polygon.

`max.auc.polygon.col`, `max.auc.polygon.lty`, `max.auc.polygon.density`, `max.auc.polygon.angle`, `max.auc.polygon.border` color (`col`), line type (`lty`), density, angle and border for the maximum AUC polygon. See [polygon](#) and [par](#) for more details.

`ci` boolean. Should we plot the confidence intervals?

`ci.type`, `ci.col` type and `col` arguments for [plot.ci](#). The special value "no" disables the plotting of confidence intervals.

... further arguments passed to or from other methods, especially arguments for `roc` and `plot.roc.roc` when calling `plot.roc.default` or `plot.roc.formula`. Note that the `plot` argument for `roc` is not allowed. Arguments for `auc` and graphical functions `plot`, `abline`, `polygon`, `points`, `text` and `plot.ci` if applicable.

## Details

This function is typically called from `roc` when `plot=TRUE` (not by default). `plot.roc.formula` and `plot.roc.default` are convenience methods that build the ROC curve (with the `roc` function) before calling `plot.roc.roc`. You can pass them arguments for both `roc` and `plot.roc.roc`. Simply use `plot.roc` that will dispatch to the correct method.

The plotting is done in the following order:

1. A new plot is created if `add=FALSE`.
2. The grid is added if `grid.v` and `grid.h` are not `NULL`.
3. The maximal AUC polygon is added if `max.auc.polygon=TRUE`.
4. The CI shape is added if `ci=TRUE`, `ci.type="shape"` and `x$ci` isn't a "ci.auc".
5. The AUC polygon is added if `auc.polygon=TRUE`.
6. The identity line if `identity=TRUE`.
7. The actual ROC line is added.
8. The CI bars are added if `ci=TRUE`, `ci.type="bars"` and `x$ci` isn't a "ci.auc".
9. The selected thresholds are printed if `print.thres` is `TRUE` or numeric.
10. The AUC is printed if `print.auc=TRUE`.

Graphical functions are called with `suppressWarnings`.

## Value

This function returns a list of class "roc" invisibly. See `roc` for more details.

## AUC specification

For `print.auc`, `auc.polygon` and `max.auc.polygon` arguments, an AUC specification is required. By default, the total AUC is plotted, but you may want a partial AUCs. The specification is defined by:

1. the "auc" field in the "roc" object if `reuse.auc` is set to `TRUE` (default). It is naturally inherited from any call to `roc` and fits most cases.
2. passing the specification to `auc` with ... (arguments `partial.auc`, `partial.auc.correct` and `partial.auc.focus`). In this case, you must ensure either that the `roc` object do not contain an `auc` field (if you called `roc` with `auc=FALSE`), or set `reuse.auc=FALSE`.

If `reuse.auc=FALSE` the `auc` function will always be called with ... to determine the specification, even if the "roc" object do contain an `auc` field.

As well if the "roc" object do not contain an `auc` field, the `auc` function will always be called with ... to determine the specification.

Warning: if the roc object passed to `plot.roc` contains an `auc` field and `reuse.auc=TRUE`, `auc` is not called and arguments such as `partial.auc` are silently ignored.

## References

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

## See Also

[roc](#), [auc](#), [ci](#)

## Examples

```
# Create a few ROC curves:
data(aSAH)
roc.s100b <- roc(aSAH$outcome, aSAH$s100b)
roc.wfns <- roc(aSAH$outcome, aSAH$wfns)
roc.ndka <- roc(aSAH$outcome, aSAH$wfns)

# Simple example:
plot(roc.s100b)

# Add a smoothed ROC:
plot(smooth(roc.s100b), add=TRUE, col="blue")
legend("bottomright", legend=c("Empirical", "Smoothed"),
      col=c(par("fg"), "blue"), lwd=2)

# With more options:
plot(roc.s100b, print.auc=TRUE, auc.polygon=TRUE, grid=c(0.1, 0.2),
      grid.col=c("green", "red"), max.auc.polygon=TRUE,
      auc.polygon.col="lightblue", print.thres=TRUE)

# To plot a different partial AUC, we need to ignore the existing value
# with reuse.auc=FALSE:
plot(roc.s100b, print.auc=TRUE, auc.polygon=TRUE, partial.auc=c(1, 0.8),
      partial.auc.focus="se", grid=c(0.1, 0.2), grid.col=c("green", "red"),
      max.auc.polygon=TRUE, auc.polygon.col="lightblue",
      print.thres=TRUE, print.thres.adj = c(1, -1),
      reuse.auc=FALSE)

# Add a second ROC curve to the previous plot:
plot(roc.wfns, add=TRUE)

# Plot some thresholds, add them to the same plot
plot(roc.ndka, print.thres="best", print.thres.best.method="youden")
plot(roc.ndka, print.thres="best", print.thres.best.method="closest.topleft",
      add = TRUE)
plot(roc.ndka, print.thres="best", print.thres.best.method="youden",
      print.thres.best.weights=c(50, 0.2),
      print.thres.adj = c(1.1, 1.25),
      add = TRUE)
```

power.roc.test

*Sample size and power computation for ROC curves***Description**

Computes sample size, power, significance level or minimum AUC for ROC curves.

**Usage**

```
power.roc.test(...)
# One or Two ROC curves test with roc objects:
## S3 method for class 'roc'
power.roc.test(roc1, roc2, sig.level = 0.05,
power = NULL, kappa = NULL, alternative = c("two.sided", "one.sided"),
reuse.auc=TRUE, method = c("delong", "bootstrap", "obuchowski"), ...)
# One ROC curve with a given AUC:
## S3 method for class 'numeric'
power.roc.test(auc = NULL, ncontrols = NULL,
ncases = NULL, sig.level = 0.05, power = NULL, kappa = 1,
alternative = c("two.sided", "one.sided"), ...)
# Two ROC curves with the given parameters:
## S3 method for class 'list'
power.roc.test(parslist, ncontrols = NULL,
ncases = NULL, sig.level = 0.05, power = NULL, kappa = 1,
alternative = c("two.sided", "one.sided"), ...)
```

**Arguments**

roc1, roc2	one or two “roc” object from the <a href="#">roc</a> function.
auc	expected AUC.
parslist	a <a href="#">list</a> of parameters for the two ROC curves test with Obuchowski variance when no empirical ROC curve is known: <b>A1</b> binormal A parameter for ROC curve 1 <b>B1</b> binormal B parameter for ROC curve 1 <b>A2</b> binormal A parameter for ROC curve 2 <b>B2</b> binormal B parameter for ROC curve 2 <b>rn</b> correlation between the variables in control patients <b>ra</b> correlation between the variables in case patients <b>delta</b> the difference of AUC between the two ROC curves For a partial AUC, the following additional parameters must be set: <b>FPR11</b> Upper bound of FPR (1 - specificity) of ROC curve 1 <b>FPR12</b> Lower bound of FPR (1 - specificity) of ROC curve 1 <b>FPR21</b> Upper bound of FPR (1 - specificity) of ROC curve 2 <b>FPR22</b> Lower bound of FPR (1 - specificity) of ROC curve 2

ncontrols, ncases	number of controls and case observations available.
sig.level	expected significance level (probability of type I error).
power	expected power of the test (1 - probability of type II error).
kappa	expected balance between control and case observations. Must be positive. Only for sample size determination, that is to determine ncontrols and ncases.
alternative	whether a one or two-sided test is performed.
reuse.auc	if TRUE (default) and the “roc” objects contain an “auc” field, re-use these specifications for the test. See the <i>AUC specification</i> section for more details.
method	the method to compute <a href="#">variance</a> and <a href="#">covariance</a> , either “delong”, “bootstrap” or “obuchowski”. The first letter is sufficient. Only for Two ROC curves power calculation. See <a href="#">var</a> and <a href="#">cov</a> documentations for more details.
...	further arguments passed to or from other methods, especially <a href="#">auc</a> (with reuse.auc=FALSE or no AUC in the ROC curve), <a href="#">cov</a> and <a href="#">var</a> (especially arguments method, boot.n and boot.stratified). Ignored (with a warning) with a parslis.

### Value

An object of class `power.htest` (such as that given by [power.t.test](#)) with the supplied and computed values.

### One ROC curve power calculation

If one or no ROC curves are passed to `power.roc.test`, a one ROC curve power calculation is performed. The function expects either `power`, `sig.level` or `auc`, or both `ncontrols` and `ncases` to be missing, so that the parameter is determined from the others with the formula by Obuchowski *et al.*, 2004 (formulas 2 and 3, p. 1123).

For the sample size, `ncases` is computed directly from formulas 2 and 3 and `ncontrols` is deduced with `kappa` (defaults to the ratio of controls to cases). AUC is optimized by [uniroot](#) while `sig.level` and `power` are solved as quadratic equations.

`power.roc.test` can also be passed a `roc` object from the [roc](#) function, but the empirical ROC will not be used, only the number of patients and the AUC.

### Two paired ROC curves power calculation

If two ROC curves are passed to `power.roc.test`, the function will compute either the required sample size (if `power` is supplied), the significance level (if `sig.level=NULL` and `power` is supplied) or the power of a test of a difference between to AUCs according to the formula by Obuchowski and McClish, 1997 (formulas 2 and 3, p. 1530–1531). The null hypothesis is that the AUC of `roc1` is the same than the AUC of `roc2`, with `roc1` taken as the reference ROC curve.

For the sample size, `ncases` is computed directly from formula 2 and `ncontrols` is deduced with `kappa` (defaults to the ratio of controls to cases in `roc1`). `sig.level` and `power` are solved as quadratic equations.

The variance and covariance of the ROC curve are computed with the [var](#) and [cov](#) functions. By default, DeLong method using the algorithm by Sun and Xu (2014) is used for full AUCs and the



bootstrap for partial AUCs. It is possible to force the use of Obuchowski's variance by specifying `method="obuchowski"`.

Alternatively when no empirical ROC curve is known, or if only one is available, a list can be passed to `power.roc.test`, with the contents defined in the "Arguments" section. The variance and covariance are computed from Table 1 and Equation 4 and 5 of Obuchowski and McClish (1997), p. 1530–1531.

Power calculation for unpaired ROC curves is not implemented.

### AUC specification

The comparison of the AUC of the ROC curves needs a specification of the AUC. The specification is defined by:

1. the "auc" field in the "roc" objects if `reuse.auc` is set to TRUE (default)
2. passing the specification to `auc` with ... (arguments `partial.auc`, `partial.auc.correct` and `partial.auc.focus`). In this case, you must ensure either that the `roc` object do not contain an `auc` field (if you called `roc` with `auc=FALSE`), or set `reuse.auc=FALSE`.

If `reuse.auc=FALSE` the `auc` function will always be called with ... to determine the specification, even if the "roc" objects do contain an `auc` field.

As well if the "roc" objects do not contain an `auc` field, the `auc` function will always be called with ... to determine the specification.

Warning: if the `roc` object passed to `roc.test` contains an `auc` field and `reuse.auc=TRUE`, `auc` is not called and arguments such as `partial.auc` are silently ignored.

### Acknowledgements

The authors would like to thank Christophe Combescure and Anne-Sophie Jannot for their help with the implementation of this section of the package.

### References

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Nancy A. Obuchowski, Donna K. McClish (1997). "Sample size determination for diagnostic accuracy studies involving binormal ROC curve indices". *Statistics in Medicine*, **16**, 1529–1542. DOI: doi: [10.1002/\(SICI\)10970258\(19970715\)16:13<1529::AID-SIM565>3.0.CO;2H](https://doi.org/10.1002/(SICI)10970258(19970715)16:13<1529::AID-SIM565>3.0.CO;2H).

Nancy A. Obuchowski, Michael L. Lieber, Frank H. Wians Jr. (2004). "ROC Curves in Clinical Chemistry: Uses, Misuses, and Possible Solutions". *Clinical Chemistry*, **50**, 1118–1125. DOI: doi: [10.1373/clinchem.2004.031823](https://doi.org/10.1373/clinchem.2004.031823).

Xu Sun and Weichao Xu (2014) "Fast Implementation of DeLong's Algorithm for Comparing the Areas Under Correlated Receiver Operating Characteristic Curves". *IEEE Signal Processing Letters*, **21**, 1389–1393. DOI: doi: [10.1109/LSP.2014.2337313](https://doi.org/10.1109/LSP.2014.2337313).

### See Also

[roc](#), [roc.test](#)

**Examples**

```

data(aSAH)

#### One ROC curve ####

# Build a roc object:
rocobj <- roc(aSAH$outcome, aSAH$s100b)

# Determine power of one ROC curve:
power.roc.test(rocobj)
# Same as:
power.roc.test(ncases=41, ncontrols=72, auc=0.73, sig.level=0.05)
# sig.level=0.05 is implicit and can be omitted:
power.roc.test(ncases=41, ncontrols=72, auc=0.73)

# Determine ncases & ncontrols:
power.roc.test(auc=rocobj$auc, sig.level=0.05, power=0.95, kappa=1.7)
power.roc.test(auc=0.73, sig.level=0.05, power=0.95, kappa=1.7)

# Determine sig.level:
power.roc.test(ncases=41, ncontrols=72, auc=0.73, power=0.95, sig.level=NULL)

# Determine detectable AUC:
power.roc.test(ncases=41, ncontrols=72, sig.level=0.05, power=0.95)

#### Two ROC curves ####

### Full AUC
roc1 <- roc(aSAH$outcome, aSAH$ndka)
roc2 <- roc(aSAH$outcome, aSAH$wfns)

## Sample size
# With DeLong variance (default)
power.roc.test(roc1, roc2, power=0.9)
# With Obuchowski variance
power.roc.test(roc1, roc2, power=0.9, method="obuchowski")

## Power test
# With DeLong variance (default)
power.roc.test(roc1, roc2)
# With Obuchowski variance
power.roc.test(roc1, roc2, method="obuchowski")

## Significance level
# With DeLong variance (default)
power.roc.test(roc1, roc2, power=0.9, sig.level=NULL)
# With Obuchowski variance
power.roc.test(roc1, roc2, power=0.9, sig.level=NULL, method="obuchowski")

### Partial AUC
roc3 <- roc(aSAH$outcome, aSAH$ndka, partial.auc=c(1, 0.9))

```

```

roc4 <- roc(aSAH$outcome, aSAH$wfns, partial.auc=c(1, 0.9))

## Sample size
# With bootstrap variance (default)
## Not run:
power.roc.test(roc3, roc4, power=0.9)

## End(Not run)
# With Obuchowski variance
power.roc.test(roc3, roc4, power=0.9, method="obuchowski")

## Power test
# With bootstrap variance (default)
## Not run:
power.roc.test(roc3, roc4)
# This is exactly equivalent:
power.roc.test(roc1, roc2, reuse.auc=FALSE, partial.auc=c(1, 0.9))

## End(Not run)
# With Obuchowski variance
power.roc.test(roc3, roc4, method="obuchowski")

## Significance level
# With bootstrap variance (default)
## Not run:
power.roc.test(roc3, roc4, power=0.9, sig.level=NULL)

## End(Not run)
# With Obuchowski variance
power.roc.test(roc3, roc4, power=0.9, sig.level=NULL, method="obuchowski")

## With only binormal parameters given
# From example 2 of Obuchowski and McClish, 1997.
ob.params <- list(A1=2.6, B1=1, A2=1.9, B2=1, rn=0.6, ra=0.6, FPR11=0,
FPR12=0.2, FPR21=0, FPR22=0.2, delta=0.037)

power.roc.test(ob.params, power=0.8, sig.level=0.05)
power.roc.test(ob.params, power=0.8, sig.level=NULL, ncases=107)
power.roc.test(ob.params, power=NULL, sig.level=0.05, ncases=107)

```

---

print

---

*Print a ROC curve object*


---

### Description

This function prints a ROC curve, AUC or CI object and return it invisibly.

**Usage**

```
## S3 method for class 'roc'
print(x, digits=max(3, getOption("digits") - 3), call=TRUE, ...)
## S3 method for class 'multiclass.roc'
print(x, digits=max(3, getOption("digits") -
  3), call=TRUE, ...)
## S3 method for class 'mv.multiclass.roc'
print(x, digits=max(3, getOption("digits") -
  3), call=TRUE, ...)
## S3 method for class 'smooth.roc'
print(x, digits=max(3, getOption("digits") - 3),
call=TRUE, ...)
## S3 method for class 'auc'
print(x, digits=max(3, getOption("digits") - 3), ...)
## S3 method for class 'multiclass.auc'
print(x, digits=max(3, getOption("digits") - 3), ...)
## S3 method for class 'ci.auc'
print(x, digits=max(3, getOption("digits") - 3), ...)
## S3 method for class 'ci.thresholds'
print(x, digits=max(3, getOption("digits") - 3), ...)
## S3 method for class 'ci.se'
print(x, digits=max(3, getOption("digits") - 3), ...)
## S3 method for class 'ci.sp'
print(x, digits=max(3, getOption("digits") - 3), ...)
## S3 method for class 'ci.coords'
print(x, digits=max(3, getOption("digits") - 3), ...)
```

**Arguments**

x	a roc, auc or ci object, from the <a href="#">roc</a> , <a href="#">auc</a> or <a href="#">ci</a> functions respectively.
call	if the call is printed.
digits	the number of significant figures to print. See <a href="#">signif</a> for more details.
...	further arguments passed to or from other methods. In particular, <code>print.roc</code> calls <code>print.auc</code> and the <code>print.ci</code> variants internally, and a <code>digits</code> argument is propagated. Not used in <code>print.auc</code> and <code>print.ci</code> variants.

**Value**

These functions return the object they were passed invisibly.

**See Also**

[roc](#), [auc](#), [ci](#), [coords](#)

**Examples**

```
data(aSAH)
```

```

# Print a roc object:
rocobj <- roc(aSAH$outcome, aSAH$s100b)
print(rocobj)

# Print a smoothed roc object
print(smooth(rocobj))

# implicit printing
roc(aSAH$outcome, aSAH$s100b)

# Print an auc and a ci object, from the ROC object or calling
# the dedicated function:
print(rocobj$auc)
print(ci(rocobj))

```

roc

*Build a ROC curve***Description**

This is the main function of the pROC package. It builds a ROC curve and returns a “roc” object, a list of class “roc”. This object can be printed, plotted, or passed to the functions [auc](#), [ci](#), [smooth.roc](#) and [coords](#). Additionally, two roc objects can be compared with [roc.test](#).

**Usage**

```

roc(...)
## S3 method for class 'formula'
roc(formula, data, ...)
## S3 method for class 'data.frame'
roc(data, response, predictor,
ret = c("roc", "coords", "all_coords"), ...)
## Default S3 method:
roc(response, predictor, controls, cases,
density.controls, density.cases,
levels=base::levels(as.factor(response)), percent=FALSE, na.rm=TRUE,
direction=c("auto", "<", ">"), algorithm = 6, quiet = FALSE,
smooth=FALSE, auc=TRUE, ci=FALSE, plot=FALSE, smooth.method="binormal",
smooth.n=512, ci.method=NULL, density=NULL, ...)
roc_(data, response, predictor, ret = c("roc", "coords", "all_coords"), ...)

```

**Arguments**

response	a factor, numeric or character vector of responses (true class), typically encoded with 0 (controls) and 1 (cases). Only two classes can be used in a ROC curve. If the vector contains more than two unique values, or if their order could be ambiguous, use <code>levels</code> to specify which values must be used as control and case value. If the first argument was a <a href="#">data.frame</a> , response should be the name
----------	---

	of the column in data containing the response, quoted for <code>roc_</code> , and optionally quoted for <code>roc.data.frame</code> (non-standard evaluation or NSE).
<code>predictor</code>	a <code>numeric</code> or <code>ordered</code> vector of the same length than <code>response</code> , containing the predicted value of each observation. If the first argument was a <code>data.frame</code> , <code>predictor</code> should be the name of the column in data containing the predictor, quoted for <code>roc_</code> , and optionally quoted for <code>roc.data.frame</code> (non-standard evaluation or NSE).
<code>controls, cases</code>	instead of <code>response</code> , <code>predictor</code> , the data can be supplied as two <code>numeric</code> or <code>ordered</code> vectors containing the predictor values for control and case observations.
<code>density.controls, density.cases</code>	a smoothed ROC curve can be built directly from two densities on identical x points, as in <code>smooth</code> .
<code>formula, data</code>	a formula of the type <code>response~predictor</code> . If multiple predictors are passed, a named list of roc objects will be returned. Additional arguments <code>data</code> and <code>subset</code> , but not <code>na.action</code> are supported, see <code>model.frame</code> for more details.
<code>levels</code>	the value of the response for controls and cases respectively. By default, the first two values of <code>levels(as.factor(response))</code> are taken, and the remaining levels are ignored. It usually captures two-class factor data correctly, but will frequently fail for other data types (response factor with more than 2 levels, or for example if your response is coded “controls” and “cases”, the levels will be inverted) and must then be specified here. If your data is coded as 0 and 1 with 0 being the controls, you can safely omit this argument.
<code>percent</code>	if the sensitivities, specificities and AUC must be given in percent (TRUE) or in fraction (FALSE, default).
<code>na.rm</code>	if TRUE, the NA values will be removed (ignored by <code>roc.formula</code> ).
<code>direction</code>	in which direction to make the comparison? “auto” (default): automatically define in which group the median is higher and take the direction accordingly. “>”: if the predictor values for the control group are higher than the values of the case group ( <code>controls &gt; t &gt;= cases</code> ). “<”: if the predictor values for the control group are lower or equal than the values of the case group ( <code>controls &lt; t &lt;= cases</code> ). You should set this explicitly to “>” or “<” whenever you are resampling or randomizing the data, otherwise the curves will be biased towards higher AUC values.
<code>algorithm</code>	the method used to compute sensitivity and specificity, an integer of length 1 between 0 and 6. 1: a safe, well-tested, pure-R code that is efficient when the number of thresholds is low. It goes with $O(T*N)$ . 2: an alternative pure-R algorithm that goes in $O(N)$ . Typically faster than 1 when the number of thresholds of the ROC curve is above 1000. Less tested than 1. 3: a C++ implementation of 1, about 3-5x faster. Typically the fastest with ROC curves with less than 50-100 thresholds, but has a very bad worst-case when that number increases. 4 (debug only, slow): runs algorithms 1 to 3 and makes sure they return the same values. 5: select 2 or 3 based on the number of thresholds. 6 (default): quickly select the algorithm on the class of the data: 2 for <code>numeric</code> and 3 for <code>ordered</code> . 0: use <b>microbenchmark</b> to choose between 2 and 3.

<code>ret</code>	for <code>roc.data.frame</code> only, whether to return the threshold sensitivity and specificity at all thresholds (“coords”), all the coordinates at all thresholds (“all_coords”) or the roc object (“roc”).
<code>quiet</code>	set to TRUE to turn off <code>messages</code> when <code>direction</code> and <code>levels</code> are auto-detected.
<code>smooth</code>	if TRUE, the ROC curve is passed to <code>smooth</code> to be smoothed.
<code>auc</code>	compute the area under the curve (AUC)? If TRUE (default), additional arguments can be passed to <code>auc</code> .
<code>ci</code>	compute the confidence interval (CI)? If set to TRUE, additional arguments can be passed to <code>ci</code> .
<code>plot</code>	plot the ROC curve? If TRUE, additional arguments can be passed to <code>plot.roc</code> .
<code>smooth.method</code> , <code>smooth.n</code> , <code>ci.method</code>	in <code>roc.formula</code> and <code>roc.default</code> , the <code>method</code> and <code>n</code> arguments to <code>smooth</code> (if <code>smooth=TRUE</code> ) and <code>of="auc"</code> ) must be passed as <code>smooth.method</code> , <code>smooth.n</code> and <code>ci.method</code> to avoid confusions.
<code>density</code>	density argument passed to <code>smooth</code> .
<code>...</code>	further arguments passed to or from other methods, and especially: <ul style="list-style-type: none"> <li>• <code>auc</code>: <code>partial.auc</code>, <code>partial.auc.focus</code>, <code>partial.auc.correct</code>.</li> <li>• <code>ci</code>: <code>of</code>, <code>conf.level</code>, <code>boot.n</code>, <code>boot.stratified</code>, <code>progress</code></li> <li>• <code>ci.auc</code>., <code>reuse.auc</code>, <code>method</code></li> <li>• <code>ci.thresholds</code>: <code>thresholds</code></li> <li>• <code>ci.se</code>: <code>sensitivities</code></li> <li>• <code>ci.sp</code>: <code>specificities</code></li> <li>• <code>plot.roc</code>: <code>add</code>, <code>col</code> and most other arguments to the <code>plot.roc</code> function. See <code>plot.roc</code> directly for more details.</li> <li>• <code>smooth</code>: <code>method</code>, <code>n</code>, and all other arguments. See <code>smooth</code> for more details.</li> </ul>

## Details

This function’s main job is to build a ROC object. See the “Value” section to this page for more details. Before returning, it will call (in this order) the `smooth`, `auc`, `ci` and `plot.roc` functions if `smooth` `auc`, `ci` and `plot.roc` (respectively) arguments are set to TRUE. By default, only `auc` is called.

Data can be provided as `response`, `predictor`, where the predictor is the numeric (or ordered) level of the evaluated signal, and the response encodes the observation class (control or case). The `level` argument specifies which response level must be taken as controls (first value of `level`) or cases (second). It can safely be ignored when the response is encoded as 0 and 1, but it will frequently fail otherwise. By default, the first two values of `levels(as.factor(response))` are taken, and the remaining levels are ignored. This means that if your response is coded “control” and “case”, the levels will be inverted.

In some cases, it is more convenient to pass the data as `controls`, `cases`, but both arguments are ignored if `response`, `predictor` was specified to non-NULL values. It is also possible to pass density data with `density.controls`, `density.cases`, which will result in a smoothed ROC curve even if `smooth=FALSE`, but are ignored if `response`, `predictor` or `controls`, `cases` are provided.

Specifications for `auc`, `ci` and `plot.roc` are not kept if `auc`, `ci` or `plot` are set to FALSE. Especially, in the following case:

```
myRoc <- roc(..., auc.polygon=TRUE, grid=TRUE, plot=FALSE)
plot(myRoc)
```

the plot will not have the AUC polygon nor the grid. Similarly, when comparing “roc” objects, the following is not possible:

```
roc1 <- roc(..., partial.auc=c(1, 0.8), auc=FALSE)
roc2 <- roc(..., partial.auc=c(1, 0.8), auc=FALSE)
roc.test(roc1, roc2)
```

This will produce a test on the full AUC, not the partial AUC. To make a comparison on the partial AUC, you must repeat the specifications when calling `roc.test`:

```
roc.test(roc1, roc2, partial.auc=c(1, 0.8))
```

Note that if `roc` was called with `auc=TRUE`, the latter syntax will not allow redefining the AUC specifications. You must use `reuse.auc=FALSE` for that.

## Value

If the data contained any NA value and `na.rm=FALSE`, NA is returned. Otherwise, if `smooth=FALSE`, a list of class “roc” with the following fields:

<code>auc</code>	if called with <code>auc=TRUE</code> , a numeric of class “auc” as defined in <a href="#">auc</a> .
<code>ci</code>	if called with <code>ci=TRUE</code> , a numeric of class “ci” as defined in <a href="#">ci</a> .
<code>response</code>	the response vector. Patients whose response is not <code>%in%</code> levels are discarded. If NA values were removed, a <code>na.action</code> attribute similar to <a href="#">na.omit</a> stores the row numbers.
<code>predictor</code>	the predictor vector converted to numeric as used to build the ROC curve. Patients whose response is not <code>%in%</code> levels are discarded. If NA values were removed, a <code>na.action</code> attribute similar to <a href="#">na.omit</a> stores the row numbers.
<code>original.predictor</code> , <code>original.response</code>	the response and predictor vectors as passed in argument.
<code>levels</code>	the levels of the response as defined in argument.
<code>controls</code>	the predictor values for the control observations.
<code>cases</code>	the predictor values for the cases.
<code>percent</code>	if the sensitivities, specificities and AUC are reported in percent, as defined in argument.
<code>direction</code>	the direction of the comparison, as defined in argument.
<code>fun.sesp</code>	the function used to compute sensitivities and specificities. Will be re-used in bootstrap operations.
<code>sensitivities</code>	the sensitivities defining the ROC curve.



**specificities** the specificities defining the ROC curve.  
**thresholds** the thresholds at which the sensitivities and specificities were computed. See below for details.  
**call** how the function was called. See [match.call](#) for more details.

If `smooth=TRUE` a list of class “smooth.roc” as returned by [smooth](#), with or without additional elements `auc` and `ci` (according to the call).

### Thresholds

Thresholds are selected as the means between any two consecutive values observed in the data. This choice is aimed to facilitate their interpretation, as any data point will be unambiguously positive or negative regardless of whether the comparison operator includes equality or not.

In rare cases it might not be possible to represent the mean between two consecutive values, or one might want to use a custom threshold. In those cases, the semantic of the comparison is as follows: with `direction = '>'`, observations are positive when they are smaller than or equal (`<=`) to the threshold. With `direction = '<'`, observations are positive when they are greater than or equal (`>=`) to the threshold.

As a corollary, thresholds do not correspond to actual values in the data.

### Experimental: pipelines

Since version 1.15.0, the `roc` function can be used in pipelines, for instance with **dplyr** or **magrittr**. This is still a highly experimental feature and will change significantly in future versions (see [issue 54](#)). The `roc.data.frame` method supports both standard and non-standard evaluation (NSE):

```
library(dplyr)
# Standard evaluation:
aSAH %>%
  filter(gender == "Female") %>%
  roc("outcome", "s100b")
# Non-Standard Evaluation:
aSAH %>%
  filter(gender == "Female") %>%
  roc(outcome, s100b)
```

For tasks involving programming and variable column names, the `roc_` function provides standard evaluation:

```
# Standard evaluation:
aSAH %>%
  filter(gender == "Female") %>%
  roc_("outcome", "s100b")
```

By default it returns the `roc` object, which can then be piped to the `coords` function to extract coordinates that can be used in further pipelines.

```

# Returns thresholds, sensitivities and specificities:
aSAH %>%
  roc(outcome, s100b) %>%
  coords(transpose = FALSE) %>%
  filter(sensitivity > 0.6,
         specificity > 0.6)

# Returns all existing coordinates, then select precision and recall:
aSAH %>%
  roc(outcome, s100b) %>%
  coords(ret = "all", transpose = FALSE) %>%
  select(precision, recall)

```

## Errors

If no control or case observation exist for the given levels of response, no ROC curve can be built and an error is triggered with message “No control observation” or “No case observation”.

If the predictor is not a numeric or ordered, as defined by `as.numeric` or `as.ordered`, the message “Predictor must be numeric or ordered” is returned.

The message “No valid data provided” is issued when the data wasn’t properly passed. Remember you need both response and predictor of the same (not null) length, or both controls and cases. Combinations such as predictor and cases are not valid and will trigger this error.

Infinite values of the predictor cannot always be thresholded by infinity and can cause ROC curves to not reach 0 or 100% specificity or sensitivity. Since version 1.13.0, pROC returns NaN with a warning message “Infinite value(s) in predictor” if predictor contains any `infinite` values.

## References

Tom Fawcett (2006) “An introduction to ROC analysis”. *Pattern Recognition Letters* **27**, 861–874. DOI: doi: [10.1016/j.patrec.2005.10.010](https://doi.org/10.1016/j.patrec.2005.10.010).

Xavier Robin, Natacha Turck, Alexandre Hainard, *et al.* (2011) “pROC: an open-source package for R and S+ to analyze and compare ROC curves”. *BMC Bioinformatics*, **7**, 77. DOI: doi: [10.1186/147121051277](https://doi.org/10.1186/147121051277).

## See Also

[auc](#), [ci](#), [plot.roc](#), [print.roc](#), [roc.test](#)

## Examples

```

data(aSAH)

# Basic example
roc(aSAH$outcome, aSAH$s100b,
    levels=c("Good", "Poor"))
# As levels aSAH$outcome == c("Good", "Poor"),
# this is equivalent to:
roc(aSAH$outcome, aSAH$s100b)

```

```
# In some cases, ignoring levels could lead to unexpected results
# Equivalent syntaxes:
roc(outcome ~ s100b, aSAH)
roc(aSAH$outcome ~ aSAH$s100b)
with(aSAH, roc(outcome, s100b))
with(aSAH, roc(outcome ~ s100b))

# With a formula:
roc(outcome ~ s100b, data=aSAH)

## Not run:
library(dplyr)
aSAH %>%
  filter(gender == "Female") %>%
  roc(outcome, s100b)

## End(Not run)

# Using subset (only with formula)
roc(outcome ~ s100b, data=aSAH, subset=(gender == "Male"))
roc(outcome ~ s100b, data=aSAH, subset=(gender == "Female"))

# With numeric controls/cases
roc(controls=aSAH$s100b[aSAH$outcome=="Good"], cases=aSAH$s100b[aSAH$outcome=="Poor"])
# With ordered controls/cases
roc(controls=aSAH$wfns[aSAH$outcome=="Good"], cases=aSAH$wfns[aSAH$outcome=="Poor"])

# Inverted the levels: "Poor" are now controls and "Good" cases:
roc(aSAH$outcome, aSAH$s100b,
    levels=c("Poor", "Good"))

# The result was exactly the same because of direction="auto".
# The following will give an AUC < 0.5:
roc(aSAH$outcome, aSAH$s100b,
    levels=c("Poor", "Good"), direction="<")

# If we are sure about levels and direction auto-detection,
# we can turn off the messages:
roc(aSAH$outcome, aSAH$s100b, quiet = TRUE)

# If we prefer counting in percent:
roc(aSAH$outcome, aSAH$s100b, percent=TRUE)

# Plot and CI (see plot.roc and ci for more options):
roc(aSAH$outcome, aSAH$s100b,
    percent=TRUE, plot=TRUE, ci=TRUE)

# Smoothed ROC curve
roc(aSAH$outcome, aSAH$s100b, smooth=TRUE)
# this is not identical to
smooth(roc(aSAH$outcome, aSAH$s100b))
# because in the latter case, the returned object contains no AUC
```

roc.test

*Compare two ROC curves***Description**

This function compares two correlated (or paired) or uncorrelated (unpaired) ROC curves. Delong and bootstrap methods test for a difference in the (partial) AUC of the ROC curves. The Venkatraman method tests if the two curves are perfectly superposed. The sensitivity and specificity methods test if the sensitivity (respectively specificity) of the ROC curves are different at the given level of specificity (respectively sensitivity). Several syntaxes are available: two object of class roc (which can be AUC or smoothed ROC), or either three vectors (response, predictor1, predictor2) or a response vector and a matrix or data.frame with two columns (predictors).

**Usage**

```
# roc.test(...)
## S3 method for class 'roc'
roc.test(roc1, roc2, method=c("delong", "bootstrap",
"venkatraman", "sensitivity", "specificity"), sensitivity = NULL,
specificity = NULL, alternative = c("two.sided", "less", "greater"),
paired=NULL, reuse.auc=TRUE, boot.n=2000, boot.stratified=TRUE,
ties.method="first", progress=getOption("pROCProgress")$name,
parallel=FALSE, conf.level=0.95, ...)
## S3 method for class 'auc'
roc.test(roc1, roc2, ...)
## S3 method for class 'smooth.roc'
roc.test(roc1, roc2, ...)
## S3 method for class 'formula'
roc.test(formula, data, ...)
## Default S3 method:
roc.test(response, predictor1, predictor2=NULL,
na.rm=TRUE, method=NULL, ...)
```

**Arguments**

roc1, roc2	the two ROC curves to compare. Either “roc”, “auc” or “smooth.roc” objects (types can be mixed).
response	a vector or factor, as for the roc function.
predictor1	a numeric or ordered vector as for the roc function, or a matrix or data.frame with predictors two colums.
predictor2	only if predictor1 was a vector, the second predictor as a numeric vector.
formula	a formula of the type response~predictor1+predictor2. Additional arguments data, subset and na.action are supported, see <a href="#">model.frame</a> for more details.
data	a matrix or data.frame containing the variables in the formula. See <a href="#">model.frame</a> for more details.

na.rm	if TRUE, the observations with NA values will be removed.
method	the method to use, either “delong”, “bootstrap” or “venkatraman”. The first letter is sufficient. If omitted, the appropriate method is selected as explained in details.
sensitivity, specificity	if method=“sensitivity” or method=“specificity”, the respective level where the test must be assessed as a numeric of length 1.
alternative	specifies the alternative hypothesis. Either of “two.sided”, “less” or “greater”. The first letter is sufficient. Default: “two.sided”. Only “two.sided” is available with method=“venkatraman”.
paired	a logical indicating whether you want a paired roc.test. If NULL, the paired status will be auto-detected by <a href="#">are.paired</a> . If TRUE but the paired status cannot be assessed by <a href="#">are.paired</a> will produce an error.
reuse.auc	if TRUE (default) and the “roc” objects contain an “auc” field, re-use these specifications for the test. See the <i>AUC specification</i> section for more details.
boot.n	for method=“bootstrap” and method=“venkatraman” only: the number of bootstrap replicates or permutations. Default: 2000.
boot.stratified	for method=“bootstrap” only: should the bootstrap be stratified (same number of cases/controls in each replicate than in the original sample) or not. Ignored with method=“venkatraman”. Default: TRUE.
ties.method	for method=“venkatraman” only: argument for <a href="#">rank</a> specifying how ties are handled. Defaults to “first” as described in the paper.
progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <a href="#">create_progress_bar</a> for more information), but a list as returned by <a href="#">create_progress_bar</a> is also accepted. See also the “Progress bars” section of <a href="#">this package’s documentation</a> .
parallel	if TRUE, the bootstrap is processed in parallel, using parallel backend provided by <a href="#">plyr</a> (foreach).
conf.level	a numeric scalar between 0 and 1 (non-inclusive) which species the confidence level to use for any calculated CI’s.
...	further arguments passed to or from other methods, especially arguments for <a href="#">roc</a> and <a href="#">roc.test.roc</a> when calling <a href="#">roc.test.default</a> or <a href="#">roc.test.formula</a> . Arguments for <a href="#">auc</a> , and <a href="#">txtProgressBar</a> (only char and style) if applicable.

## Details

This function compares two ROC curves. It is typically called with the two [roc](#) objects to compare. [roc.test.default](#) is provided as a convenience method and creates two [roc](#) objects before calling [roc.test.roc](#).

Three methods are available: “delong”, “bootstrap” and “venkatraman” (see “Computational details” section below). “delong” and “bootstrap” are tests over the AUC whereas “venkatraman” compares the the ROC curves themselves.

Default is to use “delong” method except for comparison of partial AUC, smoothed curves and curves with different direction, where bootstrap is used. Using “delong” for partial AUC and

smoothed ROCs is not supported in pROC and result in an error. It is spurious to use “delong” for `roc` with different direction (a warning is issued but the spurious comparison is enforced). “venkatraman”’s test cannot be employed to compare smoothed ROC curves, or curves with partial AUC specifications. In addition, and comparison of ROC curves with different direction should be used with care (a warning is produced as well).

If `alternative="two.sided"`, a two-sided test for difference in AUC is performed. If `alternative="less"`, the alternative is that the AUC of `roc1` is smaller than the AUC of `roc2`. For `method="venkatraman"`, only “two.sided” test is available.

If the `paired` argument is not provided, the `are.paired` function is employed to detect the paired status of the ROC curves. It will test if the original response is identical between the two ROC curves (this is always the case if the call is made with `roc.test.default`). This detection is unlikely to raise false positives, but this possibility cannot be excluded entirely. It would require equal sample sizes and response values and order in both ROC curves. If it happens to you, use `paired=FALSE`. If you know the ROC curves are paired you can pass `paired=TRUE`. However this is useless as it will be tested anyway.

For [smoothed ROC curves](#), smoothing is performed again at each bootstrap replicate with the parameters originally provided. If a density smoothing was performed with `user-provided density.cases` or `density.controls` the bootstrap cannot be performed and an error is issued.

## Value

A list of class "htest" with following content:

<code>p.value</code>	the p-value of the test.
<code>statistic</code>	the value of the Z ( <code>method="deLong"</code> ) or D ( <code>method="bootstrap"</code> ) statistics.
<code>conf.int</code>	the confidence interval of the test (currently only returned for the paired DeLong’s test). Has an attribute <code>conf.level</code> specifying the level of the test.
<code>alternative</code>	the alternative hypothesis.
<code>method</code>	the character string “DeLong’s test for two correlated ROC curves” (if <code>method="deLong"</code> ) or “Bootstrap test for two correlated ROC curves” (if <code>method="bootstrap"</code> ).
<code>null.value</code>	the expected value of the statistic under the null hypothesis, that is 0.
<code>estimate</code>	the AUC in the two ROC curves.
<code>data.name</code>	the names of the data that was used.
<code>parameter</code>	for <code>method="bootstrap"</code> only: the values of the <code>boot.n</code> and <code>boot.stratified</code> arguments.

## AUC specification

The comparison of the AUC of the ROC curves needs a specification of the AUC. The specification is defined by:

1. the “auc” field in the “roc” objects if `reuse.auc` is set to TRUE (default)
2. passing the specification to `auc` with `...(arguments partial.auc, partial.auc.correct and partial.auc.focus)`. In this case, you must ensure either that the `roc` object do not contain an `auc` field (if you called `roc` with `auc=FALSE`), or set `reuse.auc=FALSE`.

If `reuse.auc=FALSE` the `auc` function will always be called with `...` to determine the specification, even if the “roc” objects do contain an `auc` field.

As well if the “roc” objects do not contain an `auc` field, the `auc` function will always be called with `...` to determine the specification.

The AUC specification is ignored in the Venkatraman test.

Warning: if the roc object passed to `roc.test` contains an `auc` field and `reuse.auc=TRUE`, `auc` is not called and arguments such as `partial.auc` are silently ignored.

### Computation details

With `method="bootstrap"`, the processing is done as follow:

1. `boot.n` bootstrap replicates are drawn from the data. If `boot.stratified` is `TRUE`, each replicate contains exactly the same number of controls and cases than the original sample, otherwise if `FALSE` the numbers can vary.
2. for each bootstrap replicate, the AUC of the two ROC curves are computed and the difference is stored.
3. The following formula is used:

$$D = \frac{AUC1 - AUC2}{s}$$

where `s` is the standard deviation of the bootstrap differences and `AUC1` and `AUC2` the AUC of the two (original) ROC curves.

4. `D` is then compared to the normal distribution, according to the value of `alternative`.

See also the Bootstrap section in [this package's documentation](#).

With `method="deLong"`, the processing is done as described in DeLong *et al.* (1988) for paired ROC curves, using the algorithm of Sun and Xu (2014). Only comparison of two ROC curves is implemented. The method has been extended for unpaired ROC curves where the p-value is computed with an unpaired t-test with unequal sample size and unequal variance, with

$$D = \frac{V^r(\theta^r) - V^s(\theta^s)}{\sqrt{S^r + S^s}}$$

With `method="venkatraman"`, the processing is done as described in Venkatraman and Begg (1996) (for paired ROC curves) and Venkatraman (2000) (for unpaired ROC curves) with `boot.n` permutation of sample ranks (with ties breaking). For consistency reasons, the same argument `boot.n` as in `bootstrap` defines the number of permutations to execute, even though no bootstrap is performed.

For `method="specificity"`, the test assesses if the sensitivity of the ROC curves are different at the level of specificity given by the `specificity` argument, which must be a numeric of length 1. Bootstrap is employed as with `method="bootstrap"` and `boot.n` and `boot.stratified` are available. This is identical to the test proposed by Pepe *et al.* (2009). The `method="sensitivity"` is very similar, but assesses if the specificity of the ROC curves are different at the level of sensitivity given by the `sensitivity` argument.

## Warnings

If “auc” specifications are different in both roc objects, the warning “Different AUC specifications in the ROC curves. Enforcing the inconsistency, but unexpected results may be produced.” is issued. Unexpected results may be produced.

If one or both ROC curves are “smooth.roc” objects with different smoothing specifications, the warning “Different smoothing parameters in the ROC curves. Enforcing the inconsistency, but unexpected results may be produced.” is issued. This warning can be benign, especially if ROC curves were generated with `roc(..., smooth=TRUE)` with different arguments to other functions (such as `plot`), or if you really want to compare two ROC curves smoothed differently.

If `method="venkatraman"`, and `alternative` is “less” or “greater”, the warning “Only two-sided tests are available for Venkatraman. Performing two-sided test instead.” is produced and a two tailed test is performed.

Both DeLong and Venkatraman’s test ignores the direction of the ROC curve so that if two ROC curves have a different `direction`, the warning “(DeLong|Venkatraman)’s test should not be applied to ROC curves with different directions.” is printed. However, the spurious test is enforced.

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, or that there are not enough points for smoothing, producing a NA area. The warning “NA value(s) produced during bootstrap were ignored.” will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

When both ROC curves have an `auc` of 1 (or 100%), their variances and covariance will always be null, and therefore the p-value will always be 1. This is true for both “delong”, “bootstrap” and “venkatraman” methods. This result is misleading, as the variances and covariance are of course not null. A `warning` will be displayed to inform of this condition, and of the misleading output.

## Errors

An error will also occur if you give a `predictor2` when `predictor1` is a `matrix` or a `data.frame`, if `predictor1` has more than two columns, or if you do not give a `predictor2` when `predictor1` is a vector.

If `density.cases` and `density.controls` were provided for smoothing, the error “Cannot compute the statistic on ROC curves smoothed with `density.controls` and `density.cases`.” is issued.

If `method="venkatraman"` and one of the ROC curves is smoothed, the error “Using Venkatraman’s test for smoothed ROCs is not supported.” is produced.

With `method="specificity"`, the error “Argument ‘specificity’ must be numeric of length 1 for a specificity test.” is given unless the `specificity` argument is specified as a numeric of length 1. The “Argument ‘sensitivity’ must be numeric of length 1 for a sensitivity test.” message is given for `method="sensitivity"` under similar conditions.

## Acknowledgements

We would like to thank E. S. Venkatraman and Colin B. Begg for their support in the implementation of their test.



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## See Also

[roc](#), [power.roc.test](#)

CRAN package **plyr**, employed in this function.

## Examples

```
data(aSAH)

# Basic example with 2 roc objects
roc1 <- roc(aSAH$outcome, aSAH$s100b)
roc2 <- roc(aSAH$outcome, aSAH$wfns)
roc.test(roc1, roc2)

## Not run:
# The latter used Delong's test. To use bootstrap test:
roc.test(roc1, roc2, method="bootstrap")
# Increase boot.n for a more precise p-value:
roc.test(roc1, roc2, method="bootstrap", boot.n=10000)

## End(Not run)
```

```

# Alternative syntaxes
roc.test(aSAH$outcome, aSAH$s100b, aSAH$wfns)
roc.test(aSAH$outcome, data.frame(aSAH$s100b, aSAH$wfns))

# If we had a good a priori reason to think that wfns gives a
# better classification than s100b (in other words, AUC of roc1
# should be lower than AUC of roc2):
roc.test(roc1, roc2, alternative="less")

## Not run:
# Comparison can be done on smoothed ROCs
# Smoothing is re-done at each iteration, and execution is slow
roc.test(smooth(roc1), smooth(roc2))
# or:
roc.test(aSAH$outcome, aSAH$s100b, aSAH$wfns, smooth=TRUE, boot.n=100)

## End(Not run)
# or from an AUC (no smoothing)
roc.test(auc(roc1), roc2)

## Not run:
# Comparison of partial AUC:
roc3 <- roc(aSAH$outcome, aSAH$s100b, partial.auc=c(1, 0.8), partial.auc.focus="se")
roc4 <- roc(aSAH$outcome, aSAH$wfns, partial.auc=c(1, 0.8), partial.auc.focus="se")
roc.test(roc3, roc4)
# This is strictly equivalent to:
roc.test(roc3, roc4, method="bootstrap")

# Alternatively, we could re-use roc1 and roc2 to get the same result:
roc.test(roc1, roc2, reuse.auc=FALSE, partial.auc=c(1, 0.8), partial.auc.focus="se")

# Comparison on specificity and sensitivity
roc.test(roc1, roc2, method="specificity", specificity=0.9)
roc.test(roc1, roc2, method="sensitivity", sensitivity=0.9)

## End(Not run)

# Spurious use of DeLong's test with different direction:
roc5 <- roc(aSAH$outcome, aSAH$s100b, direction="<")
roc6 <- roc(aSAH$outcome, aSAH$s100b, direction=">")
roc.test(roc5, roc6, method="delong")

## Not run:
# Comparisons of the ROC curves
roc.test(roc1, roc2, method="venkatraman")

## End(Not run)

# Unpaired tests
roc7 <- roc(aSAH$outcome, aSAH$s100b)
# artificially create an roc8 unpaired with roc7
roc8 <- roc(aSAH$outcome[1:100], aSAH$s100b[1:100])
## Not run:

```

```

roc.test(roc7, roc8, paired=FALSE, method="delong")
roc.test(roc7, roc8, paired=FALSE, method="bootstrap")
roc.test(roc7, roc8, paired=FALSE, method="venkatraman")
roc.test(roc7, roc8, paired=FALSE, method="specificity", specificity=0.9)

## End(Not run)

```

---

smooth

*Smooth a ROC curve*


---

## Description

This function smoothes a ROC curve of numeric predictor. By default, a binormal smoothing is performed, but density or custom smoothings are supported.

## Usage

```

smooth(...)
## Default S3 method:
smooth(...)
## S3 method for class 'roc'
smooth(roc,
method=c("binormal", "density", "fitdistr", "logcondens",
"logcondens.smooth"), n=512, bw = "nrd0", density=NULL,
density.controls=density, density.cases=density,
start=NULL, start.controls=start, start.cases=start,
reuse.auc=TRUE, reuse.ci=FALSE, ...)
## S3 method for class 'smooth.roc'
smooth(smooth.roc, ...)

```

## Arguments

roc, smooth.roc	a “roc” object from the <a href="#">roc</a> function, or a “smooth.roc” object from the <a href="#">smooth</a> function.
method	“binormal”, “density”, “fitdistr”, “logcondens”, “logcondens.smooth”.
n	the number of equally spaced points where the smoothed curve will be calculated.
bw	if method=“density” and density.controls and density.cases are not provided, bw is passed to <a href="#">density</a> to determine the bandwidth of the density Can be a character string (“nrd0”, “nrd”, “ucv”, “bcv” or “SJ”, but any name <a href="#">matching</a> a function prefixed with “bw.” is supported) or a numeric value, as described in <a href="#">density</a> . Defaults to “nrd0”.
density, density.controls, density.cases	if method=“density”, a numeric value of density (over the y axis) or a function returning a density (such as <a href="#">density</a> . If method=“fitdistr”, a densfun argument for <a href="#">fitdistr</a> . If the value is different for control and case observations,

density.controls and density.cases can be employed instead, otherwise density will be propagated to both density.controls and density.cases.

start, start.controls, start.cases  
 if method="fitdistr", optional start arguments for . start.controls and start.cases allows to specify different distributions for controls and cases.

reuse.auc, reuse.ci  
 if TRUE (default for reuse.auc) and the "roc" objects contain "auc" or "ci" fields, re-use these specifications to regenerate auc or ci on the smoothed ROC curve with the original parameters. If FALSE, the object returned will not contain "auc" or "ci" fields. It is currently not possible to redefine auc and ci options directly: you need to call auc or ci later for that.

... further arguments passed to or from other methods, and especially to density (only cut, adjust, and kernel, plus window for compatibility with S+) and fitdistr.

## Details

If method="binormal", a linear model is fitted to the quantiles of the sensitivities and specificities. Smoothed sensitivities and specificities are then generated from this model on n points. This simple approach was found to work well for most ROC curves, but it may produce hooked smooths in some situations (see in Hanley (1988)).

With method="density", the density function is employed to generate a smooth kernel density of the control and case observations as described by Zhou *et al.* (1997), unless density.controls or density.cases are provided directly. bw can be given to specify a bandwidth to use with density. It can be a numeric value or a character string ("nrd0", "nrd", "ucv", "bcv" or "SJ", but any name matching a function prefixed with "bw." is supported). In the case of a character string, the whole predictor data is employed to determine the numeric value to use on both controls and cases. Depending on your data, it might be a good idea to specify the kernel argument for density. By default, "gaussian" is used, but "epanechnikov", "rectangular", "triangular", "biweight", "cosine" and "optcosine" are supported. As all the kernels are symmetrical, it might help to normalize the data first (that is, before calling roc), for example with quantile normalization:

```
norm.x <- qnorm(rank(x)/(length(x)+1))
smooth(roc(response, norm.x, ...), ...)
```

Additionally, density can be a function which must return either a numeric vector of densities over the y axis or a list with a "y" item like the density function. It must accept the following input:

```
density.fun(x, n, from, to, bw, kernel, ...)
```

It is important to honour n, from and to in order to have the densities evaluated on the same points for controls and cases. Failing to do so and returning densities of different length will produce an error. It is also a good idea to use a constant smoothing parameter (such as bw) especially when controls and cases have a different number of observations, to avoid producing smoother or rougher densities.

If `method="fitdistr"`, the `fitdistr` function from the **MASS** package is employed to fit parameters for the density function `density` with optional start parameters `start`. The density function are fitted separately in control (`density.controls`, `start.controls`) and case observations (`density.cases`, `start.cases`). `density` can be one of the character values allowed by `fitdistr` or a density function (such as `dnorm`, `dweibull`, ...).

The `method="logcondens"` and `method="logcondens.smooth"` use the **logcondens** package to generate a non smoothed or smoothed (respectively) log-concave density estimate of the control and case observation with the `logConROC` function.

`smooth.default` forces the usage of the `smooth` function in the **stats** package, so that other code relying on `smooth` should continue to function normally.

Smoothed ROC curves can be passed to `smooth` again. In this case, the smoothing is not re-applied on the smoothed ROC curve but the original "roc" object will be re-used.

Note that a `smooth.roc` curve has no threshold.

## Value

A list of class "smooth.roc" with the following fields:

<code>sensitivities</code>	the smoothed sensitivities defining the ROC curve.
<code>specificities</code>	the smoothed specificities defining the ROC curve.
<code>percent</code>	if the sensitivities, specificities and AUC are reported in percent, as defined in argument.
<code>direction</code>	the direction of the comparison, as defined in argument.
<code>call</code>	how the function was called. See <code>match.call</code> for more details.
<code>smoothing.args</code>	a list of the arguments used for the smoothing. Will serve to apply the smoothing again in further bootstrap operations.
<code>auc</code>	if the original ROC curve contained an AUC, it is computed again on the smoothed ROC.
<code>ci</code>	if the original ROC curve contained a CI, it is computed again on the smoothed ROC.
<code>fit.controls</code> , <code>fit.cases</code>	with <code>method="fitdistr"</code> only: the result of <b>MASS</b> 's <code>fitdistr</code> function for controls and cases, with an additional "densfun" item indicating the density function, if possible as character.
<code>logcondens</code>	with <code>method="logcondens"</code> and <code>method="logcondens.smooth"</code> only: the result of <b>logcondens</b> 's <code>logConROC</code> function.
<code>model</code>	with <code>method="binormal"</code> only: the linear model from <code>lm</code> used to smooth the ROC curve.

**Attributes:** Additionally, the original `roc` object is stored as a "roc" attribute.

## Errors

The message “The ‘density’ function must return a numeric vector or a list with a ‘y’ item.” will be displayed if the density function did not return a valid output. The message “Length of ‘density.controls’ and ‘density.cases’ differ.” will be displayed if the returned value differ in length.

Binormal smoothing cannot smooth ROC curve defined by only one point. Any such attempt will fail with the error “ROC curve not smoothable (not enough points).”.

If the smooth ROC curve was generated by `roc` with `density.controls` and `density.cases` numeric arguments, it cannot be smoothed and the error “Cannot smooth a ROC curve generated directly with numeric ‘density.controls’ and ‘density.cases’.” is produced.

`fitdistr` and density smoothing methods require a `numeric` predictor. If the ROC curve to smooth was generated with an ordered factor only binormal smoothing can be applied and the message “ROC curves of ordered predictors can be smoothed only with binormal smoothing.” is displayed otherwise.

`fitdistr`, `logcondens` and `logcondens.smooth` methods require additional packages. If not available, the following message will be displayed with the required command to install the package: “Package ? not available, required with method=?”. Please install it with ‘install.packages(“?”)’.”

## References

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## See Also

[roc](#)

CRAN packages **MASS** and **logcondens** employed in this function.

## Examples

```
data(aSAH)
```

```
## Basic example
```

```

rocobj <- roc(aSAH$outcome, aSAH$s100b)
smooth(rocobj)
# or directly with roc()
roc(aSAH$outcome, aSAH$s100b, smooth=TRUE)

# plotting
plot(rocobj)
rs <- smooth(rocobj, method="binormal")
plot(rs, add=TRUE, col="green")
rs2 <- smooth(rocobj, method="density")
plot(rs2, add=TRUE, col="blue")
rs3 <- smooth(rocobj, method="fitdistr", density="lognormal")
plot(rs3, add=TRUE, col="magenta")
if (requireNamespace("logcondens")) {
rs4 <- smooth(rocobj, method="logcondens")
plot(rs4, add=TRUE, col="brown")
rs5 <- smooth(rocobj, method="logcondens.smooth")
plot(rs5, add=TRUE, col="orange")
}
legend("bottomright", legend=c("Empirical", "Binormal", "Density", "Log-normal",
                               "Log-concave density", "Smoothed log-concave density"),
       col=c("black", "green", "blue", "magenta", "brown", "orange"), lwd=2)

## Advanced smoothing

# if we know the distributions are normal with sd=0.1 and an unknown mean:
smooth(rocobj, method="fitdistr", density=dnorm, start=list(mean=1), sd=.1)
# different distributions for controls and cases:
smooth(rocobj, method="fitdistr", density.controls="normal", density.cases="lognormal")

# with densities
bw <- bw.nrd0(rocobj$predictor)
density.controls <- density(rocobj$controls, from=min(rocobj$predictor) - 3 * bw,
                           to=max(rocobj$predictor) + 3*bw, bw=bw, kernel="gaussian")
density.cases <- density(rocobj$cases, from=min(rocobj$predictor) - 3 * bw,
                        to=max(rocobj$predictor) + 3*bw, bw=bw, kernel="gaussian")
smooth(rocobj, method="density", density.controls=density.controls$y,
       density.cases=density.cases$y)
# which is roughly what is done by a simple:
smooth(rocobj, method="density")

## Not run:
## Smoothing artificial ROC curves

rand.unif <- runif(1000, -1, 1)
rand.exp <- rexp(1000)
rand.norm <-
rnorm(1000)

# two normals
roc.norm <- roc(controls=rnorm(1000), cases=rnorm(1000)+1, plot=TRUE)
plot(smooth(roc.norm), col="green", lwd=1, add=TRUE)
plot(smooth(roc.norm, method="density"), col="red", lwd=1, add=TRUE)

```

```

plot(smooth(roc.norm, method="fitdistr"), col="blue", lwd=1, add=TRUE)
if (requireNamespace("logcondens")) {
plot(smooth(roc.norm, method="logcondens"), col="brown", lwd=1, add=TRUE)
plot(smooth(roc.norm, method="logcondens.smooth"), col="orange", lwd=1, add=TRUE)
}
legend("bottomright", legend=c("empirical", "binormal", "density", "fitdistr",
                              "logcondens", "logcondens.smooth"),
      col=c(par("fg"), "green", "red", "blue", "brown", "orange"), lwd=c(2, 1, 1, 1))

# deviation from the normality
roc.norm.exp <- roc(controls=rnorm(1000), cases=rexp(1000), plot=TRUE)
plot(smooth(roc.norm.exp), col="green", lwd=1, add=TRUE)
plot(smooth(roc.norm.exp, method="density"), col="red", lwd=1, add=TRUE)
# Wrong fitdistr: normality assumed by default
plot(smooth(roc.norm.exp, method="fitdistr"), col="blue", lwd=1, add=TRUE)
# Correct fitdistr
plot(smooth(roc.norm.exp, method="fitdistr", density.controls="normal",
           density.cases="exponential"), col="purple", lwd=1, add=TRUE)
if (requireNamespace("logcondens")) {
plot(smooth(roc.norm.exp, method="logcondens"), col="brown", lwd=1, add=TRUE)
plot(smooth(roc.norm.exp, method="logcondens.smooth"), col="orange", lwd=1, add=TRUE)
}
legend("bottomright", legend=c("empirical", "binormal", "density",
                              "wrong fitdistr", "correct fitdistr",
                              "logcondens", "logcondens.smooth"),
      col=c(par("fg"), "green", "red", "blue", "purple", "brown", "orange"), lwd=c(2, 1, 1, 1, 1, 1))

# large deviation from the normality
roc.unif.exp <- roc(controls=runif(1000, 2, 3), cases=rexp(1000)+2, plot=TRUE)
plot(smooth(roc.unif.exp), col="green", lwd=1, add=TRUE)
plot(smooth(roc.unif.exp, method="density"), col="red", lwd=1, add=TRUE)
plot(smooth(roc.unif.exp, method="density", bw="ucv"), col="magenta", lwd=1, add=TRUE)
# Wrong fitdistr: normality assumed by default (uniform distributions not handled)
plot(smooth(roc.unif.exp, method="fitdistr"), col="blue", lwd=1, add=TRUE)
if (requireNamespace("logcondens")) {
plot(smooth(roc.unif.exp, method="logcondens"), col="brown", lwd=1, add=TRUE)
plot(smooth(roc.unif.exp, method="logcondens.smooth"), col="orange", lwd=1, add=TRUE)
}
legend("bottomright", legend=c("empirical", "binormal", "density",
                              "density ucv", "wrong fitdistr",
                              "logcondens", "logcondens.smooth"),
      col=c(par("fg"), "green", "red", "magenta", "blue", "brown", "orange"), lwd=c(2, 1, 1, 1, 1, 1))

## End(Not run)

# 2 uniform distributions with a custom density function
unif.density <- function(x, n, from, to, bw, kernel, ...) {
  smooth.x <- seq(from=from, to=to, length.out=n)
  smooth.y <- dunif(smooth.x, min=min(x), max=max(x))
  return(smooth.y)
}
roc.unif <- roc(controls=runif(1000, -1, 1), cases=runif(1000, 0, 2), plot=TRUE)
s <- smooth(roc.unif, method="density", density=unif.density)

```



```

plot(roc.unif)
plot(s, add=TRUE, col="grey")

## Not run:
# you can bootstrap a ROC curve smoothed with a density function:
ci(s, boot.n=100)

## End(Not run)

```

---

<code>var.roc</code>	<i>Variance of a ROC curve</i>
----------------------	--------------------------------

---

## Description

These functions compute the variance of the AUC of a ROC curve.

## Usage

```

var(...)
## Default S3 method:
var(...)
## S3 method for class 'auc'
var(auc, ...)
## S3 method for class 'roc'
var(roc, method=c("delong", "bootstrap", "obuchowski"),
boot.n = 2000, boot.stratified = TRUE, reuse.auc=TRUE,
progress = getOption("pROCProgress")$name, parallel=FALSE, ...)
## S3 method for class 'smooth.roc'
var(smooth.roc, ...)

```

## Arguments

<code>roc, smooth.roc, auc</code>	a “roc” object from the <code>roc</code> function, a “smooth.roc” object from the <code>smooth</code> function or an “auc” object from the <code>auc</code> function.
<code>method</code>	the method to use, either “delong” or “bootstrap”. The first letter is sufficient. If omitted, the appropriate method is selected as explained in details.
<code>reuse.auc</code>	if TRUE (default) and the “roc” objects contain an “auc” field, re-use these specifications for the test. See details.
<code>boot.n</code>	for <code>method="bootstrap"</code> only: the number of bootstrap replicates or permutations. Default: <i>2000</i> .
<code>boot.stratified</code>	for <code>method="bootstrap"</code> only: should the bootstrap be stratified (same number of cases/controls in each replicate than in the original sample) or not. Default: <i>TRUE</i> .

progress	the name of progress bar to display. Typically “none”, “win”, “tk” or “text” (see the name argument to <code>create_progress_bar</code> for more information), but a list as returned by <code>create_progress_bar</code> is also accepted. See also the “Progress bars” section of <a href="#">this package’s documentation</a> .
parallel	if TRUE, the bootstrap is processed in parallel, using parallel backend provided by plyr (foreach).
...	further arguments passed to or from other methods, especially arguments for <code>var.roc</code> when calling <code>var</code> , <code>var.auc</code> and <code>var.smooth.roc</code> . Arguments for <code>auc</code> (if <code>reuse.auc=FALSE</code> ) and <code>txtProgressBar</code> (only <code>char</code> and <code>style</code> ) if applicable.

## Details

The `var` function computes the variance of the AUC of a ROC curve. It is typically called with the `roc` object of interest. Two methods are available: “delong” and “bootstrap” (see “Computational details” section below).

The default is to use “delong” method except for with partial AUC and smoothed curves where “bootstrap” is employed. Using “delong” for partial AUC and smoothed ROCs is not supported.

For [smoothed ROC curves](#), smoothing is performed again at each bootstrap replicate with the parameters originally provided. If a density smoothing was performed with user-provided `density.cases` or `density.controls` the bootstrap cannot be performed and an error is issued.

`var.default` forces the usage of the `var` function in the `stats` package, so that other code relying on `var` should continue to function normally.

## Value

The numeric value of the variance.

## AUC specification

`var` needs a specification of the AUC to compute the variance of the AUC of the ROC curve. The specification is defined by:

1. the “auc” field in the “roc” objects if `reuse.auc` is set to TRUE (default)
2. passing the specification to `auc` with ... (arguments `partial.auc`, `partial.auc.correct` and `partial.auc.focus`). In this case, you must ensure either that the `roc` object do not contain an `auc` field (if you called `roc` with `auc=FALSE`), or set `reuse.auc=FALSE`.

If `reuse.auc=FALSE` the `auc` function will always be called with ... to determine the specification, even if the “roc” objects do contain an `auc` field.

As well if the “roc” objects do not contain an `auc` field, the `auc` function will always be called with ... to determine the specification.

Warning: if the `roc` object passed to `roc.test` contains an `auc` field and `reuse.auc=TRUE`, `auc` is not called and arguments such as `partial.auc` are silently ignored.

### Computation details

With `method="bootstrap"`, the processing is done as follow:

1. `boot.n` bootstrap replicates are drawn from the data. If `boot.stratified` is *TRUE*, each replicate contains exactly the same number of controls and cases than the original sample, otherwise if *FALSE* the numbers can vary.
2. for each bootstrap replicate, the AUC of the ROC curve is computed and stored.
3. the variance of the resampled AUCs are computed and returned.

With `method="delong"`, the processing is done as described in Hanley and Hajian-Tilaki (1997) using the algorithm by Sun and Xu (2014).

With `method="obuchowski"`, the processing is done as described in Obuchowski and McClish (1997), Table 1 and Equation 4, p. 1530–1531. The computation of  $g$  for partial area under the ROC curve is modified as:

$$expr1 * (2 * pi * expr2)^{(-1)} * (-expr4) - A * B * expr1 * (2 * pi * expr2^3)^{(-1/2)} * expr3$$

### Binormality assumption

The “obuchowski” method makes the assumption that the data is binormal. If the data shows a deviation from this assumption, it might help to normalize the data first (that is, before calling `roc`), for example with quantile normalization:

```
norm.x <- qnorm(rank(x)/(length(x)+1))
var(roc(response, norm.x, ...), ...)
```

“delong” and “bootstrap” methods make no such assumption.

### Warnings

If `method="delong"` and the AUC specification specifies a partial AUC, the warning “Using DeLong for partial AUC is not supported. Using bootstrap test instead.” is issued. The method argument is ignored and “bootstrap” is used instead.

If `method="delong"` and the ROC curve is smoothed, the warning “Using DeLong for smoothed ROCs is not supported. Using bootstrap test instead.” is issued. The method argument is ignored and “bootstrap” is used instead.

If `boot.stratified=FALSE` and the sample has a large imbalance between cases and controls, it could happen that one or more of the replicates contains no case or control observation, or that there are not enough points for smoothing, producing a NA area. The warning “NA value(s) produced during bootstrap were ignored.” will be issued and the observation will be ignored. If you have a large imbalance in your sample, it could be safer to keep `boot.stratified=TRUE`.

When the ROC curve has an `auc` of 1 (or 100%), the variance will always be null. This is true for both “delong” and “bootstrap” methods that can not properly assess the variance in this case. This result is misleading, as the variance is of course not null. A `warning` will be displayed to inform of this condition, and of the misleading output.

## Errors

If `density.cases` and `density.controls` were provided for smoothing, the error “Cannot compute the covariance on ROC curves smoothed with `density.controls` and `density.cases`.” is issued.

## References

Elisabeth R. DeLong, David M. DeLong and Daniel L. Clarke-Pearson (1988) “Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach”. *Biometrics* **44**, 837–845.

James A. Hanley and Karim O. Hajian-Tilaki (1997) “Sampling variability of nonparametric estimates of the areas under receiver operating characteristic curves: An update”. *Academic Radiology* **4**, 49–58. DOI: doi: [10.1016/S10766332\(97\)801614](https://doi.org/10.1016/S10766332(97)801614).

Nancy A. Obuchowski, Donna K. McClish (1997). “Sample size determination for diagnostic accuracy studies involving binormal ROC curve indices”. *Statistics in Medicine*, **16**(13), 1529–1542. DOI: doi: [10.1002/\(SICI\)10970258\(19970715\)16:13<1529::AID-SIM565>3.0.CO;2H](https://doi.org/10.1002/(SICI)10970258(19970715)16:13<1529::AID-SIM565>3.0.CO;2H).

Xu Sun and Weichao Xu (2014) “Fast Implementation of DeLong’s Algorithm for Comparing the Areas Under Correlated Receiver Operating Characteristic Curves”. *IEEE Signal Processing Letters*, **21**, 1389–1393. DOI: doi: [10.1109/LSP.2014.2337313](https://doi.org/10.1109/LSP.2014.2337313).

Hadley Wickham (2011) “The Split-Apply-Combine Strategy for Data Analysis”. *Journal of Statistical Software*, **40**, 1–29. URL: doi: [10.18637/jss.v040.i01](https://doi.org/10.18637/jss.v040.i01).

## See Also

[roc](#), [cov.roc](#)

CRAN package `plyr`, employed in this function.

## Examples

```
data(aSAH)

## Basic example
roc1 <- roc(aSAH$outcome, aSAH$s100b)
roc2 <- roc(aSAH$outcome, aSAH$wfns)
var(roc1)
var(roc2)

# We could also write it in one line:
var(roc(aSAH$outcome, aSAH$s100b))

## Not run:
# The latter used DeLong. To use bootstrap:
var(roc1, method="bootstrap")
# Decrease boot.n for a faster execution
var(roc1,method="bootstrap", boot.n=1000)

## End(Not run)

# To use obuchowski:
var(roc1, method="obuchowski")
```

```
## Not run:
# Variance of smoothed ROCs:
# Smoothing is re-done at each iteration, and execution is slow
var(smooth(roc1))

## End(Not run)

# or from an AUC (no smoothing)
var(auc(roc1))

## Test data from Hanley and Hajian-Tilaki, 1997
disease.present <- c("Yes", "No", "Yes", "No", "No", "Yes", "Yes", "No",
                    "No", "Yes", "No", "No", "Yes", "No", "No")
field.strength.1 <- c(1, 2, 5, 1, 1, 1, 2, 1, 2, 2, 1, 1, 5, 1, 1)
field.strength.2 <- c(1, 1, 5, 1, 1, 1, 4, 1, 2, 2, 1, 1, 5, 1, 1)
roc3 <- roc(disease.present, field.strength.1)
roc4 <- roc(disease.present, field.strength.2)
# Assess the variance:
var(roc3)
var(roc4)

## Not run:
# With bootstrap:
var(roc3, method="bootstrap")
var(roc4, method="bootstrap")

## End(Not run)
```

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