Package ‘mosum’

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**Description**

Create bandwidths according to a default function of the sample size

**Usage**

```
bandwidths.default(n, d.min = 10, G.min = 10, G.max = min(n/2, n^(2/3)))
```

**Arguments**

- `n` integer representing the sample size
- `d.min` integer for the minimal mutual distance of change points that can be expected
- `G.min` integer for the minimal allowed bandwidth
- `G.max` integer for the maximal allowed bandwidth

**Details**

Returns an integer vector of bandwidths \((G_1, \ldots, G_m)\), with \(G_0 = G_1 = \max(G.\text{min}, 2/3*d.\text{min})\), \(G_{j+1} = G_{j-1} + G_j\) (for \(j = 1, \ldots, m-1\)) and \(m\) satisfying \(G_m \leq G.\text{max}\) while \(G_{m+1} > G.\text{max}\).

**Value**

an integer vector of bandwidths

**References**


Examples

bands <- bandwidths.default(1000, 10, 10, 200)

Description

Generate bootstrap confidence intervals for change points.

Usage

## S3 method for class 'mosum.cpts'
confint(object, parm = "cpts", level = 0.05, N_reps = 1000, ...)

Arguments

object
  an object of class mosum.cpts
parm
  specification of which parameters are to be given confidence intervals; parm = "cpts" is supported
level
  numeric value in (0, 1), such that the 100(1-level)% confidence bootstrap intervals are computed
N_reps
  number of bootstrap replications
...
  not in use

Details

See the referenced literature for further details

Value

S3 object of class cpts.ci, containing the following fields:

level, N_reps  input parameters
CI            data frame of five columns, containing the estimated change points (column cpts), the pointwise confidence intervals (columns pw.left and pw.right) and the uniform confidence intervals (columns unif.left and unif.right) for the corresponding change points

References


Examples

```r
x <- testData(lengths = rep(100, 3), means = c(0, 3, 1), sds = rep(1, 3), seed = 1337)$x
m <- mosum(x, G = 40)
ci <- confint(m, N_reps = 5000)
print(ci$CI)
```

---

**confint.multiscale.cpts**

*Confidence intervals for change points*

**Description**

Generate bootstrap confidence intervals for change points.

**Usage**

```r
## S3 method for class 'multiscale.cpts'
confint(object, parm = "cpts", level = 0.05, N_reps = 1000, ...)
```

**Arguments**

- `object`: an object of class `multiscale.cpts`
- `parm`: specification of which parameters are to be given confidence intervals; `parm = "cpts"` is supported
- `level`: numeric value in (0, 1), such that the $100(1\text{-level})\%$ confidence bootstrap intervals are computed
- `N_reps`: number of bootstrap replications
- `...`: not in use

**Details**

See the referenced literature for further details

**Value**

S3 object of class `cpts.ci`, containing the following fields:

- `level`, `N_reps`: input parameters
- `CI`: data frame of five columns, containing the estimated change points (column `cpts`), the pointwise confidence intervals (columns `pw.left` and `pw.right`) and the uniform confidence intervals (columns `unif.left` and `unif.right`) for the corresponding change points
mosum

References

Examples
x <- testData(lengths = rep(100, 3), means = c(0, 3, 1), sds = rep(1, 3), seed = 1337)$x
mlp <- multiscale.localPrune(x, G = c(8, 15, 30, 70))
CI <- confint(mlp, N_reps = 5000)
print(CI$CI)

mosum

MOSUM procedure for multiple change point estimation

Description
Computes the MOSUM detector, detects (multiple) change points and estimates their locations.

Usage
mosum(
  x,
  G,
  G.right = G,
  var.est.method = c("mosum", "mosum.min", "mosum.max", "custom")[1],
  var.custom = NULL,
  boundary.extension = TRUE,
  threshold = c("critical.value", "custom")[1],
  alpha = 0.1,
  threshold.custom = NULL,
  criterion = c("eta", "epsilon")[1],
  eta = 0.4,
  epsilon = 0.2,
  do.confint = FALSE,
  level = 0.05,
  N_reps = 1000
)

Arguments
x input data (a numeric vector or an object of classes ts and timeSeries)
G an integer value for the moving sum bandwidth; G should be less than length(n)/2. Alternatively, a number between 0 and 0.5 describing the moving sum bandwidth relative to length(x) can be given
mosum

G.right

if G.right != G, the asymmetric bandwidth (G,G.right) will be used; if max(G,G.right)/min(G,G.right) > 4, a warning message is generated

var.est.method

how the variance is estimated; possible values are

- "mosum" both-sided MOSUM variance estimator
- "mosum.min" minimum of the sample variance estimates from the left and right summation windows
- "mosum.max" maximum of the sample variance estimates from the left and right summation windows
- "custom" a vector of length(x) is to be parsed by the user; use var.custom in this case to do so

var.custom

a numeric vector (of the same length as x) containing local estimates of the variance or long run variance; use iff var.est.method = "custom"

boundary.extension

a logical value indicating whether the boundary values should be filled-up with CUSUM values

threshold

string indicating which threshold should be used to determine significance. By default, it is chosen from the asymptotic distribution at the given significance level alpha. Alternatively it is possible to parse a user-defined numerical value with threshold.custom

alpha

a numeric value for the significance level with 0 <= alpha <= 1; use iff threshold = "critical.value"

threshold.custom

a numeric value greater than 0 for the threshold of significance; use iff threshold = "custom"

criterion

string indicating how to determine whether each point k at which MOSUM statistic exceeds the threshold is a change point; possible values are

- "eta" there is no larger exceeding in an eta*G environment of k
- "epsilon" k is the maximum of its local exceeding environment, which has at least size epsilon*G

eta

a positive numeric value for the minimal mutual distance of changes, relative to moving sum bandwidth (iff criterion = "eta")

epsilon

a numeric value in (0,1] for the minimal size of exceeding environments, relative to moving sum bandwidth (iff criterion = "epsilon")

do.confint

flag indicating whether to compute the confidence intervals for change points

level

use iff do.confint = TRUE; a numeric value (0 <= level <= 1) with which 100(1-level)% confidence interval is generated

N_reps

use iff do.confint = TRUE; number of bootstrap replicates to be generated

Value

S3 object of class mosum.cpts, which contains the following fields:

x

input data

G.left, G.right

left and right summation bandwidths
\texttt{mosum.criticalValue}

\begin{flushleft}
\begin{verbatim}
var.est.method, var.custom, boundary.extension
    input parameters
stat
    a series of MOSUM statistic values; the first \texttt{G} and last \texttt{G.right} values are \texttt{NA}
    iff \texttt{boundary.extension = FALSE}
rollsums
    a series of MOSUM detector values; equals \texttt{stat*sqrt(var.estimation)}
var.estimation
    the local variance estimated according to \texttt{var.est.method}
threshold, alpha, threshold.custom
    input parameters
threshold.value
    threshold value of the corresponding MOSUM test
criterion, eta, epsilon
    input parameters
cpts
    a vector containing the estimated change point locations
cpts.info
    data frame containing information about change point estimators including detection bandwidths, asymptotic p-values for the corresponding MOSUM statistics and (scaled) size of jumps
do.confint
    input parameter
ci
    S3 object of class \texttt{cpts.ci} containing confidence intervals for change points iff \texttt{do.confint=TRUE}
\end{verbatim}
\end{flushleft}

\section*{References}


\section*{Examples}

\begin{verbatim}
x <- testData(lengths = rep(100, 3), means = c(0, 5, -2), sds = rep(1, 3), seed = 1234)$x
m <- mosum(x, G = 40)
plot(m)
summary(m)
\end{verbatim}

\begin{verbatim}
mosum.criticalValue
\end{verbatim}

\textit{MOSUM asymptotic critical value}

\section*{Description}

Computes the asymptotic critical value for the MOSUM test.
multiscale.bottomUp

Usage

mosum.criticalValue(n, G.left, G.right, alpha)

Arguments

n
an integer value for the length of the input data

G.left, G.right
integer values for the left and right moving sum bandwidth (G.left, G.right)

alpha
a numeric value for the significance level with 0 <= alpha <= 1

Value

a numeric value for the asymptotic critical value for the MOSUM test

Examples

x <- testData(lengths = rep(100, 3), means = c(0, 5, -2), sds = rep(1, 3), seed = 1234)$x
m <- mosum(x, G = 40)
par(mfrow = c(2, 1))
plot(m$stat, type = "l", xlab = "Time", ylab = "", main = "mosum")
abline(h = mosum.criticalValue(300, 40, 40, .1), col = 4)
abline(v = m$cpts, col = 2)
plot(m, display = "mosum") # identical plot is produced

multiscale.bottomUp

Multiscale MOSUM algorithm with bottom-up merging

Description

Multiscale MOSUM procedure with symmetric bandwidths combined with bottom-up bandwidth-

Usage

multiscale.bottomUp(
  x,
  G = bandwidths.default(length(x), G.min = max(20, ceiling(0.05 * length(x)))),
  threshold = c("critical.value", "custom")[1],
  alpha = 0.1,
  threshold.function = NULL,
  eta = 0.4,
  do.confint = FALSE,
  level = 0.05,
  N_reps = 1000,
  ...
)
Arguments

- **x**: input data (a numeric vector or an object of classes `ts` and `timeSeries`)
- **G**: a vector of (symmetric) bandwidths, given as either integers less than `length(x)/2`, or numbers between 0 and 0.5 describing the moving sum bandwidths relative to `length(x)`. If the smallest bandwidth is smaller than \(\min(20, 0.05 \times \text{length}(x))\) (0.05 if relative bandwidths are given) and `threshold = "critical.value"`, it generates a warning message.
- **threshold**: string indicating which threshold should be used to determine significance. By default, it is chosen from the asymptotic distribution at the given significance level `alpha`. Alternatively, it is possible to parse a user-defined function with `threshold.function`.
- **alpha**: a numeric value for the significance level with \(0 \leq \alpha \leq 1\); use iff `threshold = "critical.value"`
- **threshold.function**: function object of form `function(G, length(x), alpha)`, to compute a threshold of significance for different bandwidths `G`; use iff `threshold = "custom"`
- **eta**: see `mosum`
- **do.confint**: flag indicating whether to compute the confidence intervals for change points.
- **level**: use if `do.confint = TRUE`; a numeric value (0 <= level <= 1) with which 100(1-level)% confidence interval is generated
- **N_reps**: use if `do.confint = TRUE`; number of bootstrap replicates to be generated
- **...**: further arguments to be passed to the `mosum` calls

Details

See Algorithm 1 in the first referenced paper for a comprehensive description of the procedure and further details.

Value

S3 object of class `multiscale.cpts`, which contains the following fields:

- **x**: input data
- **cpts**: estimated change points
- **cpts.info**: data frame containing information about estimated change points
- **pooled.cpts**: set of change point candidates that have been considered by the algorithm
- **G**: bandwidths
- **threshold, alpha, threshold.function**: input parameters
- **eta**: input parameters
- **do.confint**: input parameter
- **ci**: object of class `cpts.ci` containing confidence intervals for change points iff `do.confint = TRUE`
References


Examples

```r
x1 <- testData(lengths = c(100, 200, 300, 300),
means = c(0, 1, 2, 2.7), sds = rep(1, 4), seed = 123)$x
mbu1 <- multiscale.bottomUp(x1)
plot(mbu1)
summary(mbu1)

x2 <- testData(model = "mix", seed = 1234)$x
threshold.custom <- function(G, n, alpha) {
  mosum.criticalValue(n, G, G, alpha) * log(n/G)^0.1
}
mbu2 <- multiscale.bottomUp(x2, G = 10:40, threshold = "custom",
threshold.function = threshold.custom)
plot(mbu2)
summary(mbu2)
```

multiscale.localPrune  
*Multiscale MOSUM algorithm with localised pruning*

Description

Multiscale MOSUM procedure with (possibly) assymmetric bandwidths and localised pruning based on Schwarz criterion.

Usage

```r
multiscale.localPrune(
  x,
  G = bandwidths.default(length(x)),
  max.unbalance = 4,
  threshold = c("critical.value", "custom")[1],
  alpha = 0.1,
  threshold.function = NULL,
  criterion = c("eta", "epsilon")[1],
  eta = 0.4,
  epsilon = 0.2,
  rule = c("pval", "jump")[1],
)```
multiscale.localPrune

penalty = c("log", "polynomial")[1],
pen.exp = 1.01,
do.confint = FALSE,
level = 0.05,
N_reps = 1000,
...
)

Arguments

x input data (a numeric vector or an object of classes ts and timeSeries)
G a vector of bandwidths, given as either integers less than length(x)/2, or numbers between 0 and 0.5 describing the moving sum bandwidths relative to length(x). Asymmetric bandwidths obtained as the Cartesian product of the set G with itself are used for change point analysis
max.unbalance a numeric value for the maximal ratio between maximal and minimal bandwidths to be used for candidate generation, 1 <= max.unbalance <= Inf
threshold string indicating which threshold should be used to determine significance. By default, it is chosen from the asymptotic distribution at the significance level alpha. Alternatively, it is possible to parse a user-defined function with threshold.function
alpha a numeric value for the significance level with 0 <= alpha <= 1. Use iff threshold = "critical.value"
threshold.function function object of form function(G_l,G_r,length(x),alpha), to compute a threshold of significance for different bandwidths (G_l,G_r); use iff threshold = "custom"
criterion how to determine whether an exceeding point is a change point; to be parsed to mosum
eta, epsilon see mosum
rule string for the choice of sorting criterion for change point candidates in merging step. Possible values are:
  • "pval"smallest p-value
  • "jump"largest (rescaled) jump size
penalty string specifying the type of penalty term to be used in Schwarz criterion; possible values are:
  • "log"use penalty = log(length(x))^{pen.exp}
  • "polynomial"use penalty = length(x)^{pen.exp}
pen.exp exponent for the penalty term (see penalty);
do.confint flag indicating whether confidence intervals for change points should be computed
level use iff do.confint = TRUE; a numeric value (0 <= level <= 1) with which 100(1-level)% confidence interval is generated
N_reps use iff do.confint = TRUE; number of bootstrap replicates to be generated
... further arguments to be parsed to mosum calls
Details

See Algorithm 2 in the first referenced paper for a comprehensive description of the procedure and further details.

Value

S3 object of class multiscale.cpts, which contains the following fields:

- **x**: input data
- **cpts**: estimated change points
- **cpts.info**: data frame containing information about estimated change points
- **sc**: Schwarz criterion values of the estimated change point set
- **pooled.cpts**: set of change point candidates that have been considered by the algorithm
- **G**: input parameter
  - threshold, alpha, threshold.function: input parameters
- **criterion, eta, epsilon**: input parameters
- **rule, penalty, pen.exp**: input parameters
- **do.confint**: input parameter
- **ci**: object of class cpts.ci containing confidence intervals for change points iff do.confint = TRUE

References


Examples

```r
x <- testData(model = "mix", seed = 123)$x
mlp <- multiscale.localPrune(x, G = c(8, 15, 30, 70), do.confint = TRUE)
print(mlp)
summary(mlp)
par(mfcol=c(2, 1), mar = c(2, 4, 2, 2))
plot(mlp, display = "data", shaded = "none")
plot(mlp, display = "significance", shaded = "CI", CI = "unif")
```
Description

3D Visualisation of multiscale MOSUM statistics.

Usage

```r
persp3D.multiscaleMosum(
  x,
  mosum.args = list(),
  threshold = c("critical.value", "custom")[1],
  alpha = 0.1,
  threshold.function = NULL,
  pal.name = "YlOrRd",
  expand = 0.2,
  theta = 120,
  phi = 20,
  xlab = "G",
  ylab = "time",
  zlab = "MOSUM",
  ticktype = "detailed",
  NAcol = "#800000FF",
  ...
)
```

Arguments

- **x**: a numeric input data vector
- **mosum.args**: a named list containing further arguments to be parsed to the respective `mosum` function calls, see `mosum`; the bandwidths are chosen by the function and should not be given as an argument in `mosum.args`
- **threshold**: string indicating which threshold should be used for normalisation of MOSUM statistics computed with different bandwidths. By default, it is chosen from the asymptotic distribution at the given significance level `alpha`. Alternatively it is possible to parse a user-defined numerical value with `threshold.custom`; see also Details.
- **alpha**: a numeric value for the significance level with $0 \leq \alpha \leq 1$; use iff `threshold = "critical.value"
- **threshold.function**: function object of form `function(G)` to compute a threshold of significance for different bandwidths `G`; use iff `threshold='custom'`
- **pal.name**: a string containing the name of the ColorBrewer palette to be used; sequential palettes are recommended. See `RColorBrewer::brewer.pal.info` for details
plot.mosum.cpts

plot.mosum.cpts

plot.mosum.cpts

plot.mosum.cpts

Details

The visualisation is based on persp3D. MOSUM statistics computed with different bandwidths are rescaled for making them visually comparable. Rescaling is done either by dividing by their respective critical value at the significance level alpha (iff threshold = "critical.value") or by a custom value given by threshold.function (iff threshold = "custom"). By default, clim argument of persp3D is given so that the three lightest (for sequential palettes) hues indicate insignificance of the corresponding MOSUM statistics, while darker hues indicate the presence of significant changes.

Value

see persp3D

Examples

## Not run:
# If you run the example be aware that this may take some time
print("example may take some time to run")

x <- testData(model = "blocks", seed = 1234)$x
persp3D.multiscaleMosum(x, mosum.args = list(boundary.extension = FALSE))

## End(Not run)
critical.value.col = "blue",
xlab = "Time",
...
)

Arguments

x a mosum.cpts object
display which to be plotted against the change point estimators; possible values are
  • "data" input time series is plotted along with the estimated piecewise constant signal
  • "mosum" scaled MOSUM detector values are plotted
cpts.col a specification for the color of the vertical lines at the change point estimators, see par
critical.value.col a specification for the color of the horizontal line indicating the critical value, see par; use iff display = "mosum"
xlab graphical parameter
... additional graphical arguments, see plot and abline

Details

The location of each change point estimator is plotted as a vertical line against the input time series and the estimated piecewise constant signal (display = "data") or MOSUM detector values (display = "mosum").

Examples

x <- testData(lengths = rep(100, 3), means = c(0, 5, -2), sds = rep(1, 3), seed = 1234)$x
m <- mosum(x, G = 40)
par(mfrow = c(2, 1), mar = c(2.5, 2.5, 2.5, .5))
plot(m, display = "data")
plot(m, display = "mosum")

plot.multiscale.cpts  Plotting the output from multiscale MOSUM procedure

Description

Plotting method for S3 objects of class "multiscale.cpts".
Usage

```r
## S3 method for class 'multiscale.cpts'
plot(
x, 
    display = c("data", "significance")[[1]],
    shaded = c("CI", "bandwidth", "none")[[1]],
    level = 0.05,
    N_reps = 1000,
    CI = c("pw", "unif")[[1]],
    xlab = "Time",
    ...
)
```

Arguments

- **x**: a `multiscale.cpts` object
- **display**: which to be plotted against the estimated change point locations; possible values are
  - "data": input time series is plotted along with the estimated piecewise constant signal
  - "significance": one minus the p-values associated with the detection of change point estimators are represented as the height of vertical lines indicating their locations
- **shaded**: string indicating which to display as shaded areas surrounding the estimated change point locations. Possible values are
  - "bandwidth": respective detection intervals are plotted
  - "CI": bootstrap confidence intervals are plotted
  - "none": none is plotted
- **level, N_reps**: argument to be parsed to `confint.multiscale.cpts`; use iff `shaded = "CI"`.
- **CI**: string indicating whether pointwise (`CI = "pw"`) or uniform (`CI = "unif"`) confidence intervals are to be plotted; use iff `shaded = "CI"`
- **xlab**: graphical parameter
- **...**: not in use

Details

The locations of change point estimators are plotted against the input time series and the estimated piecewise constant signal (`display = "data"`), or the significance of each estimator is represented by the corresponding $1 - p$-value derived from the asymptotic distribution of MOSUM test statistic (`display = "significance"`). It also produces the rectangles representing the detection intervals (if `shaded = "bandwidth"`) or bootstrap confidence intervals of the corresponding change points (if `shaded = "CI"`) around their locations.
print.mosum.cpts

Examples
x <- testData(model = "blocks", seed = 1234)$x
mlp <- multiscale.localPrune(x)
par(mfrow = c(2, 1))
plot(mlp, display = "data", shaded = "bandwidth")
plot(mlp, display = "significance", shaded = "CI")

print.mosum.cpts  Change points estimated by MOSUM procedure

Description
Print method for objects of class mosum.cpts

Usage
## S3 method for class 'mosum.cpts'
print(x, ...)

Arguments
x a mosum.cpts object
... not in use

Examples
x <- testData(lengths = rep(100, 3), means = c(0, 5, -2), sds = rep(1, 3), seed = 1234)$x
m <- mosum(x, G = 40)
print(m)

print.multiscale.cpts  Change points estimated by multiscale MOSUM procedure

Description
Print method for objects of class multiscale.cpts

Usage
## S3 method for class 'multiscale.cpts'
print(x, ...)

Arguments
x a multiscale.cpts object
... not in use
Examples

```r
x <- testData(model = "mix", seed = 12345)$x
mlp <- multiscale.localPrune(x)
print(mlp)
```

```
summary.mosum.cpts  Summary of change points estimated by MOSUM procedure

Description

Summary method for objects of class mosum.cpts

Usage

## S3 method for class 'mosum.cpts'
summary(object, ...)

Arguments

object a mosum.cpts object
...
not in use

Details

Provide information about each estimated change point, including the bandwidths used for its estimation, associated p-value and (scaled) jump size; if `object$do.confint=TRUE`, end points of the pointwise and uniform confidence intervals are also provided.

Examples

```r
x <- testData(lengths = rep(100, 3), means = c(0, 5, -2), sds = rep(1, 3), seed = 1234)$x
m <- mosum(x, G = 40, do.confint = TRUE)
summary(m)
```

```
summary.multiscale.cpts
Summary of change points estimated by multiscale MOSUM procedure

Description

Summary method for objects of class multiscale.cpts

Usage

## S3 method for class 'multiscale.cpts'
summary(object, ...)
```
Arguments

object a multiscale.cpts object
... not in use

Details

Provide information about each estimated change point, including the bandwidths used for its detection, associated p-value and (scaled) jump size; if object$do.confint=TRUE, end points of the pointwise and uniform confidence intervals are also provided.

Examples

x <- testData(model = "mix", seed = 12345)$x
mlp <- multiscale.localPrune(x, do.confint = TRUE)
summary(mlp)

Description

Generate piecewise stationary time series with independent innovations and change points in the mean.

Usage

testData(
  model = c("custom", "blocks", "fms", "mix", "stairs10", "teeth10")[1],
  lengths = NULL,
  means = NULL,
  sds = NULL,
  rand.gen = rnorm,
  seed = NULL,
  ...
)

Arguments

model a string indicating from which model a realisation is to be generated; possible values are "custom" (for user-specified model using lengths, means and sds), and "blocks", "fms", "mix", "stairs10", "teeth10" (for the referenced test signals)
lengths use iff model = "custom"; an integer vector for the lengths of the piecewise stationary segments
means use iff model = "custom"; a numeric vector for the means of the piecewise stationary segments
use iff model = "custom": a numeric vector for the deviation scaling of the piecewise stationary segments. The values are multiplied to the outcome of rand.gen, coinciding with the standard deviation in the case of standard normal innovations (rand.gen = rnorm)

rand.gen optional; a function to generate the noise/innovations

seed optional; if a seed value is provided (!is.null(seed)), then set.seed(seed) is called beforehand

... further arguments to be parsed to rand.gen

Details

See Appendix B in the reference for details about the test signals.

Value

a list containing the following entries:

- x a numeric vector containing a realisation of the piecewise time series model, given as signal + noise
- mu mean vector of piecewise stationary time series model
- sigma scaling vector of piecewise stationary time series model
- cpts a vector of change points in the piecewise stationary time series model

References


Examples

# visualise estimated changepoints by solid vertical lines
# and true changepoints by broken vertical lines
td <- testData(lengths = c(50, 50, 200, 300, 300), means = c(0, 1, 2, 3, 2.3),
sds = rep(1, 5), seed = 123)
mbu <- multiscale.bottomUp(td$x)
plot(mbu, display = "data")
abline(v = td$cpts, col = 2, lwd = 2, lty = 2)

# visualise estimated piecewise constant signal by solid line
# and true signal by broken line
td <- testData("blocks", seed = 123)
mlp <- multiscale.localPrune(td$x)
plot(mlp, display = "data")
lines(td$mu, col = 2, lwd = 2, lty = 2)
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