

Package ‘BiSeq’

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Author Katja Hebestreit, Hans-Ulrich Klein

Maintainer Katja Hebestreit <katja.hebestreit@uni-muenster.de>

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Description The BiSeq package provides useful classes and functions to handle and analyze targeted bisulfite sequencing (BS) data such as reduced-representation bisulfite sequencing (RRBS) data. In particular, it implements an algorithm to detect differentially methylated regions (DMRs). The package takes already aligned BS data from one or multiple samples.

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annotateGRanges	<i>Annotates a GRanges object by means of a second GRanges object</i>
-----------------	---

Description

Each genomic location of object is checked for overlapping with genomic ranges of regions. In case of an overlapping, this genomic location is marked as TRUE, or with the identifier of respective the regions object (if any).

Usage

```
annotateGRanges(object, regions, name, regionInfo)
```

Arguments

object	A GRanges.
regions	A GRanges.
name	A string specifying the name of the elementMetadata column with the overlapping information to be added to object. Usually the type of the regions object, e.g. 'Promoter'.

regionInfo OPTIONAL: A string or integer specifying the `elementMetadata` column of `regions` object containing the identifiers, e.g. entrez gene IDs of the promoters. If not specified, the genomic locations of object are labeled as TRUE (overlap) or FALSE (no overlap).

Details

If multiple ranges of `regions` overlap with a genomic region in object, the identifier names of the overlapping regions are separated by ','.

Value

A `GRanges` object similar to object containing an additional `elementMetadata` column with the overlapping information.

Author(s)

Katja Hebestreit

See Also

`GRanges-class`

Examples

```
# load detected DMRs:
data(DMRs)

# annotate the DMRs with a GRanges object:
data(promoters)
DMRs.anno <- annotateGRanges(object = DMRs,
                             regions = promoters,
                             name = 'Promoter',
                             regionInfo = 'acc_no')

DMRs.anno
```

betaRegression

A function to estimate and test a group factor within a beta regression

Description

This function models the methylation level within a beta regression. The first independent variable in `formula` is tested to be unequal to zero.

Usage

```
betaRegression(formula, link, object, mc.cores, ...)
```

Arguments

formula	Symbolic description of the model. For the first independent variable the P value (Wald test) and the effect on methylation is returned. For details see below.
link	A character specifying the link function in the mean model (μ). Currently, "logit", "probit", "cloglog", "log", "loglog" are supported.
object	A BSrel object.
mc.cores	Passed to mclapply.
...	Other parameters passed to the betareg function.

Details

See betareg function for details.

mclapply

Value

A data.frame containing the position, chromosome, P value, estimated methylation level in group 1 and group 2 and methylation difference of group 1 and group 2.

Author(s)

Katja Hebestreit

References

Hebestreit, K., Dugas, M., and Klein HU. Detection of significantly differentially methylated regions in targeted bisulfite sequencing Data. In preparation. *Bioinformatics*. 2013 Jul 1;29(13):1647-53.

See also reference list in the documentation of [betareg](#).

See Also

[betareg](#)

Examples

```
# load RRBS data, subset to save time, find CpG clusters and smooth methylation data:
data(rrbs)
rrbs.small <- rrbs[1:1000,]
rrbs.clust.unlim <- clusterSites(object = rrbs.small,
                                groups = colData(rrbs)$group,
                                perc.samples = 4/5,
                                min.sites = 20,
                                max.dist = 100)

ind.cov <- totalReads(rrbs.clust.unlim) > 0
quant <- quantile(totalReads(rrbs.clust.unlim)[ind.cov], 0.9)
rrbs.clust.lim <- limitCov(rrbs.clust.unlim, maxCov = quant)
```

```
# with a small subset to save calculation time:
rrbs.part <- rrbs.clust.lim[1:100,]

predictedMeth <- predictMeth(object=rrbs.part)

betaResults <- betaRegression(formula = ~group, link = "probit",
                             object = predictedMeth, type="BR")
```

betaResults *The output of betaRegression*

Description

Please see the package vignette for description.

Usage

```
data(betaResults)
```

Format

A data frame with 4276 observations on the following 10 variables:

chr a factor with levels chr1 chr2

pos a numeric vector

p.val a numeric vector

meth.group1 a numeric vector

meth.group2 a numeric vector

meth.diff a numeric vector

estimate a numeric vector

std.error a numeric vector

pseudo.R.sqrt a numeric vector

cluster.id a character vector

Examples

```
data(betaResults)
head(betaResults)
```

betaResultsNull *The output of betaRegression for resampled data*

Description

Please see the package vignette for description.

Usage

```
data(betaResultsNull)
```

Format

A data frame with 4276 observations on the following 10 variables.

chr a factor with levels chr1 chr2

pos a numeric vector

p.val a numeric vector

meth.group1 a numeric vector

meth.group2 a numeric vector

meth.diff a numeric vector

estimate a numeric vector

std.error a numeric vector

pseudo.R.sqrt a numeric vector

cluster.id a character vector

Examples

```
data(betaResultsNull)
head(betaResultsNull)
```

binomLikelihoodSmooth *Calculates local likelihood estimations for binomial random variables*

Description

For a given set of binomial random variables with 1-dimensional coordinates, this function calculates the local likelihood estimation of the success probability p at a given point. For this purpose, a weighted likelihood estimation with weights obtained by a triangular kernel with given bandwidth is used. This can be used to predict values at points where no variable has been observed and/or to smooth observations using neighboured observations.

Usage

```
binomLikelihoodSmooth(pred.pos, pos, m, n, h)
```

Arguments

pred.pos	A vector of positions where p should be estimated.
pos	A vector of positions where binomial variables have been observed.
m	A vector of length pos with the number of successful experiments.
n	A vector of length pos with the number of experiments.
h	The bandwidth of the kernel.

Details

For a given position x , the weighted likelihood for parameter p

$$L(p; m, n, w) = \prod_{i=1}^k B(m_i | n_i, p)^{w_i}$$

is maximized. B denotes the binomial probability function. The weights w_i are calculated using a triangular kernel with bandwidth h :

$$w_i = K(x_i) = (1 - (|x - x_i|)/h) \mathbf{1}_{(|x - x_i|)/h \leq 1}$$

Value

A vector of length `pred.pos` giving the local likelihood estimation of the success probability p at the given positions.

Author(s)

Hans-Ulrich Klein

See Also

[predictMeth](#)

Examples

```
n = rpois(100, lambda=10)
E = c(rep(0.4, 30), rep(0.8, 40), rep(0.1, 30))
m = rbinom(100, n, E)
pos = 1:100
p_10 = binomLikelihoodSmooth(pos, pos, m, n, h=10)
p_20 = binomLikelihoodSmooth(pos, pos, m, n, h=20)

## Not run: plot(x=pos, y=m/n)
points(x=pos, y=p_10, col="green")
lines(x=pos, y=p_10, col="green")
points(x=pos, y=p_20, col="red")
lines(x=pos, y=p_20, col="red")
## End(Not run)
```

BSraw-class*Class to contain raw Bisulfite Sequencing (BiSeq) Data*

Description

The BSraw class is derived from SummarizedExperiment and contains a SimpleList of matrices named methReads and totalReads as assays.

Objects from the Class

Objects can be created by calls of the form `BSraw(exptData = SimpleList(), rowData, colData = DataFrame(rowData))`. However, one will most likely create a BSraw object when use `readBismark` to load data.

Slots

exptData: An optional SimpleList of arbitrary content describing the overall experiment.
rowData: Object of class "GRanges" containing the genome positions of CpG-sites covered by bisulfite sequencing.
colData: Object of class "DataFrame" containing information on variable values of the samples.
assays: Object of class SimpleList of two matrices, named totalReads and methReads. The matrix totalReads contains the number of reads spanning a CpG-site. The rows represent the CpG sites in rowData and the columns represent the samples in colData. The matrix methReads contains the number of methylated reads spanning a CpG-site.

Extends

Class "`SummarizedExperiment`", directly.

Methods

totalReads signature(x = "BSraw"): Gets the totalReads slot.
totalReads<- signature(x = "BSraw", value = "matrix"): Sets the totalReads slot.
methReads signature(x = "BSraw"): Gets the methReads slot.
methReads<- signature(x = "BSraw", value = "matrix"): Sets the methReads slot.
combine signature(x = "BSraw", y = "BSraw"): Combines two BSraw objects.

Author(s)

Katja Hebestreit

See Also

SummarizedExperiment, [BSrel-class](#), [readBismark](#)

Examples

```
showClass("BSraw")

## How to create a BSraw object by hand:
exptData <- SimpleList(Sequencer = "Sequencer", Year = "2013")
rowData <- GRanges(seqnames = "chr1",
                  ranges = IRanges(start = c(1,2,3), end = c(1,2,3)))
colData <- DataFrame(group = c("cancer", "control"),
                    row.names = c("sample_1", "sample_2"))
totalReads <- matrix(c(rep(10L, 3), rep(5L, 3)), ncol = 2)
methReads <- matrix(c(rep(5L, 3), rep(5L, 3)), ncol = 2)
BSraw(exptData = exptData,
      rowData = rowData,
      colData = colData,
      totalReads = totalReads,
      methReads = methReads)

## A more realistic example can be loaded:
data(rrbs)
rrbs

head(totalReads(rrbs))
head(methReads(rrbs))
```

 BSrel-class

Class to contain Bisulfite Sequencing (BiSeq) Data

Description

The BSrel class is derived from SummarizedExperiment and contains a SimpleList of one matrix named methLevel as assays.

Objects from the Class

Objects can be created by calls of the form BSrel(exptData = SimpleList(), rowData, colData = DataFrame(row.names, col.names))
 However, one will most likely create a BSraw object when use [readBismark](#) to load data.

Slots

exptData: An optional SimpleList of arbitrary content describing the overall experiment.
rowData: Object of class "GRanges" containing the genome positions of CpG-sites covered by bisulfite sequencing.
colData: Object of class "DataFrame" containing information on variable values of the samples.
assays: Object of class SimpleList of a matrix, named methLevel containing the methylation levels (between 0 and 1) per CpG site. The rows represent the CpG sites in rowData and the columns represent the samples in colData.

Extends

Class "[SummarizedExperiment](#)", directly.

Methods

methLevel signature(x = "BSrel"): Gets the methLevel slot.

methLevel<- signature(x = "BSrel", value = "matrix"): Sets the methLevel slot.

combine signature(x = "BSrel", y = "BSrel"): Combines two BSrel objects.

Author(s)

Katja Hebestreit

See Also

[SummarizedExperiment](#), [BSraw-class](#), [readBismark](#)

Examples

```
showClass("BSrel")

## How to create a BSrel object by hand:
exptData <- SimpleList(Sequencer = "Sequencer", Year = "2013")
rowData <- GRanges(seqnames = "chr1",
                  ranges = IRanges(start = c(1,2,3), end = c(1,2,3)))
colData <- DataFrame(group = c("cancer", "control"),
                    row.names = c("sample_1", "sample_2"))
methLevel <- matrix(c(rep(0.5, 3), rep(1, 3)), ncol = 2)
BSrel(exptData = exptData,
      rowData = rowData,
      colData = colData,
      methLevel = methLevel)

# Or get a BSrel object out of a BSraw object:
data(rrbs)
rrbs.rel <- rawToRel(rrbs)
```

clusterSites

Assigns CpG cluster memberships on CpG sites within BSraw objects

Description

Within a BSraw object `clusterSites` searches for agglomerations of CpG sites across all samples. In a first step the data is reduced to CpG sites covered in `round(perc.samples*ncol(object))` samples, these are called 'frequently covered CpG sites'. In a second step regions are detected where not less than `min.sites` frequently covered CpG sites are sufficiently close to each other (`max.dist`). Note, that the frequently covered CpG sites are considered to define the boundaries of the CpG clusters only. For the subsequent analysis the methylation data of all CpG sites within these clusters are used.

Usage

```
clusterSites(object, groups, perc.samples, min.sites, max.dist,  
mc.cores, ...)
```

Arguments

object	A BSraw.
groups	OPTIONAL. A factor specifying two or more sample groups within the given object. See Details.
perc.samples	A numeric between 0 and 1. Is passed to <code>filterBySharedRegions</code> .
min.sites	A numeric. Clusters should comprise at least <code>min.sites</code> CpG sites which are covered in at least <code>perc.samples</code> of samples, otherwise clusters are dropped.
max.dist	A numeric. CpG sites which are covered in at least <code>perc.samples</code> of samples within a cluster should not be more than <code>max.dist</code> bp apart from their nearest neighbors.
mc.cores	Passed to <code>mclapply</code> Default is 1.
...	Further arguments passed to the <code>filterBySharedRegions</code> function.

Details

Within a BSraw object this function searches for agglomerations of CpG sites across all samples. In a first step the data is reduced to CpG sites covered in at least `round(perc.samples*ncol(object))` samples. In a second step regions are defined where not less than `min.sites` of these CpG sites are sufficiently close. If argument `group` is given `perc.samples` or `no.samples` are applied for all group levels.

Value

A BSraw object reduced to CpG sites within CpG cluster regions. A `cluster.id` in the `elementMetadata` slot of `rowData` assigns cluster memberships per CpG site.

Author(s)

Katja Hebestreit

See Also

[filterBySharedRegions](#), `mclapply`

Examples

```
data(rrbs)  
rrbs.clust <- clusterSites(object = rrbs, groups = colData(rrbs)$group,  
perc.samples = 4/5, min.sites = 20,  
max.dist = 100)
```

clusterSitesToGR	<i>A function to obtain a GRanges object of CpG clusters from BSraw and BSrel objects</i>
------------------	---

Description

This function allows to get the start and end positions of CpG clusters from a BSraw or BSrel object, when there is a `cluster.id` column in the `rowData` slot.

Usage

```
clusterSitesToGR(object)
```

Arguments

object	A BSraw or BSrel object with a <code>cluster.id</code> column in the <code>rowData</code> slot. Usually the output of <code>clusterSites</code> .
--------	---

Value

An object of class `GRanges` is returned.

Author(s)

Katja Hebestreit

See Also

[clusterSites](#)

Examples

```
data(rrbs)
rrbs.clustered <- clusterSites(rrbs)

clusterSitesToGR(rrbs.clustered)
```

compareTwoSamples *Detects DMRs by comparing two samples*

Description

Determines the differences of (smoothed) methylation levels between two samples and aggregates the sites surpassing a minimum difference to DMRs.

Usage

```
compareTwoSamples(object, sample1, sample2, minDiff, max.dist)
```

Arguments

object	A BSrel.
sample1	A numeric or character specifying the first sample to be used.
sample2	A numeric or character specifying the second sample to be used.
minDiff	A numeric greater than 0 and smaller or equal to 1.
max.dist	Numeric. The maximum distance between two CpG sites (or grid points) with absolute methylation differences greater or equal than minDiff in a DMR. If grid points are used: should be the same as grid.dist in predictMeth.

Details

This function determines the differences between the methylation levels of sample1 and sample2 for each site. Successive sites with methylation differences smaller or equal to minDiff are summarized.

Value

A GRanges object.

Author(s)

Katja Hebestreit

See Also

[predictMeth](#)

Examples

```
data(rrbs)
rrbs <- rrbs[, c(1,6)]
CpG.clusters <- clusterSites(object = rrbs, perc.samples = 1,
                             min.sites = 20, max.dist = 100)
predictedMeth <- predictMeth(object = CpG.clusters)
DMRs <- compareTwoSamples(predictedMeth, sample1 = 1, sample2 = 2,
                           minDiff = 0.3, max.dist = 100)
```

covBoxplots

Creates boxplots of coverages per sample

Description

A boxplot per sample is plotted for the coverages of CpG-sites. It is constrained to CpG-sites which are covered in the respective sample (coverage != 0 and not NA).

Usage

```
R
covBoxplots(object, ...)
```

Arguments

object	A BSraw.
...	Other graphical parameters passed to the boxplot function.

Author(s)

Katja Hebestreit

See Also

boxplot

Examples

```
data(rrbs)
covBoxplots(rrbs)
```

covStatistics	<i>Prints a short summary of coverage statistics per sample</i>
---------------	---

Description

This function produces information per samples about 1.) the covered CpG-sites 2.) the median of their coverages.

Usage

```
covStatistics(object)
```

Arguments

object A BiSeq object.

Author(s)

Katja Hebestreit

Examples

```
data(rrbs)
covStatistics(rrbs)
```

DMRs	<i>The output of findDMRs</i>
------	-------------------------------

Description

Please see the package vignette for description.

Usage

```
data(DMRs)
```

Format

A GRanges of the chromosomes, start and end positions of the detected DMRs together with information (in the elementMetadata slot) on DMRs: median.p, codemedian.meth.group1, codemedian.meth.group2, median.meth.diff.

Examples

```
data(DMRs)
head(DMRs)
```

`estLocCor`*Estimates the correlations of the z-scores*

Description

For each location the correlation of this location's z-score to \bar{Z} of its CpG cluster is estimated.

Usage

```
estLocCor(vario.sm)
```

Arguments

`vario.sm` Output of `smoothVariogram`.

Value

A list:

`variogram` A variogram matrix, usually created by `smoothVariogram` beforehand.
`pValsList` A list of the test results per CpG cluster.
`sigma.cluster` The standard deviations of z-scores within each cluster.
`Z.cluster` The arithmetic means of the z-scores for each cluster.
`length.cluster` The widths (number of base pairs) of each cluster.

Author(s)

Katja Hebestreit

References

Yoav Benjamini and Ruth Heller (2007): False Discovery Rates for Spatial Signals. *American Statistical Association*, 102 (480): 1272-81.

See Also

[makeVariogram](#), [smoothVariogram](#)

Examples

```
data(betaResultsNull)

vario <- makeVariogram(betaResultsNull)
vario.sm <- smoothVariogram(vario, sill = 1)

locCor <- estLocCor(vario.sm)
```

filterByCov	<i>Filters regions (or single CpGs) of a BSraw object with a minimum coverage</i>
-------------	---

Description

This method reduces a BSraw object to its regions (or single CpGs) with a minimum number of reads.

Usage

```
filterByCov(object, minCov, global)
```

Arguments

object	A BSraw.
minCov	Minimum number of reads overlapping the CpG sites.
global	A logical indicating whether the regions should achieve the minimum coverage in each sample. If <code>global = TRUE</code> the filtered object will consist of the regions achieving the minimum coverage in all samples. If <code>global = FALSE</code> (default) this function filters the regions for each sample separately, irrespectively of the coverages in other samples. <code>totalReads</code> and <code>methReads</code> are set to zero, if the minimum coverage is not obtained. Regions covered too sparse in all samples are dropped.

Value

A BSraw object containing the CpGs or regions achieving the minimum coverage in all (if `global=TRUE`) or at least one (if `global=FALSE`) samples.

Author(s)

Katja Hebestreit

See Also

[filterBySharedRegions](#)

Examples

```
data(rrbs)
rrbs.reduced <- filterByCov(object=rrbs, minCov=10, global=TRUE)
```

`filterBySharedRegions` *Reduces a BSraw or BSrel object to regions (or single CpGs) shared by a fraction of samples*

Description

This method determines the regions which are covered in a given fraction of samples and reduces the BSraw or BSrel object to these regions.

Usage

```
filterBySharedRegions(object, groups, perc.samples, no.samples, minCov)
```

Arguments

<code>object</code>	A BSraw or BSrel object.
<code>groups</code>	OPTIONAL. A factor specifying two or more groups within the given object. See Details.
<code>perc.samples</code>	A numeric vector with elements between 0 and 1 of length 1 or of the same length as levels in group. Default is 1.
<code>no.samples</code>	Alternative to <code>perc.samples</code> . An integer vector of length 1 or of the same length as levels in group.
<code>minCov</code>	A numeric: If <code>object</code> is a BSraw object the minimum coverage may be set. Default is 1.

Details

If argument `group` is given `perc.samples` or `no.samples` are applied for all group levels.

Value

An object of the same class as `object` storing methylation information solely for regions or single CpGs covered in at least $\text{round}(\text{perc.samples} * \text{ncol}(\text{object}))$ samples, if `perc.samples` is given. Alternatively, the number of samples can be given directly by using `no.samples`.

Author(s)

Katja Hebestreit

See Also

[filterByCov](#)

Examples

```
data(rrbs)
rrbs.reduced <- filterBySharedRegions(object = rrbs, perc.samples = 1)

# Or filter CpG sites where at least 50% of cancer and 50% of normal samples have coverage:
rrbs.reduced <- filterBySharedRegions(object=rrbs, groups = colData(rrbs)$group,
                                     perc.samples = 0.5)
```

findDMRs

Aggregates CpG sites to DMRs

Description

This function aggregates CpG sites to DMRs on the basis of their P values.

Usage

```
findDMRs(test.out, alpha, max.dist, diff.dir)
```

Arguments

test.out	An object returned by betaRegression.
alpha	OPTIONAL. A DMR contains CpG sites with P values smaller or equal than alpha.
max.dist	Numeric. The maximum distance between two P values smaller than alpha in a DMR. Should be the same as grid.dist in predictMeth.
diff.dir	Logical. Should DMRs be separated if the direction of methylation differences changes? If TRUE (default), than resulting DMRs will consist of sites which are all hypomethylated, or hypermethylated respectively.

Value

A GRanges object storing the start and end positions of the DMRs with information in elementMetadata:

median.p	median of P values
median.meth.group1	median of modeled methylation level of group1.
median.meth.group2	median of modeled methylation level of group2.
median.meth.diff	median of difference of modeled methylation levels of group1 and group2.

Author(s)

Katja Hebestreit

See Also

[predictMeth](#), [betaRegression](#)

Examples

```
## Variogram under Null hypothesis (for resampled data):
data(vario)

plot(vario$variogram)
vario.sm <- smoothVariogram(vario, sill=0.9)

# auxiliary object to get the pValsList for the test
# results of interest:
data(betaResults)
vario.aux <- makeVariogram(betaResults, make.variogram=FALSE)

# Replace the pValsList slot:
vario.sm$pValsList <- vario.aux$pValsList

## vario.sm contains the smoothed variogram under the Null hypothesis as
## well as the p Values that the group has an effect on DNA methylation.

locCor <- estLocCor(vario.sm)

clusters.rej <- testClusters(locCor, FDR.cluster = 0.1)

clusters.trimmed <- trimClusters(clusters.rej, FDR.loc = 0.05)

DMRs <- findDMRs(clusters.trimmed, max.dist=100, diff.dir=TRUE)
```

limitCov

Limits the coverage of a BSraw object

Description

Number of methylated and unmethylated reads of a CpG site with coverage above maxCov are reduced such that the methylation level remains unchanged.

Usage

```
limitCov(object, maxCov)
```

Arguments

object	A BSraw.
maxCov	The maximum number of reads a CpG should have. All coverages above this threshold are limited. (Default is 50)

Details

This function might be useful prior to the use of `predictMeth` to limit the weights of CpGs with extremely high coverages. See `binomLikelihoodSmooth` for details.

Value

A BSraw object.

Author(s)

Katja Hebestreit

See Also

[predictMeth](#), [binomLikelihoodSmooth](#)

Examples

```
data(rrbs)

rrbs.clust.unlim <- clusterSites(object = rrbs,
                                groups = colData(rrbs)$group,
                                perc.samples = 4/5,
                                min.sites = 20, max.dist = 100)

covBoxplots(rrbs.clust.unlim)

# 90% quantile of coverage is 39x
quantile(totalReads(rrbs.clust.unlim)[totalReads(rrbs.clust.unlim)>0],
0.9)

rrbs.clust.lim <- limitCov(rrbs.clust.unlim, maxCov = 39)
covBoxplots(rrbs.clust.lim)
```

logisticRegression *Estimates and tests a group factor*

Description

It is used to fit a linear model on the log odds of each (smoothed) methylation level. The first independent variable in formula is tested to be unequal to zero.

Usage

```
logisticRegression(formula, link, object, mc.cores)
```

Arguments

formula	An object of class formula. For the first independent variable the p-value and the effect on methylation is returned.
link	A character specifying the link function. Currently, "logit", "probit", "cloglog", "log", "loglog" are supported.
object	A BSrel object.
mc.cores	Passed to mclapply.

Value

A data.frame containing the position, chromosome, P value, estimated methylation level in group 1 and group 2 and methylation difference of group 1 and group 2.

Author(s)

Katja Hebestreit

See Also

mclapply, glm

Examples

```
data(predictedMeth)

logisticResults <- logisticRegression(formula = ~group, link = "logit",
                                     object = predictedMeth)
```

makeVariogram	<i>Variogram estimator.</i>
---------------	-----------------------------

Description

A function which estimates the variogram of the z-scores in the given data frame.

Usage

```
makeVariogram(test.out, make.variogram)
```

Arguments

test.out	A data.frame. Usually the output of betaRegression. Must contain columns chr, pos, p.val and cluster.id.
make.variogram	A logical. Default is TRUE.

Details

For each CpG site the z-score is determined by `qnorm(1 - P value)`. The variogram of the z-scores of locations k and l within one cluster is estimated robustly by

$$2\hat{\gamma}(h) = [\text{median}(Z_k - Z_l)^2 : (s_k, s_l) \in N(h)]/.455$$

Value

A list:

<code>variogram</code>	A matrix with columns <code>h</code> and <code>v</code> .
<code>pValsList</code>	A list of data frames. Each data frame corresponds to a CpG cluster and contains same information as <code>test.out</code> plus the columns <code>z.score</code> and <code>pos.new</code> (position corresponding to the respective CpG cluster).

Author(s)

Katja Hebestreit

References

Yoav Benjamini and Ruth Heller (2007): False Discovery Rates for Spatial Signals. American Statistical Association, 102 (480): 1272-81.

See Also

[betaRegression](#)

Examples

```
data(betaResults)

vario <- makeVariogram(betaResults)

plot(vario$variogram)
```

<code>plotBindingSites</code>	<i>Plots the mean methylation of given regions</i>
-------------------------------	--

Description

`plotBindingSites` takes several genomic regions (e.g. protein binding sites), centers them such that the position 0 refers to the center of each region and finally calculates the mean methylation of all regions for each given sample. If several samples are given, the median of the samples' methylation values and optionally other quantiles are plotted.

Usage

```
plotBindingSites(object, regions, width, groups, quantiles, bandwidth, ...)
```

Arguments

object	An object of class BSraw or BSrel.
regions	Regions given a GRanges object. The regions may have different widths.
width	The width of the genomic region that is plotted. Default value is the width of the largest given region.
groups	An optional factor defining two or more groups within the given object. The mean methylation is then plotted for each group separately.
quantiles	Other quantiles to be plotted besides the median. Default are the 25% and the 75% quantiles.
bandwidth	The bandwidth of the kernel smoother used for smoothing methylation values. Default value is 1/8 width.
...	Other graphical parameters passed to the plot function.

Details

First, all regions were expanded or shrunk to the given width by adding or removing base pairs symmetrically at both ends of the regions (not by scaling). A new coordinate system is centered at the middle of the equally sized regions. Next, the relative methylation values for each sample are averaged across all regions. That means, if there are several CpGs from different regions lying the same position, the mean methylation value is calculated for that position. Then, the median of these methylation values across all samples is calculated. Optionally, other quantiles are calculated, too. The median of the methylation is then plotted for each position after smoothing using a gaussian kernel with the given bandwidth.

If the given regions correspond to binding sites of a certain protein, the plot can be used to discover whether the protein induces changes in the DNA methylation in the proximity of its binding sites.

Author(s)

Hans-Ulrich Klein

See Also

[BSraw-class](#), [BSrel-class](#)

Examples

```
data(rrbs)
data(promoters)
plotBindingSites(object=rrbs,
                 regions=promoters,
                 width=4000,
                 groups=colData(rrbs)$group)
```

plotMeth	<i>Plots raw and smoothed methylation data for a given region</i>
----------	---

Description

This function plots the raw and the smoothed methylation data for one sample and a given region. The smoothed data is shown as a line (one line per CpG cluster) and the raw data is shown as points with color intensities proportional to the coverage.

Usage

```
plotMeth(object.raw, object.rel, region, col.lines, lwd.lines, col.points, ...)
```

Arguments

<code>object.raw</code>	A <code>BSraw</code> with only one sample.
<code>object.rel</code>	A <code>BSrel</code> with only one sample.
<code>region</code>	A <code>GRanges</code> of length one.
<code>col.lines</code>	OPTIONAL. The color for the line representing the smoothed methylation values.
<code>lwd.lines</code>	OPTIONAL. The line width for the line representing the smoothed methylation values.
<code>col.points</code>	OPTIONAL. The color for the points representing the raw methylation levels.
<code>...</code>	Other graphical parameters passed to the plot function.

Author(s)

Katja Hebestreit

See Also

[plotSmoothMeth](#), [plot](#)

Examples

```
data(rrbs)
data(predictedMeth)

region <- GRanges(seqnames="chr1",
                  ranges=IRanges(start = 875200,
                                end = 875500))

plotMeth(object.raw = rrbs[,6],
         object.rel = predictedMeth[,6],
         region = region)
```

`plotMethMap`*Plots methylation values of multiple samples in a given region*

Description

A heatmap like plot is generated showing the relative methylation of single CpG sites. Samples are clustered hierarchically.

Usage

```
plotMethMap(object, region, groups, intervals, ...)
```

Arguments

<code>object</code>	A <code>BSraw</code> or <code>BSrel</code> object storing the methylation values.
<code>region</code>	A <code>GRanges</code> object giving the region of interest.
<code>groups</code>	OPTIONAL. A factor that will be encoded by a color bar.
<code>intervals</code>	OPTIONAL. A logical indicating whether neighbored CpG sites should be placed side by side (if <code>FALSE</code>) or whether the intervals between CpG sites should be preserved (if <code>TRUE</code>).
<code>...</code>	Further arguments passed to the heatmap function.

Details

The relative methylation values are passed to the heatmap function. Default colors are green (not methylated), black and red (methylated). To ensure that a relative methylation of 0 corresponds to green, 0.5 to black and 1 to red, the default value for the `zlim` argument of the `heatmap` function is set to `c(0, 1)`. And the default for the `scale` parameter is set to "none".

If argument `intervals` is set to `TRUE`, region should not be too large (< 1kb) and respect the resolution of your screen.

Author(s)

Hans-Ulrich Klein

See Also

`heatmap`, [BSraw-class](#), [BSrel-class](#), [filterBySharedRegions](#), [filterByCov](#)

Examples

```
data(rrbs)
data(predictedMeth)
data(DMRs)

plotMethMap(rrbs, region = DMRs[4], groups = colData(rrbs)[, "group"])
```

```
plotMethMap(predictedMeth, region = DMRs[4],
            groups = colData(rrbs)[,"group"], intervals = FALSE)
```

plotSmoothMeth	<i>Plots smoothed methylation values for a bunch of samples and a given region</i>
----------------	--

Description

This function plots the smoothed methylation data as lines for a given region and all given samples. It is also possible to average the data for groups of samples.

Usage

```
plotSmoothMeth(object.rel, region, groups, group.average, ...)
```

Arguments

object.rel	A BSrel.
region	A GRanges of length one.
groups	OPTIONAL. A factor defining two or more sample groups within the given object.
group.average	OPTIONAL. A logical. If TRUE, then the data is averaged for the groups given in groups. Default is FALSE..
...	Other graphical parameters passed to the plot function.

Author(s)

Katja Hebestreit

See Also

[plotMeth](#), [plot](#)

Examples

```
data(predictedMeth)
data(DMRs)

plotSmoothMeth(object.rel = predictedMeth,
               region = DMRs[3] + 200,
               groups = colData(predictedMeth)$group,
               col=c("magenta", "blue"))
legend("topright",
      lty=1,
      legend=levels(colData(predictedMeth)$group),
      col=c("magenta", "blue"))
```

predictedMeth	<i>The output of predictMeth</i>
---------------	----------------------------------

Description

Please see the package vignette for description.

Usage

```
data(predictedMeth)
```

Format

A BSrel object with the smoothed methylation data.

Examples

```
data(predictedMeth)
show(predictedMeth)
```

predictMeth	<i>Predicts methylation levels along CpG sites or for a grid of sites in CpG clusters.</i>
-------------	--

Description

Uses local regression to predict methylation levels per sample.

Usage

```
predictMeth(object, h, grid.dist, mc.cores)
```

Arguments

object	A BSraw with a cluster.id column in the elementMetadata, usually the output of clusterSites.
h	Bandwidth in base pairs. Large values produce a smoother curve. Default is 80.
grid.dist	OPTIONAL. If numeric, than methylation values are predicted at intervals of grid.dist base pairs. By default, methylation is smoothed at each CpG site.
mc.cores	Passed to mclapply. Default is 1.

Details

Uses binomLikelihoodSmooth with pos = CpG position, m = number methylated reads and n = number of reads. pred.pos corresponds to all CpG positions, or to the grid sites respectively, within the CpG clusters.

Value

A BSrel object containing the predicted methylation levels in the methLevel slot.

Author(s)

Katja Hebestreit

See Also

[clusterSites](#), [binomLikelihoodSmooth](#), [mclapply](#)

Examples

```
data(rrbs)

rrbs.clust.unlim <- clusterSites(object = rrbs,
                                groups = colData(rrbs)$group,
                                perc.samples = 4/5,
                                min.sites = 20, max.dist = 100)

ind.cov <- totalReads(rrbs.clust.unlim) > 0
quant <- quantile(totalReads(rrbs.clust.unlim)[ind.cov], 0.9)
rrbs.clust.lim <- limitCov(rrbs.clust.unlim, maxCov = quant)

# with a small subset to save calculation time:
rrbs.part <- rrbs.clust.lim[1:100,]

predictedMeth <- predictMeth(object=rrbs.part)
```

promoters

A GRanges of promoters of the human genome

Description

Please see the package vignette for description.

Usage

```
data(promoters)
```

Format

A GRanges object with the chromosomes, start and end positions of defined human promoter regions together with an accession number in the elementMetadata slot.

Examples

```
data(promoters)
head(promoters)
```

rawToRel	<i>Converts a BSraw object to a BSrel object</i>
----------	--

Description

Determines the methLevel matrix via: `methReads(object) / totalReads(object)`.

Usage

```
rawToRel(object)
```

Arguments

object A BSraw.

Value

A BSrel.

Author(s)

Katja Hebestreit

See Also

[BSraw-class](#) [BSrel-class](#)

Examples

```
data(rrbs)
rrbs.rel <- rawToRel(rrbs)
```

readBismark	<i>Reads cytosine methylation stati determined by Bismark</i>
-------------	---

Description

Bismark is a bisulfite read mapper and methylation caller. This method reads Bismark's output files and returns a BSraw object.

Usage

```
readBismark(files, colData)
```

Arguments

files	A character pointing to bedGraph files created by Bismark's <code>methylation_extractor</code> and <code>bismark2bedGraph</code> ; see Details .
colData	Samples' names plus additional sample information as character, <code>data.frame</code> or <code>DataFrame</code> .

Details

Input files are created with Bismark as follows (from the command line):

```
bismark_methylation_extractor -s --comprehensive test_sample.sam
```

```
bismark2bedGraph --counts -o CpG_context_test_sample.bedGraph CpG_context_test_sample.txt
```

In this example, the file `CpG_context_test_sample.bedGraph` is then the input file to `readBismark`.

The `colData` argument should specify the sample names as character. Alternatively, a `data.frame` or `DataFrame` can be given. Then, the row names are used as sample names and the data frame is passed to the final `BSraw` object.

Value

A `BSraw` object storing coverage and methylation information.

Author(s)

Hans-Ulrich Klein

References

<http://www.bioinformatics.bbsrc.ac.uk/projects/bismark/>

See Also

[BSraw-class](#)

Examples

```
file <- system.file("extdata", "CpG_context_test_sample.bedGraph", package = "BiSeq")
rrbs <- readBismark(file,
                   colData= DataFrame(row.names="sample_1"))
```

`rrbs`*RRBS data of APL patient samples and controls.*

Description

RRBS data of the CpG sites CpG sites from genomic regions on p arms of chromosome 1 and 2 covered in at least one sample. Data was obtained from 5 APL patient samples and 5 control samples (APL in remission). RRBS data was preprocessed with the Bismark software version 0.5.

Usage`rrbs`**Format**

A `BSraw-class` object.

Source

Schoofs T, Rohde C, Hebestreit K, Klein HU, Goellner S, Schulze I, Lerdrup M, Dietrich N, Agrawal-Singh S, Witten A, Stoll M, Lengfelder E, Hofmann WK, Schlenke P, Buechner T, Hansen K, Berdel WE, Rosenbauer F, Dugas M, Mueller-Tidow C (2012). DNA methylation changes are a late event in acute promyelocytic leukemia and coincide with loss of transcription factor binding. *Blood*.

References

Krueger F, Andrews SR. Bismark: a flexible aligner and methylation caller for Bisulfite-Seq applications. *Bioinformatics*. 2011;27:1571-1572.

Examples

```
data(rrbs)
show(rrbs)
```

`smoothVariogram`*Smooths variogram*

Description

Nonparametric smoothing with kernel regression estimators and adaptable bandwidth for variogram smoothing.

Usage

```
smoothVariogram(variogram, sill, bandwidth)
```


Arguments

variogram	A list or a matrix. Usually the output of makeVariogram.
sill	A numeric. The sill (upper bound) of the variogram. See Details.
bandwidth	A numeric vector of same length as the variogram (number of rows). Default: seq(10,1000, length.out=nrow(variogram)). See Details.

Details

It is necessary to smooth the variogram. Especially for greater h the variogram tends to oscillate strongly. This is the reason why the default bandwidth increases with increasing h . Nevertheless, the smoothed variogram may further increase or decrease after a horizontal part (sill). This is mostly due to the small number of observations for high distances. To wipe out this bias it is useful to set the smoothed variogram to a fixed value above a certain h , usually the mean value of the horizontal part. If a smoothed value $v.sm$ is greater than sill for distance h_{range} , this $v.sm$ and all other smoothed values with $h > h_{range}$ are set to sill. Internally, the function lokerns from package lokerns is used for smoothing.

Value

The variogram matrix (or a list with the variogram matrix) with an additional column of the smoothed v values.

Author(s)

Katja Hebestreit

See Also

[makeVariogram](#), [lokerns](#)

Examples

```
data(vario)

# Find out the sill (this is more obvious for larger data sets):
plot(vario$variogram)

vario.sm <- smoothVariogram(vario, sill = 0.9)

plot(vario$variogram)
lines(vario.sm$variogram[,c("h", "v.sm")],
      col = "red")
```

summarizeRegions	<i>Aggregates methylation information of single CpG sites</i>
------------------	---

Description

This method summarizes the methylation states of single CpG sites to a single methylation state for a given genomic region.

Usage

```
summarizeRegions(object, regions, outputAll)
```

Arguments

object	An BSraw or BSrel object.
regions	A GRanges object storing the genomic regions.
outputAll	A logical. If outputAll = TRUE, all regions will be returned. If FALSE (default), regions are dropped if their coverage is zero.

Details

When the given object is of class [BSraw-class](#), all (methylated) reads of all CpG site lying within a region are summed up and assign as total number of (methylated) reads to that region. It is recommended to use [limitCov](#) before applying summarizeRegions to an [BSraw-class](#) object in order to avoid an excessive influence of a single CpG site on the methylation value of a region. When the given object is of class [BSrel-class](#), the mean relative methylation of all CpGs within a region is assign to that region.

The rowData slot of the returned object is the given object regions with all columns preserved.

Value

An BSraw or an BSrel object storing methylation information about the given regions.

Author(s)

Hans-Ulrich Klein

See Also

[BSraw-class](#), [BSrel-class](#), [limitCov](#)

Examples

```

data(rrbs)
rrbs.clustered <- clusterSites(rrbs)
regions <- clusterSitesToGR(rrbs.clustered)

rrbs <- limitCov(rrbs, maxCov=50)
rrbsRegion <- summarizeRegions(rrbs, regions)
totalReads(rrbsRegion)

```

testClusters	<i>Tests CpG clusters</i>
--------------	---------------------------

Description

CpG clusters are tested with a cluster-wise FDR level.

Usage

```
testClusters(locCor, FDR.cluster)
```

Arguments

locCor	Output of estLocCor.
FDR.cluster	A numeric. The WFDR (weighted FDR) level at which the CpG clusters should be tested. Default is 0.05.

Details

CpG clusters containing at least one differentially methylated location are detected.

Value

A list is returned:

FDR.cluster	Chosen WFDR (weighted FDR) for clusters.
CpGs.clust.reject	A list of the CpG sites together with test results within clusters that were rejected.
CpGs.clust.not.reject	A list of the CpG sites together with test results within clusters that were not rejected.
clusters.reject	A GRanges of the clusters that were rejected.
clusters.not.reject	A GRanges of the clusters that were not rejected.
sigma.clusters.reject	The standard deviations for z-scores within each rejected cluster.

variogram	The variogram matrix.
m	Number of clusters tested.
k	Number of clusters rejected.
u.1	Cutoff point of the largest P value rejected.

Author(s)

Katja Hebestreit

References

Yoav Benjamini and Ruth Heller (2007): False Discovery Rates for Spatial Signals. American Statistical Association, 102 (480): 1272-81.

See Also

[estLocCor](#), [trimClusters](#)

Examples

```
## Variogram under Null hypothesis (for resampled data):
data(vario)

plot(vario$variogram)
vario.sm <- smoothVariogram(vario, sill=0.9)

# auxiliary object to get the pValsList for the test
# results of interest:
data(betaResults)
vario.aux <- makeVariogram(betaResults, make.variogram=FALSE)

# Replace the pValsList slot:
vario.sm$pValsList <- vario.aux$pValsList

## vario.sm contains the smoothed variogram under the Null hypothesis as
## well as the p Values that the group has an effect on DNA methylation.

locCor <- estLocCor(vario.sm)

clusters.rej <- testClusters(locCor, FDR.cluster = 0.1)
```

trimClusters

Trims CpG clusters

Description

CpG clusters rejected in a previous step are trimmed.

Usage

```
trimClusters(clusters.rej, FDR.loc)
```

Arguments

clusters.rej	Output of testClusters.
FDR.loc	Location-wise FDR level. Default is 0.2.

Details

Not differentially methylated CpG sites are removed within the CpG clusters rejected by testClusters.

Value

A data.frame containing the differentially methylated CpG sites.

Author(s)

Katja Hebestreit

References

Yoav Benjamini and Ruth Heller (2007): False Discovery Rates for Spatial Signals. American Statistical Association, 102 (480): 1272-81.

See Also

[testClusters](#)

Examples

```
## Variogram under Null hypothesis (for resampled data):
data(vario)

plot(vario$variogram)
vario.sm <- smoothVariogram(vario, sill=0.9)

# auxiliary object to get the pValsList for the test
# results of interest:
data(betaResults)
vario.aux <- makeVariogram(betaResults, make.variogram=FALSE)

# Replace the pValsList slot:
vario.sm$pValsList <- vario.aux$pValsList

## vario.sm contains the smoothed variogram under the Null hypothesis as
## well as the p Values that the group has an effect on DNA methylation.

locCor <- estLocCor(vario.sm)

clusters.rej <- testClusters(locCor, FDR.cluster = 0.1)
```

```
clusters.trimmed <- trimClusters(clusters.rej, FDR.loc = 0.05)
```

vario	<i>Output of makeVariogram</i>
-------	--------------------------------

Description

Please see the package vignette for description.

Usage

```
data(vario)
```

Format

A list consisting of the variogram (a matrix) and the pValsList (a list of the data frames of test results).

Examples

```
data(vario)
names(vario)
```

writeBED	<i>Writes BSraw and BSrel data to a bed file suitable for the IGV</i>
----------	---

Description

The created bed files contains an entry for each CpG site. Strand information, relative methylation and absolute number of reads covering the CpG sites are stored. The relative methylation is indicated by colors: green via black to red for unmethylated to methylated.

Usage

```
writeBED(object, name, file)
```

Arguments

object	A BSraw or BSrel object.
name	Track names (sample names) written to the bed file's header.
file	Character vector with names of the bed file.

Details

The written bed file contains the following extra information:

1. score: the relative methylation of the CpG site
2. name: the coverage of the CpG site
3. itemRgb: a color value visualizing the methylation score

A separate bed file is created for each sample in the given object. The lengths of the arguments `name` and `file` should equal the number of samples.

Value

Nothing. Bed files are written.

Author(s)

Hans-Ulrich Klein

See Also

[readBismark](#)

Examples

```
data(rrbs)
s1 <- rrbs[,1]
out <- tempfile(), fileext = ".bed"
writeBED(s1, name = colnames(s1), file = out)
```

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