## Package ‘RiboProfiling’

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**Type** Package

**Title** Ribosome Profiling Data Analysis: from BAM to Data Representation and Interpretation

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**Description** Starting with a BAM file, this package provides the necessary functions for quality assessment, read start position recalibration, the counting of reads on CDS, 3'UTR, and 5'UTR, plotting of count data: pairs, log fold-change, codon frequency and coverage assessment, principal component analysis on codon coverage.

**biocViews** RiboSeq, Sequencing, Coverage, Alignment, QualityControl, Software, PrincipalComponent

**Depends** R (>= 3.2.2), Biostrings

**Imports** BiocGenerics, GenomeInfoDb, GenomicRanges, IRanges, reshape2, GenomicFeatures, grid, plyr, S4Vectors, GenomicAlignments, ggplot2, ggbio, Rsamtools, rtracklayer, data.table, sqldf

**Suggests** knitr, BiocStyle, TxDb.Hsapiens.UCSC.hg19.knownGene, BSgenome.Hsapiens.UCSC.hg19, testthat, SummarizedExperiment

**LazyLoad** yes

**License** GPL-3

**VignetteBuilder** knitr

**NeedsCompilation** no

**RoxygenNote** 5.0.1

### R topics documented:

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aroundPromoter

Returns the flank size around the TSS for the x % CDSs

Usage

aroundPromoter(txdb, alnGRanges, percBestExpressed, flankSize)

Arguments

taxdb: a TxDb object containing the annotations info to intersect with the alignment files.
alnGRanges: A GRanges object containing the alignment information. In order to improve the performance of this function the GAlignments BAM object should be transformed into a GRanges object containing the cigar match size information as metadata.
percBestExpressed: a numeric [between 0 and 1]. The percentage of the best expressed CDSs on which to plot the coverage around the TSS. Necessary if the shiftValue parameter must be estimated. Default value 0.03 (3%).
flankSize: a numeric positive integer. How many bp left and right of the TSS should the coverage be performed? Ex. flankSize <- 20

Value

A GRanges object containing the 1 bp ranges for the selected CDSs in the TSS defined flanking region.

Examples

# read the BAM into a GAlignments object using
# GenomicAlignments::readGAlignments
# the GAlignments object should be similar to ctrlGAlignments
data(ctrlGAlignments)

aln <- ctrlGAlignments

# transform the GAlignments object into a GRanges object (faster processing)
alnGRanges <- readsToStartOrEnd(aln, what="start")
# make a txdb object containing the annotations for the specified species.
# In this case hg19.
# Please make sure that seqnames of txdb correspond to
# the seqnames of the alignment files ("chr" particle)
# if not rename the txdb seqlevels
# renameSeqlevels(txdb, sub("chr", ",", seqlevels(txdb)))
# get the flanking region around the promoter of the best expressed CDSs
oneBinRanges <- aroundPromoter(txdb, alnGRanges)

codonDataCtrl

Codon frequency and coverage in ORFs on chromosome 1, for dataset ctrlGAlignments

Description
A list of 2 data.frame objects: one with the number of times each codon type is found in each ORF and one with the number of reads for each codon type in each ORF.

Usage
data(codonDataCtrl)

Format
A list of 2 lists.

Value
A list of 2 lists.

codonIndexCovCtrl
The read coverage for each codon in ORFs on chromosome 1, for dataset ctrlGAlignments

Description
A list containing the number of reads for each codon in each ORF. Codons are reported on their index in the ORF and no information is available about their type/sequence.

Usage
data(codonIndexCovCtrl)

Format
A list of 2 columns dataframes.

Value
A list of 2 columns dataframes.
**Description**

Associates the read counts on codons with the codon type for each ORF.

**Usage**

```r
codonInfo(listReadsCodon, genomeSeq, orfCoord, motifSize)
```

**Arguments**

- `listReadsCodon`: a list of data.frame objects. It contains the number of reads per codon in a CDS.
- `genomeSeq`: a BSgenome object. It contains the full genome sequences for the organism.
- `orfCoord`: a GRangesList. The coordinates of the ORFs on the genome.
- `motifSize`: an integer. The number of nucleotides in each motif on which to compute coverage and usage. Default 3 nucleotides (codon). No motif longer than 6 nucleotides is accepted. Attention! For long motifs, the function can be quite slow!!

**Value**

a list of 2 data.frame objects: one with the number of times each codon type is found in each ORF and one with the number of reads for each codon type in each ORF.

**Examples**

```r
# for each codon in each ORF get the read coverage
# parameter listReadsCodon can be returned by the riboSeqFromBam function
# it corresponds to the 2nd element in the list returned by riboSeqFromBam
data(codonIndexCovCtrl)
listReadsCodon <- codonIndexCovCtrl


data(codonIndexCovCtrl)
listReadsCodon <- codonIndexCovCtrl


# get the names of the ORFs
# grouped by transcript
cds <- GenomicFeatures::cdsBy(txdb, use.names=TRUE)
orfCoord <- cds[names(cds) %in% names(listReadsCodon)]

data(codonIndexCovCtrl)
listReadsCodon <- codonIndexCovCtrl


# get the genome, please check that the genome has the same seqlevels
genomeSeq <- BSgenome.Hsapiens.UCSC.hg19::BSgenome.Hsapiens.UCSC.hg19
# if not rename it
genomeSeq <- GenomeInfoDb::renameSeqlevels(genomeSeq, sub("chr", "", GenomeInfoDb::seqlevels(genomeSeq))

# codon frequency, coverage, and annotation
codonData <- codonInfo(listReadsCodon, genomeSeq, orfCoord)
```
Description

PCA graphs on codon coverage

Usage

codonPCA(data, typeData)

Arguments

data a list of 2 data.frames: one with the number of times each codon type is found in each ORF and one with the number of reads for each codon in each ORF.
typeData a character string. It is used as title for the PCA. Ex. typeData="codonCoverage"

Value

a list of length 2: PCA_scores - matrix of the scores on the first 4 principal components. PCA_plots - a list of 5 PCA scatterplots.

Examples

#How to perform a PCA analysis based on codon coverage
#adapted from
#http://stackoverflow.com/questions/20260434/test-significance-of-clusters-on-a-pca-plot
#either get the codon frequency, coverage, and annotation using a function
#such as codonInfo in this package
#or create a list of matrices with the above information
data(codonDataCtrl)
codonData <- codonDataCtrl
codonUsage <- codonData[[1]]
codonCovMatrix <- codonData[[2]]

#keep only genes with a minimum number of reads
nbrReadsGene <- apply(codonCovMatrix, 1, sum)
ixExpGenes <- which(nbrReadsGene >= 50)
codonCovMatrix <- codonCovMatrix[ixExpGenes,]

codonCovMatrixTransp <- t(codonCovMatrix)
rownames(codonCovMatrixTransp) <- colnames(codonCovMatrix)
colnames(codonCovMatrixTransp) <- rownames(codonCovMatrix)

listPCACodonCoverage <- codonPCA(codonCovMatrixTransp, "codonCoverage")
print(listPCACodonCoverage[[2]])
#See aditional examples in the pdf manual
countShiftReads Apply an offset on the read start along the transcript and returns the coverage on the 5pUTR, CDS, 3pUTR, as well as a matrix of codon coverage per ORF.

Description
Apply an offset on the read start along the transcript and returns the coverage on the 5pUTR, CDS, 3pUTR, as well as a matrix of codon coverage per ORF.

Usage
countShiftReads(exonGRanges, cdsPosTransc, alnGRanges, shiftValue, motifSize)

Arguments
exonGRanges a GRangesList. It contains the exon coordinates grouped by transcript.
cdsPosTransc a list. It contains the relative positions of the start and end of the ORFs. The transcript names in exonGRanges and cdsPosTransc should be the same.
alnGRanges A GRanges object containing the alignment information. In order to improve the performance the GAlignments BAM object should be transformed into a GRanges object with cigar match size metadata.
shiftValue integer. The offset for recalibrating reads on transcripts when computing coverage. The default value for this parameter is 0, no offset should be performed.
motifSize an integer. The number of nucleotides in each motif on which to compute coverage and usage. Default 3 nucleotides (codon).

Value
a list with 2 objects. The first object in the list is a data.frame containing: information on ORFs (names, chromosomal position, length) as well as the counts on the 5pUTR, CDS and 3pUTR once the offset is applied. The second object in the list is a list in itself. It contains for each ORF in the cdsPosTransc, for each codon the sum of read starts covering the 3 codon nucleotides. This per codon coverage does not contain information on the codon type, just its position in the ORF and its coverage.

Examples
#read the BAM file into a GAlignments object using
#GenomicAlignments::readGAlignments
#the GAlignments object should be similar to ctrlGAlignments
data(ctrlGAlignments)
aln <- ctrlGAlignments

#transform the GAlignments object into a GRanges object (faster processing)
alnGRanges <- readsToStartOrEnd(aln, what="start")

#make a txdb object containing the annotations for the specified species.
#In this case hg19.
#Please make sure that seqnames of txdb correspond to
countsPlot

Graphs of sample read counts (quality assessment)

**Description**

Graphs of sample read counts (quality assessment)

**Usage**

```r
countsPlot(listCounts, ixCounts, log2Bool)
```

**Arguments**

- `listCounts`: a list of data.frame objects. It contains the counts on the genomic features. Each data.frame in the list should have the same number of columns.
- `ixCounts`: a numeric (a vector of integers). It contains the index of the columns containing counts in the dataFrame.
- `log2Bool`: a numeric, either 0 or 1. 0 (default) for no log2 transformation and 1 for log2 transformation.

**Value**

A list of pairs and boxplots between the counts data in each data.frame.

**Examples**

```r
#read the BAM file into a GAlignments object using
#GenomicAlignments::readGAlignments
#the GAlignments object should be similar to ctrlGAlignments
data(ctrlGAlignments)
aln <- ctrlGAlignments

#transform the GAlignments object into a GRanges object (faster processing)
alnGRanges <- readsToStartOrEnd(aln, what="start")

#make a txdb object containing the annotations for the specified species.
#In this case hg19.
```
ctrlGAlignments

Ribosome profiling data on chr1 in human primary BJ fibroblasts control data: PMID: 23594524.

Description
A dataset containing the alignment information on chromosome 1 from the control BAM. The data object is a GAlignments object containing 3,504,859 hg19 mapped reads.

Usage
data(ctrlGAlignments)

Format
A GAlignments object with 3,504,859 reads.

Value
the GAlignments object of reads on chr 1
### histMatchLength

*Histogram of match length distribution of reads.*

**Description**

Histogram of match length distribution of reads.

**Usage**

```r
histMatchLength(aln, log10Transf = 0, titleHist)
```

**Arguments**

- `aln`: A GAlignments object of the BAM mapping file.
- `log10Transf`: A boolean. Either 0 (default) or 1 (log10).

**Value**

A list with 2 elements. The first element: a data.frame of the number of counts per match length distribution. The second element in the list: a ggplot2 histogram of the match length distribution.

**Examples**

```r
# starting from a GAlignment object
data(ctrlGAlignments)
aln <- ctrlGAlignments
# no log10 scaling
matchLenDistr <- histMatchLength(aln, 0)
# to plot the histogram
matchLenDistr[[2]]
```

### orfRelativePos

*Relative position of the start and stop codon along the transcript*

**Description**

Relative position of the start and stop codon along the transcript.

**Usage**

```r
orfRelativePos(cdsTransc, exonGRanges)
```

**Arguments**

- `cdsTransc`: a GRangesList. It contains the CDS coordinates grouped by transcript.
- `exonGRanges`: a GRangesList. It contains the exon coordinates grouped by transcript.
plotSummarizedCov

Value

A list. A list of relative positions of the start and end of ORFs.

Examples

# make a txdb object containing the annotations for the specified species.
# In this case hg19.

get all CDSs by transcript
cds <- GenomicFeatures::cdsBy(txdb, by="tx", use.names=TRUE)

get all exons by transcript
exonGRanges <- GenomicFeatures::exonsBy(txdb, by="tx", use.names=TRUE)

# retrieve the positions of start and end codons relative to the transcript
cdsPosTransc <- orfRelativePos(cds, exonGRanges)

plotSummarizedCov

Plots the summarized coverage in a specified range (e.g. around TSS) for the specified match sizes

Description

Plots the summarized coverage in a specified range (e.g. around TSS) for the specified match sizes

Usage

plotSummarizedCov(covSummarized)

Arguments

covSummarized

a list of GRanges objects. For each matchSize a GRanges object of the summarized coverage.

Value

A ggplot2 plot of read coverage in interval

Examples

# read the BAM file into a GAlignments object using
# GenomicAlignments::readGAlignments
# the GAlignments object should be similar to ctrlGAlignments
data(ctrlGAlignments)
aln <- ctrlGAlignments

# transform the GAlignments object into a GRanges object (faster processing)
alnGRanges <- readsToStartOrEnd(aln, what="start")

# make a txdb object containing the annotations for the specified species.
# In this case hg19.

# Please make sure that seqnames of txdb correspond to
# the seqnames of the alignment files ("chr" particle)
# if not rename the txdb seqlevels
#renameSeqlevels(txdb, sub("chr", ",", seqlevels(txdb)))
# get the flanking region around the promoter of the best expressed CDSs
oneBinRanges <- aroundPromoter(txdb, alnGRanges)
# the read start coverage around the TSS as a percentage for all match sizes.
covSummarized <- readStartCov(alnGRanges, oneBinRanges, matchSize="all",
c(-20,20), "aroundTSS", charPerc="perc")
trackPlotTSS <- plotSummarizedCov(covSummarized)
print(trackPlotTSS)

printPCA

Plots the PCA scatterplots produced by codonPCA function.

Description

Plots the PCA scatterplots produced by codonPCA function.

Usage

printPCA(listPCAGraphs)

Arguments

listPCAGraphs a list of 5 PCA ggplot scatterplots.

Value

a unique plot with the 5 PCA scatterplots.

Examples

# How to perform a PCA analysis based on codon coverage
data(codonDataCtrl)
codonData <- codonDataCtrl
codonUsage <- codonData[[1]]
codonCovMatrix <- codonData[[2]]

# keep only genes with a minimum number of reads
nbrReadsGene <- apply(codonCovMatrix, 1, sum)
ixExpGenes <- which(nbrReadsGene >= 50)
codonCovMatrix <- codonCovMatrix[ixExpGenes, ]

# get the PCA on the codon coverage
codonCovMatrixTransp <- t(codonCovMatrix)
rownames(codonCovMatrixTransp) <- colnames(codonCovMatrix)
colnames(codonCovMatrixTransp) <- rownames(codonCovMatrix)

listPCACodonCoverage <- codonPCA(codonCovMatrixTransp,"codonCoverage")
printPCA(listPCACodonCoverage[[2]])
readStartCov

Read start coverage around the TSS on the predefined CDSs

Description
Read start coverage around the TSS on the predefined CDSs

Usage

readStartCov(alnGRanges, oneBinRanges, matchSize = "all", fixedInterval, 
renameChr, charPerc = "perc")

Arguments

alnGRanges A GRanges object containing the alignment information. In order to improve 
the performance transform the GAlignments BAM object into a GRanges object 
containing cigar match size as metadata.

oneBinRanges A GRanges object. Transform the gene GRangesList into one big GRanges 
object. Add the info on the cds_id.

matchSize either "all" or a vector of read match sizes. If matchSize <- "all", then all the 
reads are used to compute the coverage. If the matchSize is a vector of read 
match sizes, the summarized coverage is reported per match size and for the 
sum up.

fixedInterval a numeric vector with the extremities of the interval. Ex. fixedInterval <- c(-
20,20) or fixedInterval <- c(0,40) ...

renameChr a character object. It contains the name to be given to the new summarized cov-
erage interval. Ex. renameChr <- "aroundTSS" the summarized region around 
the TSS.

charPerc a character object. Either "perc" (the default) or "sum" for percentage of counts 
per position or the sum of counts per position.

Value

a list of GRanges objects (for each matchSize chosen). It contains the summarized coverage for the 
specified read match sizes.

Examples

#read the BAM into a GAlignments object using 
#GenomicAlignments::readGAlignments 
#the GAlignments object should be similar to ctrlGAlignments 
data(ctrlGAlignments)
aln <- ctrlGAlignments

#transform the GAlignments object into a GRanges object (faster processing) 
alnGRanges <- readsToStartOrEnd(aln, what="start")

#make a txdb object containing the annotations for the specified species. 
#In this case hg19.
#Please make sure that seqnames of txdb correspond to
# the seqnames of the alignment files ("chr" particle)
# if not rename the txdb seqlevels
# renameSeqlevels(txdb, sub("chr", ",", seqlevels(txdb)))

# get the flanking region around the promoter of the best expressed CDSs
oneBinRanges <- aroundPromoter(txdb, alnGRanges, percBestExpressed=0.01)

# the coverage in the TSS flanking region for the summarized read match sizes
listPromoterCov <- readStartCov(
  alnGRanges,
  oneBinRanges,
  matchSize="all",
  fixedInterval=c(-20, 20),
  renameChr="aroundTSS",
  charPerc="perc"
)

readsToStartOrEnd

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reads in GAlignments converted to either Read Start (5’) or End (3’) Positions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>readsToStartOrEnd(aln, what)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arguments</th>
</tr>
</thead>
<tbody>
<tr>
<td>aln</td>
</tr>
<tr>
<td>what</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A GRanges object containing either the read start or end genomic positions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examples</th>
</tr>
</thead>
</table>
| #read the BAM file into a GAlignments object using
#GenomicAlignments::readGAlignments
#the GAlignments object should be similar to ctrlGAlignments object
data(ctrlGAlignments)
aln <- ctrlGAlignments
#transform the GAlignments object into a GRanges object (faster processing)
alnGRanges <- readsToStartOrEnd(aln, what = "end") |
RiboProfiling

Description
RiboProfiling.

Usage
riboSeqFromBAM(listeInputBamFile, paramScanBAM, genomeName, txdb, percBestExpressed, flankSize, offsetStartEnd, listShiftValue)

Arguments
listeInputBamFile  A character path or a vector of paths to the ribo-seq BAM file(s). If multiple BAM files are provided, they should come from the same genome alignment.

paramScanBAM  NULL or ScanBamParam object specifying what fields and which records are imported. Default value is NULL.

genomeName  a character object containing the name of the genome used for the alignment BAM file. The name should be one of the UCSC ensGene list: ucsGenomes()[","db"]. Ex. "hg19" or "mm10". This parameter is used to build the TxDb object.

taxdb  a TxDb object containing the annotations info to confront with the alignment files. Either genomeName or txdb parameters should be provided.

percBestExpressed  numeric [between 0 and 1]. The percentage of best expressed CDSs on which to plot the coverage around the TSS. Necessary if the shiftValue parameter must be estimated. Default value 0.03 (3%).

flankSize  an integer. How many bp left and right of the TSS should the coverage be performed?

offsetStartEnd  a character object. Either "start" (the default) or "end" for read start or read end to define the offset.

listShiftValue  a vector of integer. It should have the same length as the inputBamFile vector. The numeric value for shifting ranges of reads on genomic features when computing coverage. Set this parameter to 0 if no shift should be performed. If this parameter is missing, the shiftValue is computed based on the maximum peak of read start coverage around the TSS. A plot is produced to illustrate this estimation.
riboSeqFromBAM

Value

A list of list for each BAM file in the inputBamFile list. For each BAM file 2 objects are returned: one data.frame with info on the genomic features and the corresponding coverage column, and one list of per ORF codon coverage.

Examples

#the txdb object can be given as parameter or not.
#If it is not specified, a txdb object is build from UCSC.

#in this example only one BAM file is treated.
#However, multiple BAM files can be analyzed together.
myFile <- system.file("extdata", "ctrl_sample.bam", package="RiboProfiling")
listeInputBam <- c(myFile)

covData <- riboSeqFromBAM(listeInputBam, txdb=txdb, listShiftValue=c(-14))
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