

Package ‘sSNAPPY’

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Title Single Sample directionAl Pathway Perturbation analYsis

Version 1.5.0

Description A single sample pathway perturbation testing method for RNA-seq data. The method propagates changes in gene expression down gene-set topologies to compute single-sample directional pathway perturbation scores that reflect potential direction of change. Perturbation scores can be used to test significance of pathway perturbation at both individual-sample and treatment levels.

License GPL-3

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.compute_ssFC	<i>Compute single sample logFCs</i>
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Description

Compute single sample logFCs

Usage

.compute_ssFC(logCPM, metadata, sampleColumn, treatColumn, groupBy)

Arguments

- | | |
|----------|---|
| logCPM | Matrix of normalised logCPM |
| metadata | Sample metadata data frame as described in the details section. |
| factor | The factor defines how samples can be put into matching pairs. |
| control | The treatment level that is the control. |

Value

A matrix of single sample logFC

generate_permuted_scores

Permute sample labels to simulate null distribution of perturbation scores

Description

Simulate null distributions of perturbation scores for each pathway through sample permutation.

Usage

```
generate_permuted_scores(  
  expreMatrix,  
  numOfTreat,  
  NB = 1000,  
  testScore = NULL,  
  gsTopology,  
  weight,  
  BPPARAM = BiocParallel::bpparam()  
)  
  
## S4 method for signature 'matrix'  
generate_permuted_scores(  
  expreMatrix,  
  numOfTreat,  
  NB = 1000,  
  testScore = NULL,  
  gsTopology,  
  weight,  
  BPPARAM = BiocParallel::bpparam()  
)  
  
## S4 method for signature 'data.frame'  
generate_permuted_scores(  
  expreMatrix,  
  numOfTreat,  
  NB = 1000,  
  testScore = NULL,  
  gsTopology,  
  weight,  
  BPPARAM = BiocParallel::bpparam()  
)  
  
## S4 method for signature 'DGEList'
```

```

generate_permuted_scores(
  expreMatrix,
  numOfTreat,
  NB = 1000,
  testScore = NULL,
  gsTopology,
  weight,
  BPPARAM = BiocParallel::bpparam()
)

## S4 method for signature 'SummarizedExperiment'
generate_permuted_scores(
  expreMatrix,
  numOfTreat,
  NB = 1000,
  testScore = NULL,
  gsTopology,
  weight,
  BPPARAM = BiocParallel::bpparam()
)

```

Arguments

expreMatrix	matrix and data.frame of logCPM, or DGEList/SummarizedExperiment storing gene expression counts. Feature names need to be in entrez IDs
numOfTreat	Number of treatments (including control)
NB	Number of permutations to perform
testScore	Optional. Users can provide the test perturbation score data.frame (ie. output of pathwayPertScore) to restrict the permutatio step only to pathways with non-zero test scores in at least one sample.
gsTopology	List of pathway topology matrices generated using function retrieve_topology
weight	A vector of gene-wise weights derived from function weight_ss_fc
BPPARAM	The parallel back-end to uses, if not specified, it is defaulted to the one returned by BiocParallel::bpparam().

Details

This generate_permuted_scores function is a generic function that can deal with multiple types of inputs. It firstly randomly permute sample labels NB times to generate permuted logFCs, which are then used to compute permuted perturbation scores for each pathway.

The function outputs a list that is of the same length as the list storing pathway topology matrices. Each element of the output list is for a pathway and contains a vector of permuted perturbation score of length. The permuted perturbation scores will be used to estimate the null distributions of perturbation scores.

If the input is S4 object of DGEList or SummarizedExperiment, gene expression matrix will be extracted and converted to a logCPM matrix.

The default number of permutation (NB) is set to 1000. If the requested NB is larger than the maximum number of permutations possible, NB will be set to the largest number of permutations possible instead.

Value

A list where each element is a vector of perturbation scores for a pathway.

Examples

```
#compute weighted single sample logFCs
data(metadata_example)
data(logCPM_example)
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
ls <- weight_ss_fc(logCPM_example, metadata = metadata_example,
  groupBy = "patient", treatColumn = "treatment", sampleColumn = "sample")
## Not run:
load(system.file("extdata", "gsTopology.rda", package = "sSNAPPY"))

# simulate the null distribution of scores through sample permutation
permutedScore <- generate_permuted_scores(logCPM_example, numOfTreat = 3,
  NB = 10, gsTopology = gsTopology, weight = ls$weight)

# To see what other parallel back-end can be used:
BiocParallel::registered()

## End(Not run)
```

gsAnnotation_df	<i>gsAnnotation_df: Categorization of KEGG pathways used for community annotation</i>
-----------------	---

Description

gsAnnotation_df: Categorization of KEGG pathways used for community annotation

Usage

```
data(gsAnnotation_df)
```

Format

A data.frame with 549 rows and 2 columns containing categorization of 549 KEGG pathways

gs_name Gene-set name

vategory Category

Source

<https://www.genome.jp/kegg/>

logCPM_example	<i>logCPM_example: Normalised logCPM of patient-derived explant models obtained from 5 ER-positive primary breast cancer patients (GSE80098)</i>
----------------	--

Description

This data was adopted from a study by Singhal H, et al., which was published as *Genomic agonism and phenotypic antagonism between estrogen and progesterone receptors in breast cancer* in 2016.

Usage

```
data(logCPM_example)
```

Format

A data.frame with 7672 rows and 15 columns

Details

In this study, 12 primary malignant breast tissues (8PR+ and 4 PR-) were developed into patient-derived explants and treated with Vehicle, E2, E2+R5020, or R5020 for 24 or 48 hrs.

Raw data for 48-hr Vehicle-, R5020-treated and E2+R5020-treated samples were retrieved from GEO (GSE80098) and pre-processed into raw count. Filtration was sequentially performed to remove undetectable genes and the filtered counts were normalised using [conditional quantile normalisation](#) to offset effects of systematic artefacts, such as gene length and GC contents.

To reduce computing time, we randomly sampled half of the genes after filtration and used their logCPM value as the example data.

Source

<https://www.ncbi.nlm.nih.gov/geo/query/acc.cgi?acc=GSE80098>

metadata_example	<i>metadata_example: Sample metadata for malignant breast cancer tumours PDE from 5 ER+ breast cancer patients (GSE80098)</i>
------------------	---

Description

metadata_example: Sample metadata for malignant breast cancer tumours PDE from 5 ER+ breast cancer patients (GSE80098)

Usage

```
data(metadata_example)
```

Format

A data.frame with 15 rows and 4 columns

patient patient N2-3, P4-6

treatment treatment: Vehicle, R5020 or E2+R5020

PR progesterone receptor status

sample sample name, corresponding to column names of the logCPM matrix

Source

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4928895/>

normalise_by_permu	<i>Normalise test perturbation scores by permutation results</i>
--------------------	--

Description

Normalise test perturbation scores by permutation results

Usage

```
normalise_by_permu(
  permutedScore,
  testScore,
  pAdj_method = "fdr",
  sortBy = c("gs_name", "sample", "pvalue")
)
```

Arguments

permutedScore	A list. Output of generate_permuted_scores
testScore	A data.frame. Output of 'pathwayPertScore'
pAdj_method	Method for adjusting p-values for multiple comparisons. See ?p.adjust for methods available. Default to FDR.
sortBy	Sort the output by p-value, gene-set name or sample names.

Details

Normalise the test perturbation scores generated by weight_ss_fc() through the permuted perturbation scores derived from the generate_permuted_scores() function. The mean absolute deviation(MAD) and median of perturbation scores for each pathway are firstly derived from the permuted perturbation scores. The test perturbation scores are then converted to robust z-scores using MADs and medians calculated.

Value

A data.frame

Examples

```
## Not run:
load(system.file("extdata", "gsTopology.rda", package = "sSNAPPY"))
data(metadata_example)
data(logCPM_example)
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
ls <- weight_ss_fc(logCPM_example, metadata = metadata_example,
  groupBy = "patient", sampleColumn = "sample", treatColumn = "treatment")

# compute raw gene-wise perturbation scores
genePertScore <- raw_gene_pert(ls$logFC, gsTopology)

# sum gene-wise perturbation scores to derive the pathway-level
# single-sample perturbation scores
pathwayPertScore <- pathway_pert(genePertScore)

# simulate the null distribution of scores through sample permutation
permutedScore <- generate_permuted_scores(logCPM_example, numOfTreat = 3,
  NB = 5, gsTopology = gsTopology, weight = ls$weight)

# normalise the test perturbation scores using the permutation results
normalisedScores <- normalise_by_permu(permutedScore, pathwayPertScore,
  sortBy = "pvalue")

## End(Not run)
```

pathway_pert	<i>Compute Single-sample Pathway-level Perturbation Score</i>
--------------	---

Description

Sum gene-wise raw perturbation scores within each sample to derive single-sample perturbation scores for each pathway

Usage

```
pathway_pert(genePertScore)
```

Arguments

genePertScore List of gene-wise raw perturbation score matrices generated using function raw_gene_pert()

Value

A data.frame with 3 columns: score (single-sample pathway-level perturbation score), sample, and gs_name (gene-set name)

References

Tarca AL, Draghici S, Khatri P, Hassan SS, Mittal P, Kim JS, Kim CJ, Kusanovic JP, Romero R. A novel signaling pathway impact analysis. *Bioinformatics*. 2009 Jan 1;25(1):75-82.

Examples

```
#compute weighted single sample logFCs
data(metadata_example)
data(logCPM_example)
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
ls <- weight_ss_fc(logCPM_example, metadata = metadata_example,
  groupBy = "patient", treatColumn = "treatment", sampleColumn = "sample")
# extract all the KEGG pathways
gsTopology <- retrieve_topology(database = "kegg", species = "hsapiens")
# compute raw gene-wise perturbation scores
genePertScore <- raw_gene_pert(ls$logFC, gsTopology)
# sum gene-wise perturbation scores to derive the pathway-level single-sample perturbation scores
pathwayPertScore <- pathway_pert(genePertScore)
```

plot_community	<i>Visualise the community structure in significantly perturbed gene-set network</i>
----------------	--

Description

Visualise the community structure in significantly perturbed gene-set network

Usage

```
plot_community(
  normalisedScores,
  gsTopology,
  gsAnnotation = NULL,
  colorBy = "community",
  communityMethod = c("louvain", "walktrap", "spinglass", "leading_eigen",
    "edge_betweenness", "fast_greedy", "label_prop", "leiden"),
  foldGSname = TRUE,
  foldafter = 2,
  labelFun = .rm_prefix,
  layout = c("fr", "dh", "gem", "graphopt", "kk", "lgl", "mds", "sugiyama"),
  markCommunity = "ellipse",
  markAlpha = 0.2,
```

```

    color_lg_title = NULL,
    edgeAlpha = 0.8,
    scale_edgeWidth = c(0.5, 3),
    edgeLegend = FALSE,
    scale_nodeSize = c(3, 6),
    nodeShape = 16,
    lb_size = 3,
    lb_color = "black",
    plotIsolated = FALSE,
    ...
)

```

Arguments

normalisedScores

A data.frame derived from [normalise_by_permu](#)

gsTopology

List of pathway topology matrices generated using [retrieve_topology](#)

gsAnnotation

A data.frame containing gene-sets categories for pathway annotation. Must contain the two columns: c("gs_name", "category"), where gs_name denotes gene-sets names that are matched to names of pathway topology matrices, and category records a higher level category for each pathway. If customized annotation is not provided, it will be assumed that the pathways were obtained from the KEGG database and inbuilt KEGG pathway annotation information will be used

colorBy

Can be any column with in the normalisedScores object, or the additional value "community".

communityMethod

A community detection method supported by igraph. See details for all methods available.

foldGSname

logical. Should long gene-set names be folded into two lines

foldafter

The number of words after which gene-set names should be folded. Defaults to 2

labelFun

function to manipulate or modify gene-set labels. By default, any database will be stripped from the prefix using a regex pattern

layout

The layout algorithm to apply. Accepted layouts are "fr", "dh", "gem", "graphopt", "kk", "lgl", "...

markCommunity

character A geom_mark_* method supported by ggforce to annotate sets of nodes belonging to the same community. Either *NULL*, *ellipse*, *circle*, *hull*, *rect*

markAlpha

Transparency of annotation areas.

color_lg_title

Title for the color legend

edgeAlpha

Transparency of edges.

scale_edgeWidth

A numerical vector of length 2 to be provided to ggraph::scale_edge_width_continuous() for specifying the minimum and maximum edge widths after transformation.

edgeLegend

logical Should edge weight legend be shown

scale_nodeSize	A numerical vector of length 2 to be provided to <code>ggplot2::scale_size()</code> for specifying the minimum and maximum node sizes after transformation.
nodeShape	The shape to use for nodes
lb_size	Size of node text labels
lb_color	Color of node text labels
plotIsolated	<code>logical(1)</code> Should nodes not connected to any other nodes be plotted. Defaults to FALSE
...	Used to pass various potting parameters to <code>ggforce::geom_mark_*()</code>

Details

A community detection strategy specified by `communityMethod` will be applied to the pathway-pathway network, and communities will be annotated with the pathway category that had the highest number of occurrence, denoting the main biological processes perturbed in that community.

At the moment, only KEGG pathway categories are provided with the package, so if the provided `normalisedScores` contains perturbation scores of pathways derived from other databases, annotation of communities will not be performed unless pathway information is provided through the `gsAnnotation` object. The category information needs to be provided in a `data.frame` containing `gs_name` (gene-set names) and `category` (categorising the given pathways).

Plotting parameters accepted by `geom_mark_*` could be passed to the function to adjust the annotation area or the annotation label. See [geom_mark_ellipse](#) for more details.

Value

A `ggplot2` object

Examples

```
load(system.file("extdata", "gsTopology.rda", package = "sSNAPPY"))
load(system.file("extdata", "normalisedScores.rda", package = "sSNAPPY"))
#Subset the first 10 rows of the normalisedScores data.frame as an example
subset <- normalisedScores[1:15,]
subset$status <- ifelse(subset$robustZ > 0, "Activated", "Inhibited")
# Color network plot nodes by the community they were assigned to and mark
# nodes belonging to the same community by ellipses
plot_community(subset, gsTopology, colorBy = "community", layout = "kk",
color_lg_title = "Community")

# Color network plot nodes by pathways' directions of changes and mark nodes
# belonging to the same community by ellipses
plot_community(subset, gsTopology, colorBy = "status", layout = "kk",
color_lg_title = "Direction of pathway perturbation")

# To change the colour and fill of `geom_mark_*` annotation, use any
# `scale_fill_*` and/or `scale_color_*`
# functions supported by `ggplot2`. For example:
p <- plot_community(subset, gsTopology, colorBy = "status", layout = "kk",
markCommunity = "rect", color_lg_title = "Direction of pathway perturbation")
p + ggplot2::scale_color_ordinal() + ggplot2::scale_fill_ordinal()
```

plot_gene_contribution

Plot genes' contribution to a pathway's perturbation as a heatmap

Description

Plot individual genes' contributions to the pathway-level perturbation score

Usage

```
plot_gene_contribution(
  genePertMatr,
  mapEntrezID = NULL,
  topGene = 10,
  filterBy = c("mean", "sd", "max.abs"),
  annotation_df = NULL,
  ...
)
```

Arguments

genePertMatr	A matrix of gene-wise perturbation scores corresponding to a pathway. An element of the output generated using function <code>raw_gene_pert()</code>
mapEntrezID	Optional. A data.frame matching genes' entrez IDs to another identifier with preferred labels. Must contain the columns: "entrezid" and "mapTo"
topGene	Numeric(1). The number of top genes to plot
filterBy	Filter top genes by the mean, variability (sd), maximum value, or maximum absolute values
annotation_df	A data.frame for annotating heatmap columns. Must contain a "sample" column with sample names matching to the column names of the genePertMatr
...	Used to pass various potting parameters to <code>pheatmap::pheatmap()</code>

Details

The single-sample pathway-level perturbation score for a given pathway is derived from aggregating all the gene-wise perturbation scores of genes in that pathway. This function visualises individual pathway genes' perturbation scores as a heatmap to demonstrate pathway genes' contribution to a pathway perturbation.

Plotting of the heatmap is done through `pheatmap::pheatmap()` so all plotting parameters accepted by `pheatmap::pheatmap()` could also be passed to this function.

References

Kolde R (2019). *pheatmap: Pretty Heatmaps*. R package version 1.0.12, <https://CRAN.R-project.org/package=pheatmap>.

Examples

```

#compute weighted single sample logFCs
data(metadata_example)
data(logCPM_example)
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
# compute single-sample logFCs for all treated samples
ls <- weight_ss_fc(logCPM_example, metadata = metadata_example,
groupBy = "patient", treatColumn = "treatment", sampleColumn = "sample")

# extract all the KEGG pathways
gsTopology <- retrieve_topology(database = "kegg", species = "hsapiens")

# compute raw gene-wise perturbation scores
genePertScore <- raw_gene_pert(ls$logFC, gsTopology)
# sum gene-wise perturbation scores to derive the pathway-level single-sample perturbation scores
pathwayPertScore <- pathway_pert(genePertScore)

# Genes with top 10 mean absolute gene-wise perturbation scores in the
# Estrogen signaling pathway was visualised.
plot_gene_contribution(genePertScore$`kegg.Estrogen signaling pathway`,
filterBy = "mean", topGene = 10)

# Columns of the heatmap could be annotated by the pathway-level perturbation
# and treatments. Firstly, create a `data.frame` with the two annotation
# attributes and sample names matching the column names of the perturbation
# score matrix.
annotation_df <- dplyr::select(metadata_example, sample, treatment)
pathwayLevel <- dplyr::filter(pathwayPertScore,
gs_name == "kegg.Estrogen signaling pathway")
pathwayLevel$`pathway-level` <- ifelse(
pathwayLevel$score > 0, "Activated", "Inhibited")
annotation_df <- dplyr::left_join(
dplyr::select(pathwayLevel, sample, `pathway-level`),
annotation_df, unmatched = "drop")
# To make the gene labels more informative, also map genes' entrez id
# to chosen identifiers.
load(system.file("extdata", "entrez2name.rda", package = "sSNAPPY"))
plot_gene_contribution(genePertScore$`kegg.Estrogen signaling pathway`,
topGene = 10, filterBy = "mean", annotation_df = annotation_df,
mapEntrezID = entrez2name)

# Plotting parameters accepted by `pheatmap::pheatmap()` could be passed to
# this function to customise the plot. For example, changin the color of annotations
plot_gene_contribution(genePertScore$`kegg.Estrogen signaling pathway`,
topGene = 10, filterBy = "mean", annotation_df = annotation_df,
mapEntrezID = entrez2name, annotation_colors = list(
treatment = c(R5020 = "black", `E2+R5020` = "white"),
`pathway-level` = c(Activated = "darkred", Inhibited = "lightskyblue")))

```

plot_gs2gene

*Plot pathways and genes contained in them as a network***Description**

Plot pathways and genes contained in them as a network

Usage

```
plot_gs2gene(
  normalisedScores,
  gsTopology,
  geneFC = NULL,
  mapEntrezID = NULL,
  colorGsBy = NULL,
  foldGSname = TRUE,
  foldafter = 2,
  labelFun = .rm_prefix,
  filterGeneBy = 2,
  layout = c("fr", "dh", "gem", "graphopt", "kk", "lgl", "mds", "sugiyama"),
  edgeColor = "darkgrey",
  edgeAlpha = 0.8,
  edgeArc = 0.5,
  geneNodeSize = 3,
  geneNodeShape = 17,
  geneNameFace = c("italic", "plain", "bold", "bold-italic"),
  geneNameColor = "grey30",
  geneNameSize = 3,
  labelGene = TRUE,
  gsNodeSize = 2,
  gsNodeShape = 21,
  gsNodeStroke = 0.5,
  gsNodeOutline = "white",
  gsNameSize = 6,
  gsNameColor = "black",
  geneLegTitle = "Mean logFC",
  gsLegTitle = colorGsBy,
  maxOverlaps = 10,
  ...
)
```

Arguments

normalisedScores

A data.frame derived from the normalise_by_permu() function. Only gene-sets of interest should be included

gsTopology

List of pathway topology matrices generated using function retrieve_topology()

geneFC	An optional named vector of pathways' fold changes
mapEntrezID	Optional. A data.frame matching genes' entrez IDs to another identifier with preferred labels. Must contain the columns: "entrezid" and "mapTo"
colorGsBy	Column within normalisedScores to color gene-set/pathway nodes by
foldGSname	logical. Should long gene-set names be folded into two lines
foldafter	The number of words after which gene-set names should be folded.
labelFun	function to manipulate or modify gene-set labels. By default, any database will be stripped from the prefix using a regex pattern
filterGeneBy	Filtration cut-off applied to genes' connectivity (ie. how many pathways was a gene involved in).
layout	The layout algorithm to apply. Accepts all layout supported by igraph.
edgeColor, edgeAlpha	Color and transparency of edges
edgeArc	The bend of edges. 1 approximates a semi-circle whilst 0 will give a straight line.
geneNodeSize, geneNodeShape	Size and shape for gene nodes
geneNameSize, geneNameColor, geneNameFace	Size, color and fontface to use for gene labels
labelGene	logical(1) Should the gene names be included
gsNodeSize	Size for gene-set/pathway nodes
gsNodeShape	Shape for gene-set/pathway nodes. Should be a shape with a fill parameter, such as 21:25
gsNodeStroke, gsNodeOutline	Border thickness and color for gene-set/pathway nodes
gsNameSize, gsNameColor	Size and color of gene-set/pathway labels
geneLegTitle	character(1). Legend title for gene nodes
gsLegTitle	character(1) Legend title for gene-set/pathway nodes
maxOverlaps	passed to geom_node_text
...	Not used

Details

Taking the perturbation scores of a list of gene-sets derived from `normalise_by_permu()` as input, this function matches gene-sets to their associated genes by utilizing information from pathway topology matrices.

If providing logFC values as a named vector, the names must be entrezgene IDs in the format of "ENTREZID:XXXX" for compatibility with the values returned by `retrieve_topology()`. If not providing this vector, only genes associated with two or more pathways will be added to the plot, however, it should be noted that if omitting this vector, network plots can easily become unmanageable.

Users can also choose to provide a `mapEntrezID` `data.frame` to match `entrezgene` IDs to their chosen identifiers. The `data.frame` should contain the columns: `"entrezid"` and `"mapTo"`.

If `geneFC` is provided, gene nodes will be colored by values provided, otherwise all gene nodes will be drawn in grey.

Since some gene-sets could contain hundreds of genes, it is not recommended to plot all genes. If `mapEntrezID` `data.frame` is provided, only genes included in that `data.frame` will be used in the plot.

It is strongly recommended to filter genes using some criteria, such as those with the largest magnitude of change. If all pathway genes are desired, please consider setting `labelGene` to `FALSE` to remove gene names.

Value

A `ggplot2` object

Examples

```
load(system.file("extdata", "gsTopology.rda", package = "sSNAPPY"))
load(system.file("extdata", "normalisedScores.rda", package = "sSNAPPY"))

# Subset pathways significantly perturbed in sample R5020_N2_48
subset <- dplyr::filter(normalisedScores, adjPvalue < 0.05, sample == "R5020_N2_48")
subset$response <- ifelse(subset$robustZ > 0, "Activated", "Inhibited")

# Color gene-sets nodes by robust z-scores.
plot_gs2gene(
  subset, gsTopology, colorGsBy = "robustZ", labelGene = FALSE, geneNodeSize = 1,
  gsNodeSize = 4
) + scale_fill_gradient2()
# When fold-changes are not provided, gene nodes are colored grey.

# To color genes by their direction of change, firstly compute single-sample logFC
data(logCPM_example)
data(metadata_example)
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
ls <- weight_ss_fc(
  logCPM_example, metadata = metadata_example,
  groupBy = "patient", treatColumn = "treatment",
  sampleColumn = "sample"
)
# Provide fold-changes of sample R5020_N2_48 as a named vector
plot_gs2gene(
  subset, gsTopology, geneFC = ls$logFC[, "R5020_N2_48"],
  colorGsBy = "response", labelGene = FALSE
) + scale_colour_gradient2()

# By default, the function only include genes involved in at least 2 pathways,
# which can be overwritten by the `filterGeneBy` parameter. But there are still
# a large number of genes, making the plot cumbersome. Instead, only include
# fold-changes of genes within the top 500 absolute values for fold-change
```

```

top500 <- rank(1/abs(ls$logFC[, "R5020_N2_48"])) <= 500
fcByDir <- ifelse(ls$logFC[top500, "R5020_N2_48"] > 0, "Up-Regulated", "Down-Regulated")
plot_gs2gene(subset, gsTopology, geneFC = fcByDir, colorGsBy = "response") +
  scale_fill_manual(values = c("darkred", "lightskyblue")) +
  scale_colour_manual(values = c("red", "blue"))

# To make the gene labels more informative, map genes' entrez id to chosen identifiers.
load(system.file("extdata", "entrez2name.rda", package = "sSNAPPY"))
plot_gs2gene(
  subset, gsTopology, geneFC = fcByDir, mapEntrezID = entrez2name,
  colorGsBy = "response", gsNodeSize = 4
) +
  scale_fill_manual(values = c("darkred", "lightskyblue"), name = "Pathway") +
  scale_colour_manual(values = c("blue", "red"), name = "Gene\nDirection")

```

plot_gs_network

Plot significantly perturbed gene-sets as a network

Description

Plot significantly perturbed gene-sets as a network

Usage

```

plot_gs_network(
  normalisedScores,
  gsTopology,
  colorBy = NULL,
  foldGSname = TRUE,
  foldafter = 2,
  labelFun = .rm_prefix,
  layout = c("fr", "dh", "gem", "graphopt", "kk", "lgl", "mds", "sugiyama"),
  edgeAlpha = 0.8,
  edgeWidthScale = c(0.5, 3),
  edgeLegend = FALSE,
  nodeSizeScale = c(3, 6),
  nodeShape = 16,
  showLegend = TRUE,
  gsLegTitle = NULL,
  gsNameSize = 3,
  gsNameColor = "black",
  plotIsolated = FALSE,
  maxOverlaps = 10,
  ...
)

```

Arguments

normalisedScores	A data.frame of pathway perturbation scores derived from the <code>normalise_by_permu()</code> function
gsTopology	List of pathway topology matrices generated using function <code>retrieve_topology()</code>
colorBy	Choose to color nodes either by <i>robustZ</i> or <i>pvalue</i> . A column must exist in the <code>normalisedScores</code> data.frame for the chosen parameter
foldGSname	logical(1) Should long gene-set names fold across multiple lines
foldafter	The number of words after which gene-set names should be folded. Defaults to 2
labelFun	function to manipulate or modify gene-set labels. By default, any database will be stripped from the prefix using a regex pattern
layout	The layout algorithm to apply. Accept all layout supported by <code>igraph</code>
edgeAlpha	numeric(1) Transparency of edges. Default to 0.8
edgeWidthScale	A numerical vector of length 2 to be provided to <code>ggraph::scale_edge_width_continuous()</code> for specifying the minimum and maximum edge widths after transformation. Defaults to <code>c(0.5, 3)</code>
edgeLegend	logical(1) Should edge weight legend be shown
nodeSizeScale	A numeric vector of length 2 to be provided to <code>ggplot2::scale_size()</code> for specifying the minimum and maximum node sizes after transformation. Defaulted to <code>c(3,6)</code>
nodeShape	Shape of nodes
showLegend	logical(1) Should color legend be shown
gsLegTitle	Optional title for the color legend
gsNameSize	Size of node text labels
gsNameColor	Color of node text labels
plotIsolated	logical(1) Should nodes not connected to any other nodes be plotted. Defaults to FALSE
maxOverlaps	passed to geom_node_text
...	Not used

Value

A `ggplot2` object

Examples

```
load(system.file("extdata", "gsTopology.rda", package = "sSNAPPY"))
load(system.file("extdata", "normalisedScores.rda", package = "sSNAPPY"))

# Subset pathways significantly perturbed in sample R5020_N2_48
subset <- dplyr::filter(
  normalisedScores, adjPvalue < 0.05, sample == "R5020_N2_48"
```

```

)
subset[["status"]] <- ifelse(subset[["robustZ"]] > 0, "Activated", "Inhibited")

# Color network plot nodes by status
plot_gs_network(subset, gsTopology,
  colorBy = "status", layout = "dh",
  gsLegTitle = "Direction of pathway Perturbation")

# Color network plot nodes by p-values
plot_gs_network(subset, gsTopology, layout = "dh",
  colorBy = "pvalue", gsLegTitle = "P-value")

```

rank_gene_pert	<i>Rank genes by perturbation scores within each sample</i>
----------------	---

Description

Rank genes by gene-wise raw perturbation scores within each sample to compare genes' contributions to pathway perturbations.

Usage

```
rank_gene_pert(genePertScore, gsTopology)
```

Arguments

genePertScore	List of gene-wise raw perturbation score matrices generated using function <code>raw_gene_pert()</code>
gsTopology	List of pathway topology matrices generated using function <code>retrieve_topology()</code>

Details

Ranking is performed within each sample each pathway. If in a given pathway, both positive and negative gene-wise perturbation scores exist, positive and negative scores are ranked separately, where the larger a positive rank, the more the gene contributed to the pathway's activation, and the smaller a negative rank, the more the gene contributed to the pathways' inhibition. When there's a tie in two gene's perturbation score within a sample, the mean of the indices is used.

Value

A list where each element is a matrix corresponding to a pathway. Each column of an element corresponds to a sample, and each row corresponds to a pathway gene.

Examples

```
#compute weighted single sample logFCs
data(metadata_example)
data(logCPM_example)
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
ls <- weight_ss_fc(logCPM_example, metadata = metadata_example,
  groupBy = "patient", treatColumn = "treatment", sampleColumn = "sample")
# extract all the KEGG pathways
gsTopology <- retrieve_topology(database = "kegg", species = "hsapiens")
# compute raw gene-wise perturbation scores
genePertScore <- raw_gene_pert(ls$logFC, gsTopology)
# rank genes by gene-wise perturbation scores within each sample
# to compare their contributions to pathway perturbation
geneRank <- rank_gene_pert(genePertScore, gsTopology)
```

raw_gene_pert	<i>Compute Gene-wise Perturbation Score</i>
---------------	---

Description

Propagate weighted single sample logFCs down the pathway topologies to compute gene-wise perturbation score per gene per sample per pathway

Usage

```
raw_gene_pert(weightedFC, gsTopology)
```

Arguments

- weightedFC A matrix of weighted single sample logFCs derived from function weight_ss_fc()
- gsTopology List of pathway topology matrices generated using function retrieve_topology()

Details

This function use the algorithm adopted from SPIA (see citation) to integrate genes' changes in expression and gene-gene interaction to compute gene-wise perturbation score per gene per sample per pathway. The rownames of the weighted single sample logFC matrix and the pathway topology matrices must use the same type of gene identifier (ie. entrez ID).

Pathways with zero perturbation scores across all genes and samples will be dropped from the output.

Value

A list where each element is a matrix corresponding to a pathway. Each column of an element corresponds to a sample, and each row corresponds to a pathway gene.

References

Tarca AL, Draghici S, Khatri P, Hassan SS, Mittal P, Kim JS, Kim CJ, Kusanovic JP, Romero R. A novel signaling pathway impact analysis. *Bioinformatics*. 2009 Jan 1;25(1):75-82.

Examples

```
#compute weighted single sample logFCs
data(metadata_example)
data(logCPM_example)
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
ls <- weight_ss_fc(logCPM_example, metadata = metadata_example,
  groupBy = "patient", treatColumn = "treatment", sampleColumn = "sample")
# extract all the KEGG pathways
gsTopology <- retrieve_topology(database = "kegg", species = "hsapiens")
# compute raw gene-wise perturbation scores
genePertScore <- raw_gene_pert(ls$logFC, gsTopology)
```

retrieve_topology	<i>Retrieve pathway topology as weighted adjacency matrix</i>
-------------------	---

Description

Retrieve pathway topology matrices and convert them to normalized weighted directed adjacency matrices describing gene signaling networks.

Usage

```
retrieve_topology(
  database = c("kegg", "pathbank", "wikipathways", "reactome", "panther", "pharmgkb",
    "smpdb"),
  species = c("hsapiens", "athaliana", "btaurus", "celegans", "cfamiliaris",
    "dmelanogaster", "drerio", "ecoli", "ggallus", "mmusculus", "rnorvegicus",
    "scerevisiae", "sscrofa", "xlaevis"),
  keyword = NULL,
  beta = NULL
)
```

Arguments

database	A character vector of supported databases.
species	One of the supported species,
keyword	Optional. Areas of interests as a character vector.
beta	Optional. A named numeric vector of weights to be assigned to each type of gene/protein relation type. See details for more information.

Details

This function takes pathway topology information retrieved using `graphite` and converts these to normalized weighted directed adjacency matrices describing the gene signaling network, which can be used to compute gene-wise and pathway-level perturbation score through the scoring algorithm derived from the *SPIA* algorithm. See cited document for more details.

The database parameter may specify multiple databases but only one species can be provided to the species parameter.

Users can provide areas of interests as keywords, which will be matched to pathway names from chosen databases to subset pathways. Cases will be ignored in string matchings.

The beta parameter specifies weights to be assigned to each type of gene-gene interaction. It should be a named numeric vector of length 25, whose names must be: `c("activation", "compound", "binding/association", "expression", "inhibition", "activation_phosphorylation", "phosphorylation", "indirect", "inhibition_phosphorylation", "dissociation", "dephosphorylation", "activation_dephosphorylation", "state", "activation_indirect", "inhibition_indirect", "indirect_inhibition", "repression", "binding/association_phosphorylation", "dissociation_phosphorylation", "indirect_phosphorylation")`.

If unspecified, beta will be set as an integer vector with: a) values of 1 for interactions which match 'expression' or 'activation'; b) values of -1 for interactions which match 'repression' or 'inhibition'; and c) 0 elsewhere. The converted weighted adjacent matrices will be stored in a list. We recommend users to store the returned list as a file so this step only needs to be performed once for each database.

Value

A list where each element is a matrix corresponding to a pathway

References

Tarca AL, Draghici S, Khatri P, Hassan SS, Mittal P, Kim JS, Kim CJ, Kusanovic JP, Romero R. A novel signaling pathway impact analysis. *Bioinformatics*. 2009 Jan 1;25(1):75-82. Sales, G., Calura, E., Cavalieri, D. et al. `graphite` - a Bioconductor package to convert pathway topology to gene network. *BMC Bioinformatics* 13, 20 (2012).

Examples

```
# retrieve pathway topology matrices of all KEGG pathway
gsTopology <- retrieve_topology(database = "kegg", species = "hsapiens")

# If only interested in selected pathways, specify the areas of interest as
# keywords
gsTopology <- retrieve_topology(database = "kegg",
keyword = c("metabolism", "signaling"), species = "hsapiens")
```

sSNAPPY	<i>sSNAPPY: A package for testing directional single sample pathway perturbation</i>
---------	--

Description

A package for testing directional single sample pathway perturbation

weight_ss_fc	<i>Compute weighted single sample LogFCs from normalised logCPM</i>
--------------	---

Description

Compute weighted single sample logFCs for each treated samples using normalized logCPM values. Fit a lowess curve on variances ~ mean of logCPM values, and use it to predict gene-wise weights. The weighted single sample logFCs are ready to be used for computing perturbation scores.

Usage

```
weight_ss_fc(expreMatrix, metadata = NULL, sampleColumn, treatColumn, groupBy)

## S4 method for signature 'matrix'
weight_ss_fc(expreMatrix, metadata = NULL, sampleColumn, treatColumn, groupBy)

## S4 method for signature 'data.frame'
weight_ss_fc(expreMatrix, metadata = NULL, sampleColumn, treatColumn, groupBy)

## S4 method for signature 'DGEList'
weight_ss_fc(expreMatrix, metadata = NULL, sampleColumn, treatColumn, groupBy)

## S4 method for signature 'SummarizedExperiment'
weight_ss_fc(expreMatrix, metadata = NULL, sampleColumn, treatColumn, groupBy)
```

Arguments

expreMatrix	matrix or data.frame of logCPM, or DGEList/ SummarizedExperiment storing gene expression counts and sample metadata. Feature names need to be in entrez IDs, and column names need to be sample names
metadata	Sample metadata data.frame as described in the details section.
sampleColumn	Name of the column in the metadata containing column names of the expreMatrix
treatColumn	Name of the column in the metadata containing treatment information. The column must be a factor with the reference level set to be the control treatment.
groupBy	Name of the column in the metadata containing information for how samples are matched in pairs (eg. patient).

Details

This function computes weighted single-sample logFCs from normalised logCPM values, used for computing single-sample perturbation scores.

Since genes with smaller logCPM turn to have larger variances among single sample logFCs. A lowess curve will be fitted to estimate the relationship between variances and mean of logCPM, and the relationship will be used to estimate the variance of each mean logCPM value. Gene-wise weights, which are defined to be inverse of variances, will then be multiplied to single-sample logFCs to down-weight genes with low counts.

It is assumed that the genes with extremely low counts have been removed and the count matrix has been normalised prior to the logCPM matrix was derived. Row names of the matrix must be in genes' entrez IDs.

If a S4 object of DGEList or SummarizedExperiment is provided as input to `expreMatrix`, the gene expression matrix will be extracted from it and converted to a logCPM matrix. Sample metadata will also be extracted from the same S4 object unless otherwise specified.

Provided sample metadata should have the same number of rows as the number of columns in the logCPM matrix and must contain the a column for treatment, one for sample names and a column for how samples should be matched into pairs.

Value

A list with two elements: `$weight` gene-wise weights; `$logFC` weighted single sample logFC matrix

Examples

```
# Inspect metadata data frame to make sure it has treatment, sample
# and patient columns
data(metadata_example)
data(logCPM_example)
# Set the treatment column to be a factor where the reference is the control
#treatment
metadata_example <- dplyr::mutate(metadata_example, treatment = factor(
  treatment, levels = c("Vehicle", "E2+R5020", "R5020")))
ls <- weight_ss_fc(logCPM_example, metadata = metadata_example,
  sampleColumn = "sample", groupBy = "patient", treatColumn = "treatment")
```

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