Package 'EnrichmentBrowser'

October 9, 2015

Version 1.2.2

Date 2015-08-31

Title Seamless navigation through combined results of set-based and network-based enrichment analysis

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Depends R(>= 3.0.0), Biobase, GSEABase, pathview

Imports AnnotationDbi, ComplexHeatmap, DESeq2, EDASeq, GenomicRanges, GO.db, KEGGREST, KEGGgraph, MASS, PathNet, ReportingTools, Rgraphviz, S4Vectors, SparseM, SPIA, biocGraph, biomaRt, edgeR, geneplotter, graph, hwriter, limma, mixtools, neaGUI, npGSEA, safe, stringr, topGO

Suggests ALL, BiocStyle, airway, hgu95av2.db

Description The EnrichmentBrowser package implements essential functionality for the enrichment analysis of gene expression data. The analysis combines the advantages of set-based and network-based enrichment analysis in order to derive high-confidence gene sets and biological pathways that are differentially regulated in the expression data under investigation. Besides, the package facilitates the visualization and exploration of such sets and pathways.

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biocViews Microarray, RNASeq, GeneExpression, DifferentialExpression, Pathways, GraphAndNetwork, Network, GeneSetEnrichment, NetworkEnrichment, Visualization, ReportWriting

NeedsCompilation no

R topics documented:

`comb.ea.results` *Combining enrichment analysis results*

Description

Different enrichment analysis methods usually result in different gene set rankings for the same dataset. This function allows to combine results from the different set-based and network-based enrichment analysis methods. This includes the computation of average gene set ranks across methods.

Usage

```
comb.ea.results( res.list,
    rank.col=config.ebrowser("GSP.COL"),
    decreasing=FALSE,
    rank.fun = c("comp.ranks", "rel.ranks", "abs.ranks"),
    comb.fun = c("mean", "median", "min", "max", "sum") )
```

Arguments

`res.list`	A list of enrichment analysis result lists (as returned by the functions sbea and nbea).
`rank.col`	Rank column. Column name of the enrichment analysis result table that should be used to rank the gene sets. Defaults to the gene set p-value column, i.e. gene sets are ranked according to gene set significance.
`decreasing`	Logical. Should smaller (decreasing=FALSE, default) or larger (decreasing=TRUE) values in rank.col be ranked better? In case of gene set p-values the smaller the better, in case of gene set scores the larger the better.

`rank.fun` Ranking function. Used to rank gene sets according to the result table of individual enrichment methods (as returned from the `gs.ranking` function). This is typically done according to gene set p-values, but can also take into account gene set scores/statistics, especially in case of gene sets with equal p-value. Can be either one of the predefined functions ('comp.ranks', 'rel.ranks', 'abs.ranks') or a user-defined function. Defaults to 'comp.ranks', i.e. competitive (percentile) ranks are computed by calculating for each gene set the percentage of gene sets with a p-value as small or smaller. Alternatively, 'rel.ranks', i.e. relative ranks are computed in 2 steps:

1. Ranks are assigned according to distinct gene set p-value *categories*, i.e. gene sets with equal p-value obtain the *same* rank. Thus, the gene sets with lowest p-value obtain rank 1, and so on.
2. As opposed to absolute ranks (rank.fun = 'abs.ranks'), which are returned from step 1, relative ranks are then computed by dividing the absolute rank by number of distinct p-value categories and multiplying with 100 (= percentile rank).

`comb.fun` Rank combination function. Used to combine gene set ranks across methods. Can be either one of the predefined functions (mean, median, max, min, sum) or a user-defined function. Defaults to 'sum', i.e. the rank sum across methods is computed.

Value

An enrichment analysis result list that can be detailedly explored by calling `ea.browse` and from which a flat gene set ranking can be extracted by calling `gs.ranking`.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

`sbea`, `nbea`, `ea.browse`

Examples

```
# (1) expression set:
# simulated expression values of 100 genes
# in two sample groups of 6 samples each
eset <- make.example.data(what="eset")
eset <- de.ana(eset)

# (2) gene sets:
# draw 10 gene sets with 15-25 genes
gs <- make.example.data(what="gs", gnames=featureNames(eset))

# (3) make artificial enrichment analysis results:
# 2 ea methods with 5 significantly enriched gene sets each
ora.res <- make.example.data(what="ea.res", method="ora", eset=eset, gs=gs)
```

```
gsea.res <- make.example.data(what="ea.res", method="gsea", eset=eset, gs=gs)

# (4) combining the results
res.list <- list(ora.res, gsea.res)
comb.res <- comb.ea.results(res.list)

# (5) result visualization and exploration
gs.ranking(comb.res)

# user-defined ranking and combination functions
# (a) dummy ranking, give 1:nrow(res.tbl)
dummy.rank <- function(res.tbl) seq_len(nrow(res.tbl))

# (b) weighted average for combining ranks
wavg <- function(r) mean(c(1,2) * r)

comb.res <- comb.ea.results(res.list, rank.fun=dummy.rank, comb.fun=wavg)
```

`compile.grn.from.kegg` *Compilation of a gene regulatory network from KEGG pathways*

Description

To perform network-based enrichment analysis a gene regulatory network (GRN) is required. There are well-studied processes and organisms for which comprehensive and well-annotated regulatory networks are available, e.g. the RegulonDB for E. coli and Yeastract for S. cerevisiae. However, in many cases such a network is missing. A first simple workaround is to compile a network from regulations in the KEGG database.

Usage

```
compile.grn.from.kegg( pwys, out.file = NULL )
```

Arguments

`pwys`	Either a list of `KEGGPathway` objects or an absolute file path of a zip compressed archive of pathway xml files in KGML format. Alternatively, you can specify an organism in KEGG three letter code, e.g. 'hsa' for 'Homo sapiens', and the pathways will be downloaded automatically.
`out.file`	Optional output file the gene regulatory network will be written to.

Value

if(is.null(out.file)): the gene regulatory network; else: none, as the gene regulatory network is written to file

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

KEGGPathway-class, parseKGML, download.kegg.pathways

Examples

```
# (1) download human pathways
#   pwys <- download.kegg.pathways("hsa")
# (2) compile gene regulatory network
#   grn <- compile.grn.from.kegg(pwys)

pwys <- system.file("extdata/hsa_kegg_pwys.zip", package="EnrichmentBrowser")
hsa.grn <- compile.grn.from.kegg(pwys)
```

---

config.ebrowser *Configuring the EnrichmentBrowser*

Description

Function to get and set configuration parameters determining the default behavior of the EnrichmentBrowser

Usage

```
config.ebrowser( key, value = NULL )
```

Arguments

key	Configuration parameter.
value	Value to overwrite the current value of key.

Details

Important pData, fData, and result column names:

- SMPL.COL: pData column storing the sample IDs (default: "SAMPLE")
- GRP.COL: pData column storing binary group assignment (default: "GROUP")
- BLK.COL: pData column defining paired samples or sample blocks (default: "BLOCK")
- PRB.COL: fData column storing probe/feature IDs ("PROBEID", read-only)
- EZ.COL: fData column storing gene ENTREZ IDs ("ENTREZID", read-only)
- SYM.COL: fData column storing gene symbols ("SYMBOL", read-only)
- GN.COL: fData column storing gene names ("GENENAME", read-only)
- FC.COL: fData column storing (log2) fold changes of differential expression between sample groups (default: "FC")
- ADJP.COL: fData column storing adjusted (corrected for multiple testing) p-values of differential expression between sample groups (default: "ADJ.PVAL")

- GS.COL: result table column storing gene set IDs (default: "GENE.SET")
- GSP.COL: result table column storing gene set significance (default: "P.VALUE")
- PMID.COL: gene table column storing PUBMED IDs ("PUBMED", read-only)

Important URLs (all read-only):

- NCBI.URL: http://www.ncbi.nlm.nih.gov/
- PUBMED.URL: http://www.ncbi.nlm.nih.gov/pubmed/
- GENE.URL: http://www.ncbi.nlm.nih.gov/gene/
- KEGG.URL: http://www.genome.jp/dbget-bin/
- KEGG.GENE.URL: http://www.genome.jp/dbget-bin/www_bget?
- KEGG.SHOW.URL: http://www.genome.jp/dbget-bin/show_pathway?
- GO.SHOW.URL: http://amigo.geneontology.org/amigo/term/

Default output directory:

- EBROWSER.HOME: system.file(package="EnrichmentBrowser")
- OUTDIR.DEFAULT: file.path(EBROWSER.HOME, "results")

Gene set size:

- GS.MIN.SIZE: minimum number of genes per gene set (default: 5)
- GS.MAX.SIZE: maximum number of genes per gene set (default: 500)

Result appearance:

- RESULT.TITLE: (default: "Table of Results")
- NR.SHOW: maximum number of entries to show (default: 20)

Value

If is.null(value) this returns the value of the selected configuration parameter. Otherwise, it updates the selected parameter with the given value.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

Examples

```
# getting config information
config.ebrowser("GS.MIN.SIZE")

# setting config information
# WARNING: this is for advanced users only!
# inappropriate settings will impair EnrichmentBrowser's functionality
config.ebrowser(key="GS.MIN.SIZE", value=3)
```

de.ana *Differential expression analysis between two sample groups*

Description

The function carries out a differential expression analysis between two sample groups. Resulting fold changes and derived p-values are returned. Raw p-values are corrected for multiple testing.

Usage

```
de.ana( expr, grp = NULL, blk = NULL,
  de.method = c("limma", "edgeR", "DESeq"), padj.method = "BH", stat.only=FALSE )
```

Arguments

expr	Expression data. A numeric matrix. Rows correspond to genes, columns to samples. Alternatively, this can also be an object of class ExpressionSet (in case of microarray data) or an object of class SeqExpressionSet (in case of RNA-seq data). See the man page of read.eset for prerequisites for the expression data.
grp	*BINARY* group assignment for the samples. Use '0' and '1' for unaffected (controls) and affected (cases) samples, respectively. If NULL, this is assumed to be defined via a column named 'GROUP' in the pData slot if 'expr' is a (Seq)ExpressionSet.
blk	Optional. For paired samples or sample blocks. This can also be defined via a column named 'BLOCK' in the pData slot if 'expr' is a (Seq)ExpressionSet.
de.method	Differential expression method. Use 'limma' for microarray and RNA-seq data. Alternatively, differential expression for RNA-seq data can be also calculated using edgeR ('edgeR') or DESeq2 ('DESeq'). Defaults to 'limma'.
padj.method	Method for adjusting p-values to multiple testing. For available methods see the man of page the of the stats function p.adjust. Defaults to 'BH'.
stat.only	Logical. Should only the test statistic be returned? This is mainly for internal use, in order to carry out permutation tests on the DE statistic for each gene. Defaults to FALSE.

Value

A DE-table with measures of differential expression for each gene/row, i.e. a two-column matrix with log2 fold changes in the 1st column and derived p-values in the 2nd column. If 'expr' is a (Seq)ExpressionSet, the DE-table will be automatically appended to the fData slot.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

read.eset describes prerequisites for the expression data, normalize for normalization of expression data, voom for preprocessing of RNA-seq data, p.adjust for multiple testing correction, eBayes for DE analysis with limma, glmFit for DE analysis with edgeR, and DESeq for DE analysis with DESeq.

Examples

```
# (1) microarray data: intensity measurements
ma.eset <- make.example.data(what="eset", type="ma")
ma.eset <- de.ana(ma.eset)
head(fData(ma.eset))

# (2) RNA-seq data: read counts
rseq.eset <- make.example.data(what="eset", type="rseq")
rseq.eset <- de.ana(rseq.eset, de.method="DESeq")
head(fData(rseq.eset))
```

---

download.kegg.pathways

Download of KEGG pathways for a particular organism

Description

The function downloads all metabolic and non-metabolic pathways in KEGG XML format for a specified organism.

Usage

```
download.kegg.pathways( org, out.dir = NULL, zip = FALSE )
```

Arguments

org	Organism in KEGG three letter code, e.g. 'hsa' for 'homo sapiens'.
out.dir	Output directory. If not null, pathways are written to files in the specified directory.
zip	Logical. In case pathways are written to file ('out.dir' is not null): should output files be zipped?

Value

if(is.null(out.dir)): a list of KEGGPathway objects else: none, as pathways are written to file

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

keggList, keggGet, KEGGPathway-class, parseKGML

Examples

```
pwys <- download.kegg.pathways("hsa")
```

---

ea.browse *Exploration of enrichment analysis results*

Description

Functions to extract a flat gene set ranking from an enrichment analysis result object and to detailedly explore it.

Usage

```
ea.browse( res, nr.show = -1, graph.view = NULL, html.only = FALSE )

gs.ranking( res, signif.only = TRUE )
```

Arguments

res	Enrichment analysis result list (as returned by the functions sbea and nbea).
nr.show	Number of gene sets to show. As default all statistically significant gene sets are displayed.
graph.view	Optional. Should a graph-based summary (reports and visualizes consistency of regulations) be created for the result? If specified, it needs to be a gene regulatory network, i.e. either an absolute file path to a tabular file or a character matrix with exactly *THREE* cols; 1st col = IDs of regulating genes; 2nd col = corresponding regulated genes; 3rd col = regulation effect; Use '+' and '-' for activation/inhibition.
html.only	Logical. Should the html file only be written (without opening the browser to view the result page)? Defaults to FALSE.
signif.only	Logical. Display only those gene sets in the ranking, which satisfy the significance level? Defaults to TRUE.

Value

gs.ranking: DataFrame with gene sets ranked by the corresponding p-value;

ea.browse: none, opens the browser to explore results.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

sbea, nbea, comb.ea.results

Examples

```
# real data
# (1) reading the expression data from file
exprs.file <- system.file("extdata/exprs.tab", package="EnrichmentBrowser")
pdat.file <- system.file("extdata/pData.tab", package="EnrichmentBrowser")
fdat.file <- system.file("extdata/fData.tab", package="EnrichmentBrowser")
probe.eset <- read.eset(exprs.file, pdat.file, fdat.file)
gene.eset <- probe.2.gene.eset(probe.eset)
gene.eset <- de.ana(gene.eset)
annotation(gene.eset) <- "hsa"

# artificial enrichment analysis results
gs <- make.example.data(what="gs", gnames=featureNames(gene.eset))
ea.res <- make.example.data(what="ea.res", method="ora", eset=gene.eset, gs=gs)

# (5) result visualization and exploration
gs.ranking(ea.res)
ea.browse(ea.res)
```

---

ebrowser *Seamless navigation through enrichment analysis results*

Description

This is the all-in-one wrapper function to perform the standard enrichment analysis pipeline implemented in the EnrichmentBrowser package.

Given flat gene expression data, the data is read in and subsequently subjected to chosen enrichment analysis methods.

The results from different methods can be combined and investigated in detail in the default browser.

Usage

```
ebrowser( meth, exprs, pdat, fdat, org, data.type = c(NA, "ma", "rseq"),
        norm.method = "quantile", de.method = "limma",
        gs, grn = NULL, perm = 1000, alpha = 0.05, beta = 1,
        comb = FALSE, browse = TRUE, nr.show = -1 )
```

Arguments

meth	Enrichment analysis method. Currently, the following enrichment analysis methods are supported: 'ora', 'safe', 'gsea', 'samgs', 'ggea', 'spia', 'nea', and 'pathnet'. See sbea and nbea for details.

exprs — Expression matrix. A tab separated text file containing *normalized* expression values on a *log* scale. Columns = samples/subjects; rows = features/probes/genes; NO headers, row or column names. Supported data types are log2 counts (microarray single-channel), log2 ratios (microarray two-color), and log2-counts per million (RNA-seq logCPMs). See limma's user guide for definition and normalization of the different data types. Alternatively, this can be an object of ExpressionSet-class, assuming the expression matrix in the 'exprs' slot.

pdat — Phenotype data. A tab separated text file containing annotation information for the samples in either *two or three* columns. NO headers, row or column names. The number of rows/samples in this file should match the number of columns/samples of the expression matrix. The 1st column is reserved for the sample IDs; The 2nd column is reserved for a *BINARY* group assignment. Use '0' and '1' for unaffected (controls) and affected (cases) sample class, respectively. For paired samples or sample blocks a third column is expected that defines the blocks. If 'exprs' is an object of ExpressionSet-class, the 'pdat' argument can be left unspecified, which then expects group and optional block assignments in respectively named columns 'GROUP' (mandatory) and 'BLOCK' (optional) in the 'pData' slot of the ExpressionSet.

fdat — Feature data. A tab separated text file containing annotation information for the features. Exactly *TWO* columns; 1st col = feature IDs; 2nd col = corresponding KEGG gene ID for each feature ID in 1st col; NO headers, row or column names. The number of rows/features in this file should match the number of rows/features of the expression matrix. If 'exprs' is an object of ExpressionSet-class, the 'fdat' argument can be left unspecified, which then expects feature and gene IDs in respectively named columns 'PROBE' and 'GENE' in the 'fData' slot of the ExpressionSet.

org — Organism under investigation in KEGG three letter code, e.g. 'hsa' for 'Homo sapiens'. See also kegg.species.code to convert your organism of choice to KEGG three letter code.

data.type — Expression data type. Use 'ma' for microarray and 'rseq' for RNA-seq data. If NA, data.type is automatically guessed. If the expression values in 'eset' are decimal numbers they are assumed to be microarray intensities. Whole numbers are assumed to be RNA-seq read counts. Defaults to NA.

norm.method — Determines whether and how the expression data should be normalized. For available microarray normalization methods see the man page of the limma function normalizeBetweenArrays. For available RNA-seq normalization methods see the man page of the EDASeq function betweenLaneNormalization. Defaults to 'quantile', i.e. normalization is carried out so that quantiles between arrays/lanes/samples are equal. Use 'none' to indicate that the data is already normalized and should not be normalized by ebrowser. See the man page of normalize for details.

de.method — Determines which method is used for per-gene differential expression analysis. See the man page of de.ana for details. Defaults to 'limma', i.e. differential expression is calculated based on the typical limma lmFit procedure.

gs — Gene sets. Either a list of gene sets (vectors of KEGG gene IDs) or a text file in GMT format storing all gene sets under investigation.

grn	Gene regulatory network. Either an absolute file path to a tabular file or a character matrix with exactly *THREE* cols; 1st col = IDs of regulating genes; 2nd col = corresponding regulated genes; 3rd col = regulation effect; Use '+' and '-' for activation/inhibition.
perm	Number of permutations of the expression matrix to estimate the null distribution. Defaults to 1000.
alpha	Statistical significance level. Defaults to 0.05.
beta	Log2 fold change significance level. Defaults to 1 (2-fold).
comb	Logical. Should results be combined if more then one enrichment method is selected? Defaults to FALSE.
browse	Logical. Should results be displayed in the browser for interactive exploration? Defaults to TRUE.
nr.show	Number of gene sets to show. As default all statistical significant gene sets are displayed.

Value

None, opens the browser to explore results.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

References

Limma User's guide: http://www.bioconductor.org/packages/limma

See Also

read.eset to read expression data from file; probe.2.gene.eset to transform probe to gene level expression; kegg.species.code maps species name to KEGG code. get.kegg.genesets to retrieve gene set definitions from KEGG; compile.grn.from.kegg to construct a GRN from KEGG pathways; sbea to perform set-based enrichment analysis; nbea to perform network-based enrichment analysis; comb.ea.results to combine results from different methods; ea.browse for exploration of resulting gene sets

Examples

```
# expression data from file
exprs.file <- system.file("extdata/exprs.tab", package="EnrichmentBrowser")
pdat.file <- system.file("extdata/pData.tab", package="EnrichmentBrowser")
fdat.file <- system.file("extdata/fData.tab", package="EnrichmentBrowser")

# getting all human KEGG gene sets
# hsa.gs <- get.kegg.genesets("hsa")
gs.file <- system.file("extdata/hsa_kegg_gs.gmt", package="EnrichmentBrowser")
hsa.gs <- parse.genesets.from.GMT(gs.file)

# set-based enrichment analysis
```

```
ebrowser(   meth="ora",
        exprs=exprs.file, pdat=pdat.file, fdat=fdat.file,
        gs=hsa.gs, org="hsa", nr.show=3)

# compile a gene regulatory network from KEGG pathways
# hsa.grn <- compile.grn.from.kegg("hsa")
pwys <- system.file("extdata/hsa_kegg_pwys.zip", package="EnrichmentBrowser")
hsa.grn <- compile.grn.from.kegg(pwys)

# network-based enrichment analysis
ebrowser(   meth="ggea",
        exprs=exprs.file, pdat=pdat.file, fdat=fdat.file,
        gs=hsa.gs, grn=hsa.grn, org="hsa", nr.show=3 )

# combining results
ebrowser(   meth=c("ora", "ggea"), comb=TRUE,
        exprs=exprs.file, pdat=pdat.file, fdat=fdat.file,
        gs=hsa.gs, grn=hsa.grn, org="hsa", nr.show=3 )
```

`get.go.genesets` *Definition of gene sets according to the Gene Ontology (GO)*

Description

This function retrieves GO gene sets for an organism under investigation either via download from BioMart or based on BioC annotation packages.

Usage

```
get.go.genesets( org, onto = c("BP", "MF", "CC"), mode = c("GO.db","biomart") )
```

Arguments

`org`	An organism in (KEGG) three letter code, e.g. 'hsa' for 'Homo sapiens'.
`onto`	Character. Specifies one of the three GO ontologies: 'BP' (biological process), 'MF' (molecular function), 'CC' (cellular component). Defaults to 'BP'.
`mode`	Character. Determines in which way the gene sets are retrieved. This can be either 'GO.db' or 'biomart'. The 'GO.db' mode creates the gene sets based on BioC annotation packages - which is fast, but represents not necessarily the most up-to-date mapping. In addition, this option is only available for the currently supported model organisms in BioC. The 'biomart' mode downloads the mapping from BioMart - which can be time consuming, but allows to select from a larger range of organisms and contains the latest mappings. Defaults to 'GO.db'.

Value

A list of gene sets (vectors of gene IDs).

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

References

http://geneontology.org/

See Also

annFUN for general GO2gene mapping used in the 'GO.db' mode, getBM for general queries to BioMart. get.kegg.genesets for defining gene sets according to KEGG, parse.genesets.from.GMT to parse user-def. gene sets from file.

Examples

```
# Typical usage for gene set enrichment analysis:
# Biological process terms based on BioC annotation (for human)
gs <- get.go.genesets("hsa")

# eq.:
# gs <- get.go.genesets(org="hsa", onto="BP", mode="GO.db")

# Alternatively:
# downloading from BioMart
# this may take a few minutes ...

gs <- get.go.genesets(org="hsa", mode="biomart")
```

---

get.kegg.genesets *Definition of gene sets according to KEGG pathways for a specified organism*

Description

To perform a gene set enrichment analysis on KEGG pathways, it is necessary to build up the gene set database in a format that the GSEA method can read. Parsing a list of gene sets from a flat text file in GMT format. This function performs the necessary steps, including the retrieval of the participating gene IDs for each pathway and the conversion to GMT format.

Usage

```
get.kegg.genesets( pwys, gmt.file = NULL )

parse.genesets.from.GMT( gmt.file )
```

Arguments

pwys	Either a list of KEGGPathway objects or an absolute file path of a zip compressed archive of pathway xml files in KGML format. Alternatively, an organism in KEGG three letter code, e.g. 'hsa' for 'Homo sapiens'.
gmt.file	Gene set file in GMT format. See details.

Details

The GMT (Gene Matrix Transposed) file format is a tab delimited file format that describes gene sets. In the GMT format, each row represents a gene set. Each gene set is described by a name, a description, and the genes in the gene set. See references.

Value

A list of gene sets (vectors of gene IDs).

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

References

GMT file format http://www.broadinstitute.org/cancer/software/gsea/wiki/index.php/Data_formats

KEGG Organism code http://www.genome.jp/kegg/catalog/org_list.html

See Also

keggList, keggLink, KEGGPathway-class, parseKGML

Examples

```
# WAYS TO DEFINE GENE SETS ACCORDING TO HUMAN KEGG PATHWAYS

# (1) from scratch: via organism ID

gs <- get.kegg.genesets("hsa")


# (2) extract from pathways
# download human pathways via:
# pwys <- download.kegg.pathways("hsa")
pwys <- system.file("extdata/hsa_kegg_pwys.zip", package="EnrichmentBrowser")
gs <- get.kegg.genesets(pwys)

# (3) parsing gene sets from GMT
gmt.file <- system.file("extdata/hsa_kegg_gs.gmt", package="EnrichmentBrowser")
gs <- parse.genesets.from.GMT(gmt.file)
```

ggea.graph *GGEA graphs of consistency between regulation and expression*

Description

Gene graph enrichment analysis (GGEA) is a network-based enrichment analysis method implemented in the EnrichmentBrowser package. The idea of GGEA is to evaluate the consistency of known regulatory interactions with the observed gene expression data. A GGEA graph for a gene set of interest displays the consistency of each interaction in the network that involves a gene set member. Nodes (genes) are colored according to expression (up-/down-regulated) and edges (interactions) are colored according to consistency, i.e. how well the interaction type (activation/inhibition) is reflected in the correlation of the expression of both interaction partners.

Usage

```
ggea.graph( gs, grn, eset,
    alpha = 0.05, beta = 1, max.edges = 50, cons.thresh = 0.7 )

ggea.graph.legend()
```

Arguments

gs	Gene set under investigation. This should be a character vector of KEGG gene IDs.
grn	Gene regulatory network. Character matrix with exactly *THREE* cols; 1st col = IDs of regulating genes; 2nd col = corresponding regulated genes; 3rd col = regulation effect; Use '+' and '-' for activation/inhibition.
eset	Expression set. An object of class ExpressionSet containing the gene expression set. See read.eset and probe.2.gene.eset for required annotations in the pData and fData slot.
alpha	Statistical significance level. Defaults to 0.05.
beta	Log2 fold change significance level. Defaults to 1 (2-fold).
max.edges	Maximum number of edges that should be displayed. Defaults to 50.
cons.thresh	Consistency threshold. Graphical parameter that correspondingly increases line width of edges with a consistency above the chosen threshold (defaults to 0.7).

Value

None, plots to a graphics device.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

nbea to perform network-based enrichment analysis. ea.browse for exploration of resulting gene sets.

Examples

```
# (1) expression set:
# simulated expression values of 100 genes
# in two sample groups of 6 samples each
eset <- make.example.data(what="eset")
eset <- de.ana(eset)

# (2) gene sets:
# draw 10 gene sets with 15-25 genes
gs <- make.example.data(what="gs", gnames=featureNames(eset))

# (3) compiling artificial regulatory network
grn <- make.example.data(what="grn", nodes=featureNames(eset))

# (4) plot consistency graph
ggea.graph(gs=gs[[1]], grn=grn, eset=eset)

# (5) get legend
ggea.graph.legend()
```

---

make.example.data *Example data for the EnrichmentBrowser package*

Description

Functionality to construct example data sets for demonstration. This includes expression data, gene sets, gene regulatory networks, and enrichment analysis results.

Usage

```
make.example.data( what = c("eset", "gs", "grn", "ea.res"), ... )
```

Arguments

what	Kind of example data set to be constructed. This should be one out of: • eset: Expression set • gs: Gene set list • grn: Gene regulatory network • ea.res: Enrichment analysis result object as returned by the functions sbea and nbea
...	Additional arguments to fine-tune the specific example data sets. For what='eset':

- type: Expression data type. Should be either 'ma' (Microarray intensity measurements) or 'rseq' (RNA-seq read counts).
- nfeat: Number of features/genes. Defaults to 100.
- nsmpl: Number of samples. Defaults to 12.
- blk: Create sample blocks. Defaults to TRUE.
- norm: Should the expression data be normalized? Defaults to FALSE.
- de.ana: Should an differential expression analysis be carried out automatically? Defaults to FALSE.

For what='gs':

- gnames: gene names from which the sets will be sampled. Per default the sets will be drawn from c(g1, ..., g100).
- n: number of sets. Defaults to 10.
- min.size: minimal set size. Defaults to 15.
- max.size: maximal set size. Defaults to 25.

For what='grn':

- nodes: gene node names for which edges will be drawn. Per default node names will be c(g1, ..., g100).
- edge.node.ratio: ratio number of edges / number of nodes. Defaults to 3, i.e. creates 3 times more edges than nodes.

For what='ea.res':

- eset: Expression set. Calls make.example.data(what="eset") per default.
- gs: Gene sets. Calls make.example.data(what="gs") per default.
- method: Enrichment analysis method. Defaults to 'ora'.
- alpha: Statistical significance level. Defaults to 0.05.

Value

Depends on the 'what' argument.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

Examples

```
eset <- make.example.data(what="eset")
```

nbea *Network-based enrichment analysis (NBEA)*

Description

This is the main function for network-based enrichment analysis. It implements and wraps existing implementations of several frequently used state-of-art methods and allows a flexible inspection of resulting gene set rankings.

Usage

```
nbea( method = nbea.methods(), eset, gs, grn, alpha = 0.05,
    perm = 1000, padj.method = "none", out.file = NULL, browse = FALSE, ... )

nbea.methods()
```

Arguments

method	Network-based enrichment analysis method. Currently, the following network-based enrichment analysis methods are supported: 'ggea', 'nea', 'spia', 'path-net'. See Details. Default is 'ggea'. This can also be the name of a user-defined function implementing network-based enrichment. See Details.
eset	Expression set. An object of class ExpressionSet. See read.eset and probe.2.gene.eset for required annotations in the pData and fData slot.
gs	Gene sets. Either a list of gene sets (vectors of KEGG gene IDs) or a text file in GMT format storing all gene sets under investigation.
grn	Gene regulatory network. Either an absolute file path to a tabular file or a character matrix with exactly *THREE* cols; 1st col = IDs of regulating genes; 2nd col = corresponding regulated genes; 3rd col = regulation effect; Use '+' and '-' for activation/inhibition.
alpha	Statistical significance level. Defaults to 0.05.
perm	Number of permutations of the expression matrix to estimate the null distribution. Defaults to 1000. If using method='ggea', it is possible to set 'perm=0' to use a fast approximation of gene set significance to avoid permutation testing. See Details.
padj.method	Method for adjusting nominal gene set p-values to multiple testing. For available methods see the man of page the of the stats function p.adjust. Defaults to 'none', i.e. leaves the nominal gene set p-values unadjusted.
out.file	Optional output file the gene set ranking will be written to.
browse	Logical. Should results be displayed in the browser for interactive exploration? Defaults to FALSE.
...	Additional arguments passed to individual nbea methods. This includes currently for GGEA: • beta: Log2 fold change significance level. Defaults to 1 (2-fold).

- cons.thresh: edge consistency threshold between -1 and 1. # Defaults to 0.3, i.e. only edges of the GRN with consistency >= 0.3 are included in the analysis. Evaluation on real datasets has shown that this works best to distinguish relevant gene sets. Use consistency of -1 to include all edges.
- gs.edges: Decides which edges of the grn are considered for a gene set under investigation. Should be one out of c('&', 'l'), denoting logical AND and OR. respectively. Accordingly, this either includes edges for which regulator AND / OR target gene are members of the investigated gene set.

Details

'ggea': gene graph enrichment analysis, scores gene sets according to consistency within the given gene regulatory network, i.e. checks activating regulations for positive correlation and repressing regulations for negative correlation of regulator and target gene expression (Geistlinger et al., 2011). When using 'ggea' it is possible to estimate the statistical significance of the consistency score of each gene set in two different ways: (1) based on sample permutation as described in the original publication (Geistlinger et al., 2011) or (2) using an approximation based on Bioconductor's npGSEA package that is much faster.

'nea': network enrichment analysis, implemented in Bioconductor's neaGUI package.

'spia': signaling pathway impact analysis, implemented in Bioconductor's SPIA package.

'pathnet': pathway analysis using network information, implemented in Bioconductor's PathNet package.

It is also possible to use additional network-based enrichment methods. This requires to implement a function that takes 'eset', 'gs', 'grn', 'alpha', and 'perm' as arguments and returns a numeric matrix 'res.tbl' with a mandatory column named 'P.VALUE' storing the resulting p-value for each gene set in 'gs'. The rows of this matrix must be named accordingly (i.e. rownames(res.tbl) == names(gs)). See examples.

Value

nbea.methods: a character vector of currently supported methods;

nbea: if(is.null(out.file)): an enrichment analysis result object that can be detailedly explored by calling `ea.browse` and from which a flat gene set ranking can be extracted by calling `gs.ranking`. If 'out.file' is given, the ranking is written to the specified file.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

References

Geistlinger et al. (2011) From sets to graphs: towards a realistic enrichment analysis of transcriptomic systems. Bioinformatics, 27(13), i366–73.

See Also

Input: read.eset, probe.2.gene.eset, get.kegg.genesets to retrieve gene set definitions from KEGG. compile.grn.from.kegg to construct a GRN from KEGG pathways.

Output: gs.ranking to rank the list of gene sets. ea.browse for exploration of resulting gene sets.

Other: sbea to perform set-based enrichment analysis. comb.ea.results to combine results from different methods. spia for more information on signaling pathway impact analysis. nea for more information on network enrichment analysis. PathNet for more information on pathway analysis using network information.

Examples

```
# currently supported methods
nbea.methods()

# (1) expression data:
# simulated expression values of 100 genes
# in two sample groups of 6 samples each
eset <- make.example.data(what="eset")
eset <- de.ana(eset)

# (2) gene sets:
# draw 10 gene sets with 15-25 genes
gs <- make.example.data(what="gs", gnames=featureNames(eset))

# (3) make 2 artificially enriched sets:
sig.genes <- featureNames(eset)[fData(eset)$ADJ.PVAL < 0.1]
gs[[1]] <- sample(sig.genes, length(gs[[1]]))
gs[[2]] <- sample(sig.genes, length(gs[[2]]))

# (4) gene regulatory network
grn <- make.example.data(what="grn", nodes=featureNames(eset))

# (5) performing the enrichment analysis
ea.res <- nbea(method="ggea", eset=eset, gs=gs, grn=grn)

# (6) result visualization and exploration
gs.ranking(ea.res, signif.only=FALSE)

# using your own tailored function as enrichment method
dummy.nbea <- function(eset, gs, grn, alpha, perm)
{
    sig.ps <- sample(seq(0,0.05, length=1000),5)
    insig.ps <- sample(seq(0.1,1, length=1000), length(gs)-5)
    ps <- sample(c(sig.ps, insig.ps), length(gs))
    score <- sample(1:100, length(gs), replace=TRUE)
    res.tbl <- cbind(score, ps)
    colnames(res.tbl) <- c("SCORE", "P.VALUE")
    rownames(res.tbl) <- names(gs)
    return(res.tbl[order(ps),])
}
```

```
ea.res2 <- nbea(method=dummy.nbea, eset=eset, gs=gs, grn=grn)
gs.ranking(ea.res2)
```

`normalize` *Normalization of microarray and RNA-seq expression data*

Description

This function wraps commonly used functionality from limma for microarray normalization and from EDASeq for RNA-seq normalization.

Usage

```
normalize( eset,
  norm.method = "quantile", within = FALSE, data.type = c(NA, "ma", "rseq") )
```

Arguments

`eset`	Expression set. An object of `ExpressionSet-class`. See the man page of `read.eset` for prerequisites for the expression data.
`norm.method`	Determines how the expression data should be normalized. For available microarray normalization methods see the man page of the limma function `normalizeBetweenArrays`. For available RNA-seq normalization methods see the man page of the EDASeq function `betweenLaneNormalization`. Defaults to 'quantile', i.e. normalization is carried out so that quantiles between arrays/lanes/samples are equal. See details.
`within`	Logical. Is only taken into account if data.type='rseq'. Determine whether GC content normalization should be carried out (as implemented in the EDASeq function `withinLaneNormalization`). Defaults to FALSE. See details.
`data.type`	Expression data type. Use 'ma' for microarray and 'rseq' for RNA-seq data. If NA, data.type is automatically guessed. If the expression values in 'eset' are decimal numbers they are assumed to be microarray intensities. Whole numbers are assumed to be RNA-seq read counts. Defaults to NA.

Details

Normalization of high-throughput expression data is essential to make results within and between experiments comparable. Microarray (intensity measurements) and RNA-seq (read counts) data exhibit typically distinct features that need to be normalized for. For specific needs that deviate from these standard normalizations, the user should always refer to more specific functions/packages.

Microarray data is expected to be single-channel. For two-color arrays, it is expected here that normalization within arrays has been already carried out, e.g. using `normalizeWithinArrays` from limma.

RNA-seq data is expected to be raw read counts. Please note that normalization for downstream DE analysis, e.g. with edgeR and DESeq, is not ultimately necessary (and in some cases even discouraged) as many of these tools implement specific normalization approaches. See the vignette of EDASeq, edgeR, and DESeq for details.

Value

An object of ExpressionSet-class. For RNA-seq data, an object of SeqExpressionSet-class to conform with downstream DE analysis.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

read.eset describes prerequisites for the expression data;

normalizeWithinArrays and normalizeBetweenArrays for normalization of microarray data;

withinLaneNormalization and betweenLaneNormalization for normalization of RNA-seq data.

Examples

```
#
# (1) simulating expression data: 100 genes, 12 samples
#

# (a) microarray data: intensity measurements
ma.eset <- make.example.data(what="eset", type="ma")

# (b) RNA-seq data: read counts
rseq.eset <- make.example.data(what="eset", type="rseq")

#
# (2) Normalization
#

# (a) microarray ...
norm.eset <- normalize(ma.eset)

# (b) RNA-seq ...
norm.eset <- normalize(rseq.eset)

# ... normalize also for GC content
gc.content <- rnorm(100, 0.5, sd=0.1)
fData(rseq.eset)$gc <- gc.content

norm.eset <- normalize(rseq.eset, within=TRUE)
```

---

plots *Visualization of gene expression*

Description

Visualization of differential gene expression via heatmap, p-value histogram and volcano plot (fold change vs. p-value).

Usage

```
pdistr( p )
volcano( fc, p )
exprs.heatmap( expr, grp )
```

Arguments

p	Numeric vector of p-values for each gene.
fc	Numeric vector of fold changes (typically on log2 scale).
expr	Expression matrix. Rows correspond to genes, columns to samples.
grp	*BINARY* group assignment for the samples. Use '0' and '1' for unaffected (controls) and affected (cases) samples, respectively.

Value

None, plots to a graphics device.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

de.ana for differential expression analysis, heatmap and truehist for generic plotting.

Examples

```
# (1) simulating expression data: 100 genes, 12 samples
eset <- make.example.data(what="eset")

# plot heatmap
exprs.heatmap(expr=exprs(eset), grp=as.factor(pData(eset)$GROUP))

# (2) DE analysis
eset <- de.ana(eset)
pdistr(fData(eset)$ADJ.PVAL)
volcano(fc=fData(eset)$FC, p=fData(eset)$ADJ.PVAL)
```

---

probe.2.gene.eset *Transformation of probe level expression to gene level expression*

Description

Reads expression data at probe level and summarizes gene expression behavior by averaging over all probes that are annotated to a particular gene.

Usage

```
probe.2.gene.eset( probe.eset, use.mean = TRUE )
```

Arguments

probe.eset	Probe expression set of class ExpressionSet. The fData slot of the expression set must contain a 'GENE' column that lists for each probe the corresponding KEGG gene ID.
use.mean	Logical. Determining, in case of multiple probes for one gene, whether a mean value is computed (use.mean=TRUE), or the probe that discriminate the most between the two sample group is kept (use.mean=FALSE). Defaults to TRUE.

Value

An ExpressionSet on gene level.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

ExpressionSet-class, read.eset for reading expression data from file, de.ana for differential expression analysis.

Examples

```
# (1) reading the expression data from file
exprs.file <- system.file("extdata/exprs.tab", package="EnrichmentBrowser")
pdat.file <- system.file("extdata/pData.tab", package="EnrichmentBrowser")
fdat.file <- system.file("extdata/fData.tab", package="EnrichmentBrowser")
probe.eset <- read.eset(exprs.file, pdat.file, fdat.file)
gene.eset <- probe.2.gene.eset(probe.eset)
```

---

read.eset *Reading gene expression data from file into an expression set*

Description

The function reads in plain expression data from file with minimum annotation requirements for the pData and fData slots.

Usage

```
read.eset( exprs.file, pdat.file, fdat.file,
    data.type = c(NA, "ma", "rseq"), NA.method = c("mean", "rm", "keep") )
```

Arguments

exprs.file	Expression matrix. A tab separated text file containing expression values. Columns = samples/subjects; rows = features/probes/genes; NO headers, row or column names. See details.
pdat.file	Phenotype data. A tab separated text file containing annotation information for the samples in either *two or three* columns. NO headers, row or column names. The number of rows/samples in this file should match the number of columns/samples of the expression matrix. The 1st column is reserved for the sample IDs; The 2nd column is reserved for a *BINARY* group assignment. Use '0' and '1' for unaffected (controls) and affected (cases) sample class, respectively. For paired samples or sample blocks a third column is expected that defines the blocks.
fdat.file	Feature data. A tab separated text file containing annotation information for the features. In case of probe level data: exactly *TWO* columns; 1st col = probe/feature IDs; 2nd col = corresponding gene ID for each feature ID in 1st col; In case of gene level data: The list of gene IDs newline-separated (i.e. just one column). It is recommended to use *ENTREZ* gene IDs (to benefit from downstream visualization and exploration functionality of the enrichment analysis). NO headers, row or column names. The number of rows (features/probes/genes) in this file should match the number of rows/features of the expression matrix. Alternatively, this can also be the ID of a recognized platform such as 'hgu95av2' (Affymetrix Human Genome U95 chip) or 'ecoli2' (Affymetrix E. coli Genome 2.0 Array). See details.
data.type	Expression data type. Use 'ma' for microarray and 'rseq' for RNA-seq data. If NA, data.type is automatically guessed. If the expression values in 'eset' are decimal numbers they are assumed to be microarray intensities. Whole numbers are assumed to be RNA-seq read counts. Defaults to NA.
NA.method	Determines how to deal with NA's (missing values). This can be one out of: • mean: replace NA's by the row means for a feature over all samples. • rm: rows (features) that contain NA's are removed. • keep: do nothing. Missing values are kept (which, however, can then cause several issues in the downstream analysis) Defaults to 'mean'.

Details

See the limma's user guide http://www.bioconductor.org/packages/limma for definition and normalization of the different expression data types.

In case of microarry data the feature IDs typically correspond to probe IDs. Thus, the fdat.file should define a mapping from probe ID (1st column) to corresponding KEGG gene ID (2nd column). The mapping can be defined automatically by providing the ID of a recognized platform such as 'hgu95av2' (Affymetrix Human Genome U95 chip). This requires that a corresponding '.db' package exists (see http://www.bioconductor.org/packages/release/BiocViews.html#___ChipName for all available chips/packages) and that you have it installed. *However, this option should be used with care*. Existing mappings might be outdated and sometimes the KEGG gene ID does not correspond to the Entrez ID (e.g. for E. coli and S. cerevisae). In these cases probe

identifiers are mapped twice (probe ID -> Entrez ID -> KEGG ID), which almost always results in loss of information. Thus, mapping quality should always be checked and in case properly defined with a 2-column fdat.file.

Value

An object of ExpressionSet.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

See Also

ExpressionSet-class

Examples

```
# reading the expression data from file
exprs.file <- system.file("extdata/exprs.tab", package="EnrichmentBrowser")
pdat.file <- system.file("extdata/pData.tab", package="EnrichmentBrowser")
fdat.file <- system.file("extdata/fData.tab", package="EnrichmentBrowser")
eset <- read.eset(exprs.file, pdat.file, fdat.file)
```

---

sbea *Set-based enrichment analysis (SBEA)*

Description

This is the main function for the enrichment analysis of gene sets. It implements and wraps existing implementations of several frequently used state-of-art methods and allows a flexible inspection of resulting gene set rankings.

Usage

```
sbea( method = sbea.methods(), eset, gs, alpha = 0.05,
        perm = 1000, padj.method = "none", out.file = NULL, browse = FALSE )

sbea.methods()
```

Arguments

method	Set-based enrichment analysis method. Currently, the following set-based enrichment analysis methods are supported: 'ora', 'safe', 'gsea', and 'samgs'. See Details. For basic ora also set 'perm=0'. Default is 'ora'. This can also be the name of a user-defined function implementing set-based enrichment. See Details.

eset	Expression set. An object of class ExpressionSet. See read.eset and probe.2.gene.eset for required annotations in the pData and fData slots.
gs	Gene sets. Either a list of gene sets (vectors of KEGG gene IDs) or a text file in GMT format storing all gene sets under investigation.
alpha	Statistical significance level. Defaults to 0.05.
perm	Number of permutations of the expression matrix to estimate the null distribution. Defaults to 1000. For basic ora set 'perm=0'. *New*: using method="gsea" and 'perm=0' invokes the permutation approximation from the npGSEA package.
padj.method	Method for adjusting nominal gene set p-values to multiple testing. For available methods see the man page of the stats function p.adjust. Defaults to'none', i.e. leaves the nominal gene set p-values unadjusted.
out.file	Optional output file the gene set ranking will be written to.
browse	Logical. Should results be displayed in the browser for interactive exploration? Defaults to FALSE.

Details

'ora': overrepresentation analysis, simple and frequently used test based on the hypergeometric distribution (see Goeman and Buhlmann, 2007, for a critical review).

'safe': significance analysis of function and expression, generalization of ORA, includes other test statistics, e.g. Wilcoxon's rank sum, and allows to estimate the significance of gene sets by sample permutation; implemented in the safe package (Barry et al., 2005).

'gsea': gene set enrichment analysis, frequently used and widely accepted, uses a Kolmogorov-Smirnov statistic to test whether the ranks of the p-values of genes in a gene set resemble a uniform distribution (Subramanian et al., 2005).

'samgs': significance analysis of microarrays on gene sets, extends the SAM method for single genes to gene set analysis (Dinu et al., 2007).

It is also possible to use additional set-based enrichment methods. This requires to implement a function that takes 'eset', 'gs', 'alpha', and 'perm' as arguments and returns a numeric vector 'ps' storing the resulting p-value for each gene set in 'gs'. This vector must be named accordingly (i.e. names(ps) == names(gs)). See examples.

Value

sbea.methods: a character vector of currently supported methods;

sbea: if(is.null(out.file)): an enrichment analysis result object that can be detailedly explored by calling ea.browse and from which a flat gene set ranking can be extracted by calling gs.ranking. If 'out.file' is given, the ranking is written to the specified file.

Author(s)

Ludwig Geistlinger <Ludwig.Geistlinger@bio.ifi.lmu.de>

References

Goeman and Buhlmann (2007) Analyzing gene expression data in terms of gene sets: methodological issues. Bioinformatics, 23, 980-7.

Barry et al. (2005) Significance Analysis of Function and Expression. Bioinformatics, 21:1943-9.

Subramanian et al. (2005) Gene Set Enrichment Analysis: a knowledge-based approach for interpreting genome-wide expression profiles. Proc Natl Acad Sci USA, 102:15545-50.

Dinu et al. (2007) Improving gene set analysis of microarray data by SAM-GS. BMC Bioinformatics, 8:242

See Also

Input: `read.eset`, `probe.2.gene.eset` `get.kegg.genesets` to retrieve gene sets from KEGG.

Output: `gs.ranking` to retrieve the ranked list of gene sets. `ea.browse` for exploration of resulting gene sets.

Other: `nbea` to perform network-based enrichment analysis. `comb.ea.results` to combine results from different methods.

Examples

```
# currently supported methods
sbea.methods()

# (1) expression data:
# simulated expression values of 100 genes
# in two sample groups of 6 samples each
eset <- make.example.data(what="eset")
eset <- de.ana(eset)

# (2) gene sets:
# draw 10 gene sets with 15-25 genes
gs <- make.example.data(what="gs", gnames=featureNames(eset))

# (3) make 2 artificially enriched sets:
sig.genes <- featureNames(eset)[fData(eset)$ADJ.PVAL < 0.1]
gs[[1]] <- sample(sig.genes, length(gs[[1]]))
gs[[2]] <- sample(sig.genes, length(gs[[2]]))

# (4) performing the enrichment analysis
ea.res <- sbea(method="ora", eset=eset, gs=gs, perm=0)

# (5) result visualization and exploration
gs.ranking(ea.res)

# using your own tailored function as enrichment method
dummy.sbea <- function(eset, gs, alpha, perm)
{
    sig.ps <- sample(seq(0, 0.05, length=1000), 5)
    nsig.ps <- sample(seq(0.1, 1, length=1000), length(gs)-5)
    ps <- sample(c(sig.ps, nsig.ps), length(gs))
```

```
    names(ps) <- names(gs)
    return(ps)
}

ea.res2 <- sbea(method=dummy.sbea, eset=eset, gs=gs)
gs.ranking(ea.res2)
```

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