

Package ‘BLMA’

November 5, 2024

Date 2020-06-22

Type Package

Title BLMA: A package for bi-level meta-analysis

Version 1.30.0

Author

Tin Nguyen <tinn@auburn.edu>, Hung Nguyen <pzb00047@auburn.edu>, and Sorin Draghici <sorin@wayne.edu>

Maintainer Van-Dung Pham <dvp0001@auburn.edu>

Description Suit of tools for bi-level meta-analysis. The package can be used in a wide range of applications, including general hypothesis testings, differential expression analysis, functional analysis, and pathway analysis.

biocViews GeneSetEnrichment, Pathways, DifferentialExpression, Microarray

License GPL (>=2)

Depends ROntoTools, GSA, PADOG, limma, graph, stats, utils, parallel, Biobase, metafor, methods

Suggests RUnit, BiocGenerics

RoxygenNote 7.3.1

NeedsCompilation no

git_url <https://git.bioconductor.org/packages/BLMA>

git_branch RELEASE_3_20

git_last_commit 374c131

git_last_commit_date 2024-10-29

Repository Bioconductor 3.20

Date/Publication 2024-11-05

Contents

addCLT	2
bilevelAnalysisClassic	3
bilevelAnalysisGene	4
bilevelAnalysisGeneset	6
bilevelAnalysisPathway	8
fisherMethod	10

getStatistics	11
GSE17054	13
GSE33223	14
GSE42140	14
GSE57194	15
intraAnalysisClassic	16
intraAnalysisGene	17
loadKEGGPathways	18
pORACalc	19
stoufferMethod	19

Index	21
--------------	-----------

addCLT	<i>The additive method for meta-analysis</i>
--------	----------------------------------------------

Description

Combine independent studies using the average of p-values

Usage

addCLT(x)

Arguments

x is an array of independent p-values

Details

This method is based on the fact that sum of independent uniform variables follow the Irwin-Hall distribution [1a,1b]. When the number of p-values is small ($n < 20$), the distribution of the average of p-values can be calculated using a linear transformation of the Irwin-Hall distribution. When n is large, the distribution is approximated using the Central Limit Theorem to avoid underflow/overflow problems [2,3,4,5].

Value

combined p-value

Author(s)

Tin Nguyen and Sorin Draghici

References

- [1a] P. Hall. The distribution of means for samples of size n drawn from a population in which the variate takes values between 0 and 1, all such values being equally probable. *Biometrika*, 19(3-4):240-244, 1927.
- [1b] J. O. Irwin. On the frequency distribution of the means of samples from a population having any law of frequency with finite moments, with special reference to Pearson's Type II. *Biometrika*, 19(3-4):225-239, 1927.

- [2] T. Nguyen, R. Tagett, M. Donato, C. Mitrea, and S. Draghici. A novel bi-level meta-analysis approach – applied to biological pathway analysis. *Bioinformatics*, 32(3):409-416, 2016.
- [3] T. Nguyen, C. Mitrea, R. Tagett, and S. Draghici. DANUBE: Data-driven meta-ANalysis using UnBiased Empirical distributions – applied to biological pathway analysis. *Proceedings of the IEEE, PP(99):1-20*, 2016.
- [4] T. Nguyen, D. Diaz, R. Tagett, and S. Draghici. Overcoming the matched-sample bottleneck: an orthogonal approach to integrate omic data. *Scientific Reports*, 6:29251, 2016.
- [5] T. Nguyen, D. Diaz, and S. Draghici. TOMAS: A novel TOpology-aware Meta-Analysis approach applied to System biology. In *Proceedings of the 7th ACM International Conference on Bioinformatics, Computational Biology, and Health Informatics*, pages 13-22. ACM, 2016.

See Also

[fisherMethod](#), [stoufferMethod](#)

Examples

```
x <- rep(0,10)
addCLT(x)

x <- runif(10)
addCLT(x)
```

bilevelAnalysisClassic

Bi-level meta-analysis in conjunction with a classical hypothesis testing method

Description

Perform a bi-level meta-analysis in conjunction with any of the classical hypothesis testing methods, such as t-test, Wilcoxon test, etc.

Usage

```
bilevelAnalysisClassic(x, y = NULL, splitSize = 5, metaMethod = addCLT,
  func = t.test, p.value = "p.value", ...)
```

Arguments

x	a list of numeric vectors
y	an optional list of numeric vectors
splitSize	the minimum number of size in each split sample. splitSize should be at least 3. By default, splitSize=5
metaMethod	the method used to combine p-values. This should be one of addCLT (additive method [1]), fishersMethod (Fisher’s method [5]), stoufferMethod (Stouffer’s method [6]), max (maxP method [7]), or min (minP method [8])
func	the name of the hypothesis test. By default func=t.test

p.value the component that returns the p-value after performing the test provided by the *func* parameter. For example, the function t-test returns the class "htest" where the component "p.value" is the p-value of the test. By default, p.value="p.value"

... additional parameters for *func*

Details

This function performs a bi-level meta-analysis for the lists of samples [1]. It performs intra-experiment analyses to compare the vectors in x against the corresponding vectors in y using the function [intraAnalysisClassic](#) in conjunction with the test provided in *func*. For example, it compares the first vector in x with the first vector in y, the second vector in x with the second vector in y, etc. When y is null, then the comparisons are reduced to one-sample tests. After these comparisons, we have a list of p-values, one for each comparison. The function then combines these p-values to obtain a single p-value using *metaMethod*.

Value

the combined p-value

Author(s)

Tin Nguyen and Sorin Draghici

References

[1] T. Nguyen, R. Tagett, M. Donato, C. Mitrea, and S. Draghici. A novel bi-level meta-analysis approach – applied to biological pathway analysis. *Bioinformatics*, 32(3):409-416, 2016.

See Also

[intraAnalysisClassic](#), [intraAnalysisGene](#), [bilevelAnalysisGene](#)

Examples

```
set.seed(1)
l1 <- lapply(as.list(seq(3)),FUN=function (x) rnorm(n=10, mean=1))
l1
# one-sample t-test
lapply(l1, FUN=function(x) t.test(x, alternative="greater")$p.value)
# combining the p-values of one-sample t-tests:
addCLT(unlist(lapply(l1, FUN=function(x) t.test(x, alter="g")$p.value)))
#Bi-level meta-analysis
bilevelAnalysisClassic(x=l1, alternative="greater")
```

bilevelAnalysisGene *Bi-level meta-analysis of multiple expression datasets at the gene-level*

Description

Perform a bi-level meta-analysis in conjunction with the moderate t-test (limma package) for the purpose of differential expression analysis of multiple gene expression datasets

Usage

```
bilevelAnalysisGene(dataList, groupList, splitSize = 5, metaMethod = addCLT)
```

Arguments

<code>dataList</code>	a list of datasets. Each dataset is a data frame where the rows are the gene IDs and the columns are the samples
<code>groupList</code>	a list of vectors. Each vector represents the phenotypes of the corresponding dataset in <code>dataList</code> , which are either 'c' (control) or 'd' (disease).
<code>splitSize</code>	the minimum number of disease samples in each split dataset. <code>splitSize</code> should be at least 3. By default, <code>splitSize=5</code>
<code>metaMethod</code>	the method used to combine p-values. This should be one of <code>addCLT</code> (additive method [1]), <code>fishersMethod</code> (Fisher's method [5]), <code>stoufferMethod</code> (Stouffer's method [6]), <code>max</code> (maxP method [7]), or <code>min</code> (minP method [8])

Details

The bi-level framework combines the datasets at two levels: an intra- experiment analysis, and an inter-experiment analysis [1]. At the intra-experiment analysis, the framework splits a dataset into smaller datasets, performs a moderated t-test (limma package) on split datasets, and then combines p-values of individual genes using *metaMethod*. At the inter-experiment analysis, the p-values obtained for each individual datasets are combined using *metaMethod*

Value

A data frame containing the following components:

- *rownames*: gene IDs that are common in all datasets
- *pLimma*: the p-values obtained by combining pLimma values of individual datasets
- *pLimma.fdr*: FDR-corrected p-values of pLimma
- *pBilevel*: the p-values obtained from combining pIntra values of individual datasets
- *pBilevel.fdr*: FDR-corrected p-values of pBilevel

Author(s)

Tin Nguyen and Sorin Draghici

References

[1] T. Nguyen, R. Tagett, M. Donato, C. Mitrea, and S. Draghici. A novel bi-level meta-analysis approach – applied to biological pathway analysis. *Bioinformatics*, 32(3):409-416, 2016.

See Also

[bilevelAnalysisGene](#), [intraAnalysisClassic](#)

Examples

```

dataSets <- c("GSE17054", "GSE57194", "GSE33223", "GSE42140")
data(list=dataSets, package="BLMA")
names(dataSets) <- dataSets
dataList <- lapply(dataSets, function(dataset) get(paste0("data_", dataset)))
groupList <- lapply(dataSets, function(dataset) get(paste0("group_", dataset)))
Z <- bilevelAnalysisGene(dataList = dataList, groupList = groupList)
head(Z)

```

bilevelAnalysisGeneset

Bi-level meta-analysis – applied to geneset enrichment analysis

Description

Perform a bi-level meta-analysis in conjunction with geneset enrichment methods (ORA/GSA/PADOG) to integrate multiple gene expression datasets.

Usage

```

bilevelAnalysisGeneset(gslist, gs.names, dataList, groupList, splitSize = 5,
  metaMethod = addCLT, enrichment = "ORA", pCutoff = 0.05,
  percent = 0.05, mc.cores = 1, ...)

```

Arguments

<code>gslist</code>	a list of gene sets.
<code>gs.names</code>	names of the gene sets.
<code>dataList</code>	a list of datasets to be combined. Each dataset is a data frame where the rows are the gene IDs and the columns are the samples.
<code>groupList</code>	a list of vectors. Each vector represents the phenotypes of the corresponding dataset in <code>dataList</code> . The elements of each vector are either 'c' (control) or 'd' (disease).
<code>splitSize</code>	the minimum number of disease samples in each split dataset. <code>splitSize</code> should be at least 3. By default, <code>splitSize=5</code>
<code>metaMethod</code>	the method used to combine p-values. This should be one of <code>addCLT</code> (additive method [1]), <code>fisherMethod</code> (Fisher's method [5]), <code>stoufferMethod</code> (Stouffer's method [6]), <code>max</code> (maxP method [7]), or <code>min</code> (minP method [8])
<code>enrichment</code>	the method used for enrichment analysis. This should be one of "ORA", "GSA", or "PADOG". By default, enrichment is set to "ORA".
<code>pCutoff</code>	cutoff p-value used to identify differentially expressed (DE) genes. This parameter is used only when the enrichment method is "ORA". By default, <code>pCutoff=0.05</code> (five percent)
<code>percent</code>	percentage of genes with highest foldchange to be considered as differentially expressed (DE). This parameter is used when the enrichment method is "ORA". By default <code>percent=0.05</code> (five percent). Please note that only genes with p-value less than <code>pCutoff</code> will be considered
<code>mc.cores</code>	the number of cores to be used in parallel computing. By default, <code>mc.cores=1</code>
<code>...</code>	additional parameters of the GSA/PADOG functions

Details

The bi-level framework combines the datasets at two levels: an intra- experiment analysis, and an inter-experiment analysis [1]. At the intra-level analysis, the framework splits a dataset into smaller datasets, performs enrichment analysis for each split dataset (using ORA [2], GSA [3], or PADOG [4]), and then combines the results of these split datasets using *metaMethod*. At the inter-level analysis, the results obtained for individual datasets are combined using *metaMethod*

Value

A data frame (rownames are geneset/pathway IDs) that consists of the following information:

- *Name*: name/description of the corresponding pathway/geneset
- Columns that include the pvalues obtained from the intra-experiment analysis of individual datasets
- *pBLMA*: p-value obtained from the inter-experiment analysis using addCLT
- *rBLMA*: ranking of the geneset/pathway using addCLT
- *pBLMA.fdr*: FDR-corrected p-values

Author(s)

Tin Nguyen and Sorin Draghici

References

- [1] T. Nguyen, R. Tagett, M. Donato, C. Mitrea, and S. Draghici. A novel bi-level meta-analysis approach – applied to biological pathway analysis. *Bioinformatics*, 32(3):409-416, 2016.
- [2] S. Draghici, P. Khatri, R. P. Martin, G. C. Ostermeier, and S. A. Krawetz. Global functional profiling of gene expression. *Genomics*, 81(2):98-104, 2003.
- [3] B. Efron and R. Tibshirani. On testing the significance of sets of genes. *The Annals of Applied Statistics*, 1(1):107-129, 2007.
- [4] A. L. Tarca, S. Draghici, G. Bhatti, and R. Romero. Down-weighting overlapping genes improves gene set analysis. *BMC Bioinformatics*, 13(1):136, 2012.
- [5] R. A. Fisher. *Statistical methods for research workers*. Oliver & Boyd, Edinburgh, 1925.
- [6] S. Stouffer, E. Suchman, L. DeVinney, S. Star, and J. Williams, RM. *The American Soldier: Adjustment during army life*, volume 1. Princeton University Press, Princeton, 1949.
- [7] L. H. C. Tippett. *The methods of statistics*. The Methods of Statistics, 1931.
- [8] B. Wilkinson. A statistical consideration in psychological research. *Psychological Bulletin*, 48(2):156, 1951.

See Also

[bilevelAnalysisPathway](#), [phyper](#), [GSA](#), [padog](#)

Examples

```
# load KEGG pathways and create gene sets
x <- loadKEGGPathways()
gslist <- lapply(x$kpg,FUN=function(y){return (nodes(y));})
gs.names <- x$kpn[names(gslist)]
```

```

# load example data
dataSets <- c("GSE17054", "GSE57194", "GSE33223", "GSE42140")
data(list=dataSets, package="BLMA")
names(dataSets) <- dataSets
dataList <- lapply(dataSets, function(dataset) get(paste0("data_", dataset)))
groupList <- lapply(dataSets, function(dataset) get(paste0("group_", dataset)))
# perform bi-level meta-analysis in conjunction with ORA
ORAComb <- bilevelAnalysisGeneset(gslist, gs.names, dataList, groupList, enrichment = "ORA")
head(ORAComb[, c("Name", "pBLMA", "pBLMA.fdr", "rBLMA")])

# perform bi-level meta-analysis in conjunction with GSA
GSAComb <- bilevelAnalysisGeneset(gslist, gs.names, dataList, groupList, enrichment = "GSA", nperms = 200, ran
head(GSAComb[, c("Name", "pBLMA", "pBLMA.fdr", "rBLMA")])

# perform bi-level meta-analysis in conjunction with PADOG
set.seed(1)
PADOGComb <- bilevelAnalysisGeneset(gslist, gs.names, dataList, groupList, enrichment = "PADOG", NI=200)
head(PADOGComb[, c("Name", "pBLMA", "pBLMA.fdr", "rBLMA")])

```

bilevelAnalysisPathway

Bi-level meta-analysis – applied to pathway analysis

Description

Perform a bi-level meta-analysis conjunction with Impact Analysis to integrate multiple gene expression datasets

Usage

```

bilevelAnalysisPathway(kpg, kpn, dataList, groupList, splitSize = 5,
  metaMethod = addCLT, pCutoff = 0.05, percent = 0.05, mc.cores = 1,
  nboot = 200, seed = 1)

```

Arguments

kpg	list of pathway graphs as objects of type graph (e.g., graphNEL)
kpn	names of the pathways.
dataList	a list of datasets to be combined. Each dataset is a data frame where the rows are the gene IDs and the columns are the samples.
groupList	a list of vectors. Each vector represents the phenotypes of the corresponding dataset in dataList, which are either 'c' (control) or 'd' (disease).
splitSize	the minimum number of disease samples in each split dataset. splitSize should be at least 3. By default, splitSize=5
metaMethod	the method used to combine p-values. This should be one of addCLT (additive method [1]), fisherMethod (Fisher's method [5]), stoufferMethod (Stouffer's method [6]), max (maxP method [7]), or min (minP method [8])
pCutoff	cutoff p-value used to identify differentially expressed (DE) genes. This parameter is used only when the enrichment method is "ORA". By default, pCutoff=0.05 (five percent)

percent	percentage of genes with highest foldchange to be considered as differentially expressed (DE). This parameter is used when the enrichment method is "ORA". By default percent=0.05 (five percent). Please note that only genes with p-value less than pCutoff will be considered
mc.cores	the number of cores to be used in parallel computing. By default, mc.cores=1
nboot	number of bootstrap iterations. By default, nboot=200
seed	seed. By default, seed=1.

Details

The bi-level framework combines the datasets at two levels: an intra-experiment analysis, and an inter-experiment analysis [1]. At the intra-level analysis, the framework splits a dataset into smaller datasets, performs pathway analysis for each split dataset using Impact Analysis [2,3], and then combines the results of these split datasets using *metaMethod*. At the inter-level analysis, the results obtained for individual datasets are combined using *metaMethod*

Value

A data frame (rownames are geneset/pathway IDs) that consists of the following information:

- *Name*: name/description of the corresponding pathway/geneset
- Columns that include the pvalues obtained from the intra-experiment analysis of individual datasets
- *pBLMA*: p-value obtained from the inter-experiment analysis using addCLT
- *rBLMA*: ranking of the geneset/pathway using addCLT
- *pBLMA.fdr*: FDR-corrected p-values

Author(s)

Tin Nguyen and Sorin Draghici

References

- [1] T. Nguyen, R. Tagett, M. Donato, C. Mitrea, and S. Draghici. A novel bi-level meta-analysis approach – applied to biological pathway analysis. *Bioinformatics*, 32(3):409-416, 2016.
- [2] A. L. Tarca, S. Draghici, P. Khatri, S. S. Hassan, P. Mittal, J.-s. Kim, C. J. Kim, J. P. Kusanovic, and R. Romero. A novel signaling pathway impact analysis. *Bioinformatics*, 25(1):75-82, 2009.
- [3] S. Draghici, P. Khatri, A. L. Tarca, K. Amin, A. Done, C. Voichita, C. Georgescu, and R. Romero. A systems biology approach for pathway level analysis. *Genome Research*, 17(10):1537-1545, 2007.
- [4] R. A. Fisher. *Statistical methods for research workers*. Oliver & Boyd, Edinburgh, 1925.
- [5] S. Stouffer, E. Suchman, L. DeVinney, S. Star, and J. Williams, RM. *The American Soldier: Adjustment during army life*, volume 1. Princeton University Press, Princeton, 1949.
- [6] L. H. C. Tippett. *The methods of statistics*. The Methods of Statistics, 1931.
- [7] B. Wilkinson. A statistical consideration in psychological research. *Psychological Bulletin*, 48(2):156, 1951.

See Also

[bilevelAnalysisGeneset](#), [pe](#), [phyper](#)

Examples

```
# load KEGG pathways
x <- loadKEGGPathways()

# load example data
dataSets <- c("GSE17054", "GSE57194", "GSE33223", "GSE42140")
data(list=dataSets, package="BLMA")
names(dataSets) <- dataSets
dataList <- lapply(dataSets, function(dataset) get(paste0("data_", dataset)))
groupList <- lapply(dataSets, function(dataset) get(paste0("group_", dataset)))

IAComb <- bilevelAnalysisPathway(x$kpg, x$kpn, dataList, groupList)
head(IAComb[, c("Name", "pBLMA", "pBLMA.fdr", "rBLMA")])
```

fisherMethod

Fisher's method for meta-analysis

Description

Combine independent p-values using the minus log product

Usage

```
fisherMethod(x)
```

Arguments

x is an array of independent p-values

Details

Considering a set of m independent significance tests, the resulted p-values are independent and uniformly distributed between 0 and 1 under the null hypothesis. Fisher's method uses the minus log product of the p-values as the summary statistic, which follows a chi-square distribution with $2m$ degrees of freedom. This chi-square distribution is used to calculate the combined p-value.

Value

combined p-value

Author(s)

Tin Nguyen and Sorin Draghici

References

[1] R. A. Fisher. Statistical methods for research workers. Oliver & Boyd, Edinburgh, 1925.

See Also

[stoufferMethod](#), [addCLT](#)

Examples

```
x <- rep(0,10)
fisherMethod(x)
```

```
x <- runif(10)
fisherMethod(x)
```

<code>getStatistics</code>	<i>Intergrative genes statistic</i>
----------------------------	-------------------------------------

Description

Calculate genes summary statistic across multiple datasets

Usage

```
getStatistics(allGenes, dataList, groupList, ncores = 1, method = addCLT)
```

Arguments

<code>allGenes</code>	Vector of all genes names for the analysis.
<code>dataList</code>	A list of expression matrices, in which rows are genes and columns are samples.
<code>groupList</code>	A list of vectors indicating sample group corresponding with expression matrices in <code>dataList</code> .
<code>ncores</code>	Number of core to use in prallel processing.
<code>method</code>	Function for combining p-values. It must accept one input which is a vector of p-values and return a combined p-value. Three methods are embeded in this package are <code>addCLT</code> , <code>fisherMethod</code> , and <code>stoufferMethod</code> .

Details

To estimate the effect sizes of genes across all studies, first standardized mean difference for each gene in individual studies is compute. Next, the overall efect size and standard error are estimated using the random-effects model. This overall efect size represents the gene's expression change under the efect of the condition. The, z-scores and p-values of observing such efect sizes are computed. The p-values is obtained from classical hypothesis testing. By default, linear model and empirical Bayesian testing (`limma`) are used to compute the p-values for diferential expression. The two-tailed p-values are converted to one-tailed p-values (lef- and right-tailed). For each gene, the one-tailed p-values across all datasets are then combined using the `addCLT`, `stouffer` or `fisher` method. These p-values represent how likely the diferential expression is observed by chance.

Value

A data.frame of gene statistics with following columns:

pTwoTails Two-tailed p-values
pTwoTails.fdr Two-tailed p-values with false discovery rate correction
pLeft left-tailed p-values
pLeft.fdr left-tailed p-values with false discovery rate correction

pRight.fdr right-tailed p-values with false discovery rate correction

pRight right-tailed p-values

ES Effect size

ES.pTwoTails Two-tailed p-values for effect size

ES.pTwoTails.fdr Two-tailed p-values for effect size with false discovery rate correction

ES.pLeft Left-tailed p-values for effect size

ES.pLeft.fdr Left-tailed p-values for effect size with false discovery rate correction

ES.pRight Right-tailed p-values for effect size

ES.pRight.fdr Right-tailed p-values for effect size with false discovery rate correction

Author(s)

Tin Nguyen, Hung Nguyen, and Sorin Draghici

References

Nguyen, T., Shafi, A., Nguyen, T. M., Schissler, A. G., & Draghici, S. (2020). NBIA: a network-based integrative analysis framework-applied to pathway analysis. *Scientific reports*, 10(1), 1-11.

Nguyen, T., Tagett, R., Donato, M., Mitrea, C., & Draghici, S. (2016). A novel bi-level meta-analysis approach: applied to biological pathway analysis. *Bioinformatics*, 32(3), 409-416.

Smyth, G. K. (2005). *Limma: linear models for microarray data*. In *Bioinformatics and computational biology solutions using R and Bioconductor* (pp. 397-420). Springer, New York, NY.

See Also

[addCLT](#)

Examples

```
datasets <- c("GSE17054", "GSE57194", "GSE33223", "GSE42140")
data(list = datasets, package = "BLMA")
dataList <- lapply(datasets, function(dataset) {
  get(paste0("data_", dataset))
})
groupList <- lapply(datasets, function(dataset) {
  get(paste0("group_", dataset))
})
names(dataList) <- datasets
names(groupList) <- datasets

allGenes <- Reduce(intersect, lapply(dataList, rownames))

geneStat <- getStatistics(allGenes, dataList, groupList)
head(geneStat)

# perform pathway analysis
library(ROntoTools)
# get gene network
kpg <- loadKEGGPathways()$kpg
# get gene network name
kpn <- loadKEGGPathways()$kpn
# get geneset
gslist <- lapply(kpg,function(y) nodes(y))
```

```

# get differential expressed genes
DEGenes.Left <- rownames(geneStat)[geneStat$pLeft < 0.05 & geneStat$ES.pLeft < 0.05]
DEGenes.Right <- rownames(geneStat)[geneStat$pRight < 0.05 & geneStat$ES.pRight < 0.05]

DEGenes <- union(DEGenes.Left, DEGenes.Right)

# perform pathway analysis with ORA
oraRes <- lapply(gslist, function(gs){
  pORACalc(geneSet = gs, DEGenes = DEGenes, measuredGenes = rownames(geneStat))
})
oraRes <- data.frame(p.value = unlist(oraRes), pathway = names(oraRes))
rownames(oraRes) <- kpn[rownames(oraRes)]

# print results
print(head(oraRes))

# perform pathway analysis with Pathway-Express from ROntoTools
ES <- geneStat[DEGenes, "ES"]
names(ES) <- DEGenes

peRes = pe(x = ES, graphs = kpg, ref = allGenes, nboot = 1000, seed=1)

peRes.Summary <- Summary(peRes, comb.pv.func = fisherMethod)
peRes.Summary[, ncol(peRes.Summary) + 1] <- rownames(peRes.Summary)
rownames(peRes.Summary) <- kpn[rownames(peRes.Summary)]
colnames(peRes.Summary)[ncol(peRes.Summary)] = "pathway"

# print results
print(head(peRes.Summary))

```

GSE17054

Gene expression dataset GSE17054 from Majeti et al.

Description

This dataset consists of 5 acute myeloid leukemia and 4 control samples. The data frame `data_GSE17054` includes the expression data while the vector `group_GSE17054` includes the grouping information.

Usage

```
data(GSE17054)
```

Format

`data_GSE17054` is a data frame with 4738 rows and 9 columns. The rows represent the genes and the columns represent the samples.

`group_GSE17054` is a vector that represents the sample grouping for `data_GSE17054`. The elements of `group_GSE17054` are either 'c' (control) or 'd' (disease).

Source

Obtained from <http://www.ncbi.nlm.nih.gov/geo/query/acc.cgi?acc=GSE17054>

References

Majeti et al. Dysregulated gene expression networks in human acute myelogenous leukemia stem cells. *Proceedings of the National Academy of Sciences*, 106(9):3396-3401, 2009.

GSE33223

Gene expression dataset GSE33223 from Bacher et al.

Description

This dataset consists of 20 acute myeloid leukemia and 10 control samples. The data frame `data_GSE33223` includes the expression data while the vector `group_GSE33223` includes the grouping information.

Usage

```
data(GSE33223)
```

Format

`data_GSE33223` is a data frame with 4114 rows and 30 columns. The rows represent the genes and the columns represent the samples.

`group_GSE33223` is a vector that represents the sample grouping for `data_GSE33223`. The elements of `group_GSE33223` are either 'c' (control) or 'd' (disease).

Source

Obtained from <https://www.ncbi.nlm.nih.gov/geo/query/acc.cgi?acc=GSE33223>

References

Bacher et al. Multilineage dysplasia does not influence prognosis in CEBPA-mutated AML, supporting the WHO proposal to classify these patients as a unique entity. *Blood*, 119(20):4719-22, 2012.

GSE42140

The gene expression dataset GSE42140 obtained from Gene Expression Omnibus

Description

This dataset consists of 26 acute myeloid leukemia and 5 control samples. The data frame `data_GSE42140` includes the expression data while the vector `group_GSE42140` includes the grouping information.

Usage

```
data(GSE42140)
```

Format

`data_GSE42140` is a data frame with 4114 rows and 31 columns. The rows represent the genes and the columns represent the samples.

`group_GSE42140` is a vector that represents the sample grouping for `data_GSE42140`. The elements of `group_GSE42140` are either 'c' (control) or 'd' (disease).

References

<https://www.ncbi.nlm.nih.gov/geo/query/acc.cgi?acc=GSE42140>

GSE57194

Gene expression dataset GSE57194 from Abdul-Nabi et al.

Description

This dataset consists of 6 acute myeloid leukemia and 6 control samples. The data frame `data_GSE57194` includes the expression data while the vector `group_GSE57194` includes the grouping information.

Usage

```
data(GSE57194)
```

Format

`data_GSE57194` is a data frame with 4114 rows and 12 columns. The rows represent the genes and the columns represent the samples.

`group_GSE57194` is a vector that represents the sample grouping for `data_GSE57194`. The elements of `group_GSE57194` are either 'c' (control) or 'd' (disease).

Source

Obtained from <https://www.ncbi.nlm.nih.gov/geo/query/acc.cgi?acc=GSE57194>

References

Abdul-Nabi et al. In vitro transformation of primary human CD34+ cells by AML fusion oncogenes: early gene expression profiling reveals possible drug target in AML. *PLoS One*, 5(8):e12464, 2010.

intraAnalysisClassic *Intra-experiment analysis in conjunction with classical hypothesis tests*

Description

Perform an intra-experiment analysis in conjunction with any of the classical hypothesis testing methods, such as t-test, Wilcoxon test, etc.

Usage

```
intraAnalysisClassic(x, y = NULL, splitSize = 5, metaMethod = addCLT,
  func = t.test, p.value = "p.value", ...)
```

Arguments

x	a numeric vector of data values
y	an optional numeric vector of values
splitSize	the minimum number of size in each split sample. splitSize should be at least 3. By default, splitSize=5
metaMethod	the method used to combine p-values. This should be one of addCLT (additive method [1]), fishersMethod (Fisher's method [5]), stoufferMethod (Stouffer's method [6]), max (maxP method [7]), or min (minP method [8])
func	the name of the hypothesis test. By default func=t.test
p.value	the component that returns the p-value after performing the test provided by the <i>func</i> parameter. For example, the function t-test returns the class "htest" where the component "p.value" is the p-value of the test. By default, p.value="p.value"
...	additional parameters for <i>func</i>

Details

This function performs an intra-experiment analysis for the given sample(s) [1]. Given x as the numeric vector, this function first splits x into smaller samples with size *splitSize*, performs hypothesis testing using *func*, and then combines the p-values using *metaMethod*

Value

intra-experiment p-value

Author(s)

Tin Nguyen and Sorin Draghici

References

[1] T. Nguyen, R. Tagett, M. Donato, C. Mitrea, and S. Draghici. A novel bi-level meta-analysis approach – applied to biological pathway analysis. *Bioinformatics*, 32(3):409-416, 2016.

See Also

[bilevelAnalysisClassic](#), [intraAnalysisGene](#), [bilevelAnalysisGene](#)

Examples

```

set.seed(1)
x <- rnorm(10, mean = 0)
# p-value obtained from a one-sample t-test
t.test(x, mu=1, alternative = "less")$p.value
# p-value obtained from an intra-experiment analysis
intraAnalysisClassic(x, func=t.test, mu=1, alternative = "less")

# p-value obtained from a one-sample wilcoxon test
wilcox.test(x, mu=1, alternative = "less")$p.value
# p-value obtained from an intra-experiment analysis
intraAnalysisClassic(x, func=wilcox.test, mu=1, alternative = "less")

set.seed(1)
x <- rnorm(20, mean=0); y <- rnorm(20, mean=1)
# p-value obtained from a two-sample t-test
t.test(x,y,alternative="less")$p.value
# p-value obtained from an intra-experiment analysis
intraAnalysisClassic(x, y, func=t.test, alternative = "less")
# p-value obtained from a two-sample wilcoxon test
wilcox.test(x,y,alternative="less")$p.value
# p-value obtained from an intra-experiment analysis
intraAnalysisClassic(x, y, func=wilcox.test, alternative = "less")

```

intraAnalysisGene *Intra-experiment analysis of an expression dataset at the gene-level*

Description

perform an intra-experiment analysis in conjunction with the moderated t-test (limma package) for the purpose of differential expression analysis of a gene expression dataset

Usage

```
intraAnalysisGene(data, group, splitSize = 5, metaMethod = addCLT)
```

Arguments

data	a data frame where the rows are the gene IDs and the columns are the samples
group	sample grouping. The elements of <i>group</i> are either 'c' (control) or 'd' (disease). names(group) should be identical to colnames(data)
splitSize	the minimum number of disease samples in each split dataset. splitSize should be at least 3. By default, splitSize=5
metaMethod	the method used to combine p-values. This should be one of addCLT (additive method [1]), fishersMethod (Fisher's method [5]), stoufferMethod (Stouffer's method [6]), max (maxP method [7]), or min (minP method [8])

Details

This function performs an intra-experiment analysis [1] for individual genes of the given dataset. The function first splits the dataset into smaller datasets, performs a moderated t-test (limma package) for the genes of the split datasets, and then combines the p-values for individual genes using *metaMethod*

Value

A data frame (rownames are gene IDs) that consists of the following information:

- *logFC*: log foldchange (diseases versus controls)
- *pLimma*: p-value obtained from limma without splitting
- *pLimma.fdr*: FDR-corrected p-values of pLimma
- *pIntra*: p-value obtained from intra-experiment analysis
- *pIntra.fdr*: FDR-corrected p-values of pIntra

Author(s)

Tin Nguyen and Sorin Draghici

References

[1] T. Nguyen, R. Tagett, M. Donato, C. Mitrea, and S. Draghici. A novel bi-level meta-analysis approach – applied to biological pathway analysis. *Bioinformatics*, 32(3):409-416, 2016.

See Also

[bilevelAnalysisGene](#), [intraAnalysisClassic](#), [link{bilevelAnalysisClassic}](#)

Examples

```
data(GSE33223)
X <- intraAnalysisGene(data_GSE33223, group_GSE33223)
head(X)
```

loadKEGGPathways

Load KEGG pathways and names

Description

Load KEGG pathways and names

Usage

```
loadKEGGPathways(organism = "hsa", updateCache = FALSE)
```

Arguments

`organism` organism code. Default value is "hsa" (human)
`updateCache` re-download KEGG pathways. Default value is FALSE

Value

A list of the following components

- *kpg* a list of [graphNEL](#) objects encoding the pathway information.
- *kpn* a named vector of pathway tiles. The names of the vector are the pathway KEGG IDs.

Author(s)

Tin Nguyen and Sorin Draghici

See Also

[keggPathwayGraphs](#), [keggPathwayNames](#)

Examples

```
x <- loadKEGGPathways()
```

pORACalc

Over-representation Analysis

Description

Calculate p-value for over-representation Analysis

Usage

```
pORACalc(geneSet, DEGenes, measuredGenes, minSize = 0)
```

Arguments

geneSet	a vector of gene names belong to the geneset
DEGenes	a vector of differential expressed genes
measuredGenes	a vector of all genes in the analysis
minSize	the minimum number of DE genes in the geneSet

Value

p-value

stoufferMethod

Stouffer's method for meta-analysis

Description

Combine independent studies using the sum of p-values transformed into standard normal variables

Usage

```
stoufferMethod(x)
```

Arguments

x	is an array of independent p-values
---	-------------------------------------

Details

Considering a set of m independent significance tests, the resulted p-values are independent and uniformly distributed between 0 and 1 under the null hypothesis. Stouffer's method is similar to Fisher's method ([fisherMethod](#)), with the difference is that it uses the sum of p-values transformed into standard normal variables instead of the log product.

Value

combined p-value

Author(s)

Tin Nguyen and Sorin Draghici

References

[1] S. Stouffer, E. Suchman, L. DeVinney, S. Star, and R. M. Williams. The American Soldier: Adjustment during army life, volume 1. Princeton University Press, Princeton, 1949.

See Also

[fisherMethod](#), [addCLT](#)

Examples

```
x <- rep(0,10)
stoufferMethod(x)
```

```
x <- runif(10)
stoufferMethod(x)
```

Index

* dataset

GSE17054, [13](#)
GSE33223, [14](#)
GSE42140, [14](#)
GSE57194, [15](#)

addCLT, [2](#), [10](#), [12](#), [20](#)

bilevelAnalysisClassic, [3](#), [16](#)
bilevelAnalysisGene, [4](#), [4](#), [5](#), [16](#), [18](#)
bilevelAnalysisGeneset, [6](#), [9](#)
bilevelAnalysisPathway, [7](#), [8](#)

data_GSE17054 (GSE17054), [13](#)
data_GSE33223 (GSE33223), [14](#)
data_GSE42140 (GSE42140), [14](#)
data_GSE57194 (GSE57194), [15](#)

fisherMethod, [3](#), [10](#), [20](#)

getStatistics, [11](#)
graphNEL, [8](#), [18](#)
group_GSE17054 (GSE17054), [13](#)
group_GSE33223 (GSE33223), [14](#)
group_GSE42140 (GSE42140), [14](#)
group_GSE57194 (GSE57194), [15](#)
GSA, [7](#)
GSE17054, [13](#)
GSE33223, [14](#)
GSE42140, [14](#)
GSE57194, [15](#)

intraAnalysisClassic, [4](#), [5](#), [16](#), [18](#)
intraAnalysisGene, [4](#), [16](#), [17](#)

keggPathwayGraphs, [19](#)
keggPathwayNames, [19](#)

loadKEGGPathways, [18](#)

padog, [7](#)
pe, [9](#)
phyper, [7](#), [9](#)
pORACalc, [19](#)

stoufferMethod, [3](#), [10](#), [19](#)