

# Package ‘zenith’

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**Type** Package

**Title** Gene set analysis following differential expression using linear (mixed) modeling with dream

**Version** 1.15.0

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**Description** Zenith performs gene set analysis on the result of differential expression using linear (mixed) modeling with dream by considering the correlation between gene expression traits. This package implements the camera method from the limma package proposed by Wu and Smyth (2012). Zenith is a simple extension of camera to be compatible with linear mixed models implemented in `variancePartition::dream()`.

**VignetteBuilder** knitr

**License** Artistic-2.0

**Encoding** UTF-8

**URL** <https://DiseaseNeuroGenomics.github.io/zenith>

**BugReports** <https://github.com/DiseaseNeuroGenomics/zenith/issues>

**Suggests** BiocStyle, BiocGenerics, knitr, pander, rmarkdown, tweekDEseqCountData, edgeR, kableExtra, RUnit

**biocViews** RNASeq, GeneExpression, GeneSetEnrichment, DifferentialExpression, BatchEffect, QualityControl, Regression, Epigenetics, FunctionalGenomics, Transcriptomics, Normalization, Preprocessing, Microarray, ImmunoOncology, Software

**Depends** R (>= 4.2.0), limma, methods

**Imports** variancePartition (>= 1.26.0), EnrichmentBrowser (>= 2.22.0), GSEABase (>= 1.54.0), msigdbR, Rfast, ggplot2, tidyr, dplyr, reshape2, progress, utils, Rdpack, stats

**RdMacros** Rdpack

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**Author** Gabriel Hoffman [aut, cre] (ORCID:  
<<https://orcid.org/0000-0002-0957-0224>>)

**Maintainer** Gabriel Hoffman <[gabriel.hoffman@mssm.edu](mailto:gabriel.hoffman@mssm.edu)>

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`.rankSumTestWithCorrelation`

*Two Sample Wilcoxon-Mann-Whitney Rank Sum Test Allowing For Correlation*

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## Description

Same as `limma::rankSumTestWithCorrelation`, but returns effect size.

## Usage

```
.rankSumTestWithCorrelation(index, statistics, correlation = 0, df = Inf)
```

## Arguments

<code>index</code>	any index vector such that <code>statistics[index]</code> contains the values of the statistic for the test group.
<code>statistics</code>	numeric vector giving values of the test statistic.
<code>correlation</code>	numeric scalar, average correlation between cases in the test group. Cases in the second group are assumed independent of each other and other the first group.
<code>df</code>	degrees of freedom which the correlation has been estimated.

## Details

See `limma::rankSumTestWithCorrelation`

## Value

`data.frame` storing results of hypothesis test

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corInGeneSet	<i>Evaluate mean correlation between residuals in gene set</i>
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**Description**

Evaluate mean correlation between residuals in gene set based on results from dream

**Usage**

```
corInGeneSet(fit, idx, squareCorr = FALSE)
```

**Arguments**

fit	result of differential expression with dream
idx	indices or rownames to extract
squareCorr	compute the mean squared correlation instead

**Value**

list storing correlation and variance inflation factor

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get_GeneOntology	<i>Load Gene Ontology genesets</i>
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**Description**

Load Gene Ontology genesets

**Usage**

```
get_GeneOntology(
  onto = c("BP", "MF", "CC"),
  to = "ENSEMBL",
  includeOffspring = TRUE,
  org = "hsa"
)
```

**Arguments**

onto	array of categories to load
to	convert gene names to this type using <code>EnrichmentBrowser::idMap()</code> . See <code>EnrichmentBrowser::idTypes(org="hsa")</code> for valid types
includeOffspring	if TRUE, follow the GO hierarchy down and include all genes in offspring sets for a given gene set
org	organism. human ('hsa'), mouse ('mmu'), etc

**Details**

This function loads the GO gene sets using the packages EnrichmentBrowser and GO.db. It can take a minute to load because converting gene name type is slow.

**Value**

Gene sets stored as GeneSetCollection

**Examples**

```
# load GO Biological Process
# gs = get_GeneOntology('BP')

# load all gene sets
# gs = get_GeneOntology()
```

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get_MSigDB	<i>Load MSigDB genesets</i>
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**Description**

Load MSigDB genesets

**Usage**

```
get_MSigDB(
  cat,
  to = c("ENSEMBL", "SYMBOL", "ENTREZ"),
  organism = c("HS", "MM")
)
```

**Arguments**

cat	array of categories to load.
to	return genes names as 'ENSEMBL' or 'SYMBOL'
organism	organism: human ('HS') or mouse ('MS')

**Details**

This function loads the MSigDB gene sets using the packages and msigdb. It can take a minute to load because converting gene name type is slow.

**Value**

Gene sets stored as GeneSetCollection

## Examples

```
# load Hallmark gene sets
gs = get_MSigDB('H')

# load all gene sets
# gs = get_MSigDB()
```

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plotZenithResults      *Heatmap of zenith results using ggplot2*

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## Description

Heatmap of zenith results showing genesets that have the top and bottom t-statistics from each assay.

## Usage

```
plotZenithResults(
  df,
  ntop = 5,
  nbottom = 5,
  label.angle = 45,
  zmax = NULL,
  transpose = FALSE,
  sortByGeneset = TRUE
)
```

## Arguments

df	result data.frame from <a href="#">zenith_gsa</a>
ntop	number of gene sets with highest t-statistic to show
nbottom	number of gene sets with lowest t-statistic to show
label.angle	angle of x-axis label
zmax	maximum of the color scales. If not specified, used range of the observed t-statistics
transpose	transpose the axes of the plot
sortByGeneset	use hierarchical clustering to sort gene sets. Default is TRUE

## Value

Heatmap showing enrichment for gene sets and cell types

**Examples**

```

# Load packages
library(edgeR)
library(variancePartition)
library(tweedEseqCountData)

# Load RNA-seq data from LCL's
data(pickrell)
geneCounts = exprs(pickrell.eset)
df_metadata = pData(pickrell.eset)

# Filter genes
# Note this is low coverage data, so just use as code example
dsgn = model.matrix(~ gender, df_metadata)
keep = filterByExpr(geneCounts, dsgn, min.count=5)

# Compute library size normalization
dge = DGEList(counts = geneCounts[keep,])
dge = calcNormFactors(dge)

# Estimate precision weights using voom
vobj = voomWithDreamWeights(dge, ~ gender, df_metadata)

# Apply dream analysis
fit = dream(vobj, ~ gender, df_metadata)
fit = eBayes(fit)

# Load Hallmark genes from MSigDB
# use gene 'SYMBOL', or 'ENSEMBL' id
# use get_GeneOntology() to load Gene Ontology
gs = get_MSigDB("H", to="ENSEMBL")

# Run zenith analysis
res.gsa = zenith_gsa(fit, gs, 'gendermale', progressBar=FALSE )

# Show top gene sets
head(res.gsa, 2)

# for each cell type select 3 genesets with largest t-statistic
# and 1 geneset with the lowest
# Grey boxes indicate the gene set could not be evaluated because
#   to few genes were represented
plotZenithResults(res.gsa)

```

zenith

*Gene set analysis following differential expression with dream***Description**

Perform gene set analysis on the result of differential expression using linear (mixed) modeling with `variancePartition::dream` by considering the correlation between gene expression traits. This package is a slight modification of `limma::camera` to 1) be compatible with `dream`, and 2) allow identification of gene sets with log fold changes with mixed sign.

**Usage**

```
zenith(
  fit,
  coef,
  index,
  use.ranks = FALSE,
  allow.neg.cor = FALSE,
  progressbar = TRUE,
  inter.gene.cor = 0.01
)
```

**Arguments**

<code>fit</code>	result of differential expression with dream
<code>coef</code>	coefficient to test using <code>topTable(fit, coef)</code>
<code>index</code>	an index vector or a list of index vectors. Can be any vector such that <code>fit[index, ]</code> selects the rows corresponding to the test set. The list can be made using <code>ids2indices</code> .
<code>use.ranks</code>	do a rank-based test (TRUE) or a parametric test ('FALSE')?
<code>allow.neg.cor</code>	should reduced variance inflation factors be allowed for negative correlations?
<code>progressbar</code>	if TRUE, show progress bar
<code>inter.gene.cor</code>	if NA, estimate correlation from data. Otherwise, use specified value

**Details**

`zenith` gives the same results as `camera(..., inter.gene.cor=NA)` which estimates the correlation with each gene set.

For differential expression with dream using linear (mixed) models see Hoffman and Roussos (2020). For the original camera gene set test see Wu and Smyth (2012).

**Value**

- `NGenes`: number of genes in this set
- `Correlation`: mean correlation between expression of genes in this set
- `delta`: difference in mean t-statistic for genes in this set compared to genes not in this set
- `se`: standard error of delta
- `p.less`: p-value for hypothesis test of  $H_0: \text{delta} < 0$
- `p.greater`: p-value for hypothesis test of  $H_0: \text{delta} > 0$
- `PValue`: p-value for hypothesis test  $H_0: \text{delta} \neq 0$
- `Direction`: direction of effect based on `sign(delta)`
- `FDR`: false discovery rate based on Benjamini-Hochberg method in `p.adjust`

**References**

- Hoffman, G. E., & Roussos, P. (2021). Dream: powerful differential expression analysis for repeated measures designs. *Bioinformatics*, 37(2), 192-201.
- Wu, Di, and Gordon K. Smyth. "Camera: a competitive gene set test accounting for inter-gene correlation." *Nucleic acids research* 40.17 (2012): e133-e133.

**Examples**

```

library(variancePartition)

# simulate meta-data
info <- data.frame(Age=c(20, 31, 52, 35, 43, 45),Group=c(0,0,0,1,1,1))

# simulate expression data
y <- matrix(rnorm(1000*6),1000,6)
rownames(y) = paste0("gene", 1:1000)
colnames(y) = rownames(info)

# First set of 20 genes are genuinely differentially expressed
index1 <- 1:20
y[index1,4:6] <- y[index1,4:6]+1

# Second set of 20 genes are not DE
index2 <- 21:40

# perform differential expression analysis with dream
fit = dream(y, ~ Age + Group, info)
fit = eBayes(fit)

# perform gene set analysis testing Age
res = zenith(fit, "Age", list(set1=index1,set2=index2) )

head(res)

```

---

zenithPR\_gsa

*Gene set analysis using pre-computed test statistic*


---

**Description**

Perform gene set analysis on the result of a pre-computed test statistic. Test whether statistics in a gene set are larger/smaller than statistics not in the set.

**Usage**

```

zenithPR_gsa(
  statistics,
  ids,
  geneSets,
  use.ranks = FALSE,
  n_genes_min = 10,
  progressbar = TRUE,
  inter.gene.cor = 0.01,
  coef.name = "zenithPR"
)

```

**Arguments**

statistics	pre-computed test statistics
ids	name of gene for each entry in statistics

geneSets	GeneSetCollection
use.ranks	do a rank-based test TRUE or a parametric test FALSE? default: FALSE
n_genes_min	minumum number of genes in a geneset
progressbar	if TRUE, show progress bar
inter.gene.cor	correlation of test statistics with in gene set
coef.name	name of column to store test statistic

## Details

This is the same as `zenith_gsa()`, but uses pre-computed test statistics. Note that `zenithPR_gsa()` may give slightly different results for small samples sizes, if `zenithPR_gsa()` is fed t-statistics instead of z-statistics.

## Value

- `NGenes`: number of genes in this set
- `Correlation`: mean correlation between expression of genes in this set
- `delta`: difference in mean t-statistic for genes in this set compared to genes not in this set
- `se`: standard error of delta
- `p.less`: p-value for hypothesis test of  $H_0: \text{delta} < 0$
- `p.greater`: p-value for hypothesis test of  $H_0: \text{delta} > 0$
- `PValue`: p-value for hypothesis test  $H_0: \text{delta} \neq 0$
- `Direction`: direction of effect based on `sign(delta)`
- `FDR`: false discovery rate based on Benjamini-Hochberg method in `p.adjust`
- `coef.name`: name for pre-computed test statistics. Default: `zenithPR`

## See Also

`zenith_gsa()`, `limma::cameraPR()`

## Examples

```
# Load packages
library(edgeR)
library(variancePartition)
library(tweedEseqCountData)

# Load RNA-seq data from LCL's
data(pickrell)
geneCounts = exprs(pickrell.eset)
df_metadata = pData(pickrell.eset)

# Filter genes
# Note this is low coverage data, so just use as code example
dsgn = model.matrix(~ gender, df_metadata)
keep = filterByExpr(geneCounts, dsgn, min.count=5)

# Compute library size normalization
dge = DGEList(counts = geneCounts[keep,])
dge = calcNormFactors(dge)
```

```

# Estimate precision weights using voom
vobj = voomWithDreamWeights(dge, ~ gender, df_metadata)

# Apply dream analysis
fit = dream(vobj, ~ gender, df_metadata)
fit = eBayes(fit)

# Load Hallmark genes from MSigDB
# use gene 'SYMBOL', or 'ENSEMBL' id
# use get_GeneOntology() to load Gene Ontology
gs = get_MSigDB("H", to="ENSEMBL")

# Run zenithPR analysis with a test statistic for each gene
tab = topTable(fit, coef='gendermale', number=Inf)

res.gsa = zenithPR_gsa(tab$t, rownames(tab), gs)

```

---

zenith\_gsa

*Perform gene set analysis using zenith*


---

## Description

Perform a competitive gene set analysis accounting for correlation between genes.

## Usage

```

zenith_gsa(
  fit,
  geneSets,
  coefs,
  use.ranks = FALSE,
  n_genes_min = 10,
  inter.gene.cor = 0.01,
  progressbar = TRUE,
  ...
)

## S4 method for signature 'MArrayLM, GeneSetCollection'
zenith_gsa(
  fit,
  geneSets,
  coefs,
  use.ranks = FALSE,
  n_genes_min = 10,
  inter.gene.cor = 0.01,
  progressbar = TRUE,
  ...
)

```

## Arguments

fit                    results from dream()

geneSets	GeneSetCollection
coefs	list of coefficients to test using <code>topTable(fit, coef=coefs[[i]])</code>
use.ranks	do a rank-based test TRUE or a parametric test FALSE? default: FALSE
n_genes_min	minimum number of genes in a geneset
inter.gene.cor	if NA, estimate correlation from data. Otherwise, use specified value
progressbar	if TRUE, show progress bar
...	other arguments

### Details

This code adapts the widely used `camera()` analysis (Wu and Smyth, 2012) in the `limma` package (Ritchie, et al. 2015) to the case of linear (mixed) models used by `variancePartition::dream()`.

### Value

`data.frame` of results for each gene set and cell type

### References

Wu, Di, and Gordon K. Smyth. "Camera: a competitive gene set test accounting for inter-gene correlation." *Nucleic acids research* 40.17 (2012): e133-e133.

Ritchie, M. E., Phipson, B., Wu, D. I., Hu, Y., Law, C. W., Shi, W., & Smyth, G. K. (2015). `limma` powers differential expression analyses for RNA-sequencing and microarray studies. *Nucleic acids research*, 43(7), e47-e47.

### See Also

`limma::camera`

### Examples

```
# Load packages
library(edgeR)
library(variancePartition)
library(tweedEseqCountData)

# Load RNA-seq data from LCL's
data(pickrell)
geneCounts = exprs(pickrell.eset)
df_metadata = pData(pickrell.eset)

# Filter genes
# Note this is low coverage data, so just use as code example
dsgn = model.matrix(~ gender, df_metadata)
keep = filterByExpr(geneCounts, dsgn, min.count=5)

# Compute library size normalization
dge = DGEList(counts = geneCounts[keep,])
dge = calcNormFactors(dge)

# Estimate precision weights using voom
vobj = voomWithDreamWeights(dge, ~ gender, df_metadata)
```

```
# Apply dream analysis
fit = dream(vobj, ~ gender, df_metadata)
fit = eBayes(fit)

# Load Hallmark genes from MSigDB
# use gene 'SYMBOL', or 'ENSEMBL' id
# use get_GeneOntology() to load Gene Ontology
gs = get_MSigDB("H", to="ENSEMBL")

# Run zenith analysis
res.gsa = zenith_gsa(fit, gs, 'gendermale', progressbar=FALSE )

# Show top gene sets
head(res.gsa, 2)

# for each cell type select 3 genesets with largest t-statistic
# and 1 geneset with the lowest
# Grey boxes indicate the gene set could not be evaluated because
# to few genes were represented
plotZenithResults(res.gsa)
```

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