Package ‘COMPASS’

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Type Package

Title Combinatorial Polyfunctionality Analysis of Single Cells

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Description COMPASS is a statistical framework that enables unbiased analysis of antigen-specific T-cell subsets. COMPASS uses a Bayesian hierarchical framework to model all observed cell-subsets and select the most likely to be antigen-specific while regularizing the small cell counts that often arise in multi-parameter space. The model provides a posterior probability of specificity for each cell subset and each sample, which can be used to profile a subject’s immune response to external stimuli such as infection or vaccination.

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BugReports https://github.com/RGLab/COMPASS/issues

VignetteBuilder knitr

Depends R (>= 3.0.2)

LinkingTo Rcpp (>= 0.11.0)

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Imports Rcpp, data.table, RColorBrewer, scales, grid, plyr, knitr, abind, clue, grDevices, utils, pdist

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LazyData yes

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RoxygenNote 5.0.1

NeedsCompilation yes

R topics documented:

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COMPASS-package

Description

This package implements a model for the analysis of polyfunctionality in single-cell cytometry experiments. The model effectively identifies combinations of markers that are differentially expressed between samples of cells subjected to different stimulations.

See Also

- COMPASSContainer, for information on getting your cytometry data into a suitable format for use with COMPASS,
- COMPASS, for the main model fitting routine.
**categories**

<table>
<thead>
<tr>
<th>categories</th>
<th>Categories</th>
</tr>
</thead>
</table>

**Description**

Returns the categories matrix in a COMPASSResult object.

**Usage**

categories(x, counts)

**Arguments**

- **x**: A COMPASSResult object.
- **counts**: Boolean; if TRUE we return the counts (degree of functionality) as well.

**CellCounts**

Compute Number of Cells Positive for Certain Cytokine Combinations

**Description**

Compute the number of cells expressing a particular combination of markers for each sample.

**Usage**

CellCounts(data, combinations)

**Arguments**

- **data**: Either a COMPASSContainer, or a list of matrices. Each matrix i is of dimension N_i cells (rows) by K common markers (columns).
- **combinations**: A list of ‘combinations’, used to denote the subsets of interest. See the examples for usage.

**See Also**

Combinations

**Examples**

```r
set.seed(123)
## generate 10 simulated matrices of flow data
K <- 6 ## number of markers
data <- replicate(10, simplify=FALSE, {
  m <- matrix(rnorm(1E4 * K, 2000, 1000 ), ncol=K)
m[m < 2500] <- 0
colnames(m) <- c("IL2", "IL4", "IL6", "Mip1B", "IFNg", "TNFa")
return(m)
})
names(data) <- sample(letters, 10)
```
Combinations

Given an integer n, generate all binary combinations of n elements, transformed to indices. This is primarily for use with the CellCounts function, but may be useful for users in some scenarios.

Usage

Combinations(n)
COMPASS

Arguments

n An integer.

Examples

Combinations(3)

COMPASS Fit the COMPASS Model

Description

This function fits the COMPASS model.

Usage

COMPASS(data, treatment, control, subset = NULL,
  category_filter = function(x) colSums(x > 5) > 2,
  filter_lowest_frequency = 0, filter_specific_markers = NULL,
  model = "discrete", iterations = 40000, replications = 8,
  keep_original_data = FALSE, verbose = TRUE, dropDegreeOne = FALSE, ...)

Arguments

data An object of class COMPASSContainer.
treatment An R expression, evaluated within the metadata, that returns TRUE for those samples that should belong to the treatment group. For example, if the samples that received a positive stimulation were named "92TH023 Env" within a variable in meta called Stim, you could write Stim == "92TH023 Env". The expression should have the name of the stimulation vector on the left hand side.
control An R expression, evaluated within the metadata, that returns TRUE for those samples that should belong to the control group. See above for details.
subset An expression used to subset the data. We keep only the samples for which the expression evaluates to TRUE in the metadata.
category_filter A filter for the categories that are generated. This is a function that will be applied to the treatment counts matrix generated from the intensities. Only categories meeting the category_filter criteria will be kept.
filter_lowest_frequency A number specifying how many of the least expressed markers should be removed.
filter_specific_markers Similar to filter_lowest_frequency, but lets you explicitly exclude markers.
model A string denoting which model to fit; currently, only the discrete model ("discrete") is available.
iterations The number of iterations (per 'replication') to perform.
replications The number of 'replications' to perform. In order to conserve memory, we only keep the model estimates from the last replication.
keep_original_data
Keep the original COMPASSContainer as part of the COMPASS output? If memory or disk space is an issue, you may set this to FALSE.

verbose
Boolean; if TRUE we output progress information.

dropDegreeOne
Boolean; if TRUE we drop degree one categories and merge them with the negative subset.

... Other arguments; currently unused.

Value
A COMPASSResult is a list with the following components:

fit
A list of various fitted parameters resulting from the COMPASS model fitting procedure.

data
The data used as input to the COMPASS fitting procedure – in particular, the counts matrices generated for the selected categories, n_s and n_u, can be extracted from here.

orig
If keep_original_data was set to TRUE in the COMPASS fit, then this will be the COMPASSContainer passed in. This is primarily kept for easier running of the Shiny app.

The fit component is a list with the following components:

alpha_s
The hyperparameter shared across all subjects under the stimulated condition. It is updated through the COMPASS model fitting process.

A_alphas
The acceptance rate of alpha_s, as computed through the MCMC sampling process in COMPASS.

alpha_u
The hyperparameter shared across all subjects under the unstimulated condition. It is updated through the COMPASS model fitting process.

A_alphau
The acceptance rate of alpha_u, as computed through the MCMC sampling process in COMPASS.

gamma
An array of dimensions I x K x T, where I denotes the number of individuals, K denotes the number of categories / subsets, and T denotes the number of iterations. Each cell in a matrix for a given iteration is either zero or one, reflecting whether individual i is responding to the stimulation for subset k.

mean_gamma
A matrix of mean response rates. Each cell denotes the mean response of individual i and subset k.

A_gamma
The acceptance rate for the gamma. Each element corresponds to the number of times an individual’s gamma vector was updated.

categories
The category matrix, showing which categories entered the model.

model
The type of model called.

posterior
Posterior measures from the sample fit.

call
The matched call used to generate the model fit.

The data component is a list with the following components:

n_s
The counts matrix for stimulated samples.

n_u
The counts matrix for unstimulated samples.

counts_s
Total cell counts for stimulated samples.
counts_u  Total cell counts for unstimulated samples.
categories  The categories matrix used to define which categories will enter the model.
meta  The metadata. Note that only individual-level metadata will be kept; sample-specific metadata is dropped.
sample_id  The name of the vector in the metadata used to identify the samples.
individual_id  The name of the vector in the metadata used to identify the individuals.

The `orig` component (included if `keep_original_data` is TRUE) is the COMPASSContainer object used in the model fit.

### Category Filter

The category filter is used to exclude categories (combinations of markers expressed for a particular cell) that are expressed very rarely. It is applied to the treatment counts matrix, which is a N samples by K categories matrix. Those categories which are mostly unexpressed can be excluded here. For example, the default criteria,

```r
category_filter=function(x) colSums(x > 5) > 2
```

indicates that we should only retain categories for which at least three samples had at least six cells expressing that particular combination of markers.

### See Also

- COMPASSContainer, for constructing the data object required by COMPASS

### Examples

```r
data(COMPASS)  ## loads the COMPASSContainer 'CC'
fit <- COMPASS(CC,
category_filter=NULL,
treatment=trt == "Treatment",
control=trt == "Control",
verbose=FALSE,
iterations=100  ## set higher for a real analysis
)
```

---

**COMPASSContainer**

*Generate the Data Object used by COMPASS*

### Description

This function generates the data container suitable for use with COMPASS.

### Usage

```r
COMPASSContainer(data, counts, meta, individual_id, sample_id,
countFilterThreshold = 0)
```
COMPASSContainer

Arguments

data  A list of matrices. Each matrix $M_i$ is made up of $N_i$ cells by $K$ markers; for example, it could be the intensity information from an intracellular cytokine experiment. Each element of the list should be named; this name denotes which sample the cell intensities were measured from.

counts  A named integer vector of the cell counts(of the parent population) for each sample in data.

meta  A data.frame of metadata, describing the individuals in the experiment. Each row in meta should correspond to a row in data. There should be one row for each sample; i.e., one row for each element of data.

individual_id  The name of the vector in meta that denotes the individuals from which samples were drawn.

sample_id  The name of the vector in meta that denotes the samples. This vector should contain all of the names in the data input.

countFilterThreshold  Numeric; if the number of cells expressing at least one marker of interest is less than this threshold, we remove that file. Default is 0, which means filter is disabled.

Details

The names attributes for the data and counts objects passed should match.

Value

A COMPASSContainer returns a list made up of the same components as input the model, but checks and sanitizes the supplied data to ensure that it conforms to the expectations outlined above.

Examples

```r
set.seed(123)
n <- 10 ## number of samples
k <- 3 ## number of markers

## generate some sample data
sid_vec <- paste0("sid_", 1:n) ## sample ids; unique names used to denote samples
iid_vec <- rep_len( paste0("iid_", 1:(n/2) ), n ) ## individual ids

## generate n matrices of 'cell intensities'
data <- replicate(n, {
  nrow <- round(runif(1) * 1E2 + 1000)
  ncol <- k
  vals <- rexp( nrow * ncol, runif(1, 1E-5, 1E-3) )
  vals[ vals < 2000 ] <- 0
  output <- matrix(vals, nrow, ncol)
  output <- output[ apply(output, 1, sum) > 0, ]
  colnames(output) <- paste0("M", 1:k)
  return(output)
})
names(data) <- sid_vec

## make a sample metadata data.frame
meta <- data.frame(  
```

COMPASSContainer-data

```r
sid=sid_vec,
iid=iid_vec,
trt=rep(c("Control", "Treatment"), each=5)
```

## generate an example total counts
## recall that cells not expressing any marker are not included
## in the 'data' matrices
```r
counts <- sapply(data, nrow) + round(rnorm(n, 1E3, 1E2))
counts <- setNames(as.integer(counts), names(counts))
```

## insert everything into a COMPASSContainer
```r
CC <- COMPASSContainer(data, counts, meta, "iid", "sid")
```

---

### Simulated COMPASSContainer

**Description**

This dataset contains simulated data for an intracellular cytokine staining experiment. In this data set, we have paired samples from five individuals, with each pair of samples being subjected to either a 'Control' condition of a 'Treatment' condition.

**Details**

Please see `COMPASSContainer` for more information on the components of this object.

The dataset is exported as `CC`, which is a short alias for `COMPASSContainer`.

---

### COMPASSContainerFromGatingSet

Create a COMPASS Container from a GatingSet

**Description**

This code expects a `GatingSet` or `GatingSetList`. It expects a regular expression for the node name (i.e. '/4\+$' would match '/4+' in a node name with the plus sign at the end of the string. Alternatively, you can supply a partial path. The user must supply the 'individual_id', which has the default value suitable for the data we commonly see. 'sample_id' is the 'rownames' of 'pData' of 'GatingSet'. Sometimes the child node names don't match the marker names exactly. This function will try to make some guesses about how to match these up. The `filter.fun` parameter is a function that does some regular expression string substitution to try and clean up the node names by removing various symbols that are often added to gates, {+-}. The user can provide their own function to do string cleanup. Counts are extracted as well as metadata and single cell data, and these are fed into the `COMPASSContainer` constructor.

**Usage**

```r
COMPASSContainerFromGatingSet(gs = NULL, node = NULL, filter.fun = NULL, individual_id = "PTID", mp = NULL, matchmethod = c("Levenshtein", "regex"), markers = NA, swap = FALSE, countFilterThreshold = 5000)
```
COMPASSDescription

Arguments

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>gs</td>
<td>a <code>GatingSet</code> or <code>GatingSetList</code></td>
</tr>
<tr>
<td>node</td>
<td>a regular expression to match a single node in the gating tree. If more than one node is matched, an error is thrown.</td>
</tr>
<tr>
<td>filter.fun</td>
<td>a function that does string substitution to clean up node names, i.e. turns a 'CD4+' into a 'CD4' to try and match against the parameters slot of the <code>flowFrames</code> in <code>gs</code></td>
</tr>
<tr>
<td>individual_id</td>
<td>a character identifying the subject id column in the <code>gs</code> metadata</td>
</tr>
<tr>
<td>mp</td>
<td>a list mapping node names to markers. This function tries to guess, but may fail. The user can override the guesswork.</td>
</tr>
<tr>
<td>matchmethod</td>
<td>a character either 'regex' or 'Levenshtein' for matching nodes to markers.</td>
</tr>
<tr>
<td>markers</td>
<td>a character vector of marker names to include.</td>
</tr>
<tr>
<td>swap</td>
<td>a logical default FALSE. Set to TRUE if the marker and channel names are swapped.</td>
</tr>
<tr>
<td>countFilterThreshold</td>
<td>numeric threshold. if the number of cells expressing at least one marker of interest is less than this threshold, we remove that file. Default is 5000.</td>
</tr>
</tbody>
</table>

Details

There is likely not sufficient error checking.

See Also

COMPASSContainer

Examples

```r
## Not run:
## gs is a GatingSet from flowWorkspace
COMPASSContainerFromGatingSet(gs, "4+")
## End(Not run)
```

COMPASSDescription  
*Get and Set the Description for the Shiny Application*

Description

This is used for setting an informative description used in the Shiny application.

Usage

```r
COMPASSDescription(x)
COMPASSDescription(x) <- value
```
COMPASSResult-accessors

Arguments

- `x` A COMPASS fit.
- `value` A set of paragraphs describing the experiment, as a character vector.

Details

Information about the COMPASS results will be auto-generated.

COMPASSResult-accessors

COMPASSResult Accessors

Description

These functions can be used for accessing data within a COMPASSResult.

The gamma array associated with a COMPASS model fit.

Usage

Gamma(x)

MeanGamma(x)

Arguments

- `x` A COMPASSResult object.

COMPASSResult-data

Simulated COMPASS fit

Description

This dataset represents the result of fitting the COMPASS model on the accompanying dataset CC, as exported by `data(COMPASS)`. Please see the vignette (`vignette("COMPASS")`) for more details on how to interact with a COMPASS fit.

Details

The model is fit as follows, using the COMPASSContainer CC.

```r
CR <- COMPASS(CC,
    treatment=trt == "Treatment",
    control=trt == "Control",
    iterations=1000
)
```

The dataset is exported as CR, which is a short alias for `COMPASSResult`. Please see COMPASS for more information on the output from a COMPASS model fit.
FunctionalityScore

Compute the Functionality Score for each subject fit in a COMPASS model

Description

Computes the functionality score for each observation from the gamma matrix of a COMPASS model fit. The scores are normalized according to the total number of possible subsets that could be observed ($2^M - 1$).

Usage

FunctionalityScore(x, n, markers = NULL)

## S3 method for class 'COMPASSResult'
FunctionalityScore(x, n, markers = NULL)

## Default S3 method:
FunctionalityScore(x, n, markers = NULL)

Arguments

- **x**: An object of class COMPASSResult, as returned by COMPASS. Alternatively, a matrix of functionality scores, used under the assumption that the ‘null’ category has been dropped.
- **n**: The number of markers included in an experiment. It is inferred from the data when x is a COMPASSResult.
- **markers**: The set of markers for which to compute a Functionality score. By default uses all markers. Must match names returned by markers().

Value

A numeric vector of functionality scores.

Note

The null category is implicitly dropped when computing the functionality score for a COMPASS result; this is not true for the regular matrix method.

Examples

FunctionalityScore(CR)
GetThresholdedIntensities

Extract Thresholded Intensities from a GatingSet

Description

This function extracts thresholded intensities for children of a node `node`, as specified through the `map` argument.

Usage

GetThresholdedIntensities(gs, node, map)

Arguments

gs A GatingSet or GatingSetList.
node The name, or path, of a single node in a GatingSet/GatingSetList.
map A list, mapping node names to markers.

Details

`map` should be an R list, mapping node names (as specified in the gating hierarchy of the gating set) to channel names (as specified in either the `desc` or `name` columns of the parameters of the associated `flowFrame`s in the GatingSet).

Value

A list with two components:

data A list of thresholded intensity measures.
counts A named vector of total cell counts at the node `node`.

Examples

if (require("flowWorkspace")) {

## Generate an example GatingSet that could be used with COMPASS
## We then pull out the 'data' and 'counts' components that could
## be used within a COMPASSContainer

n <- 10 ## number of samples
k <- 4 ## number of markers

sid_vec <- paste0("sid_", 1:n) ## sample ids; unique names used to denote samples
iid_vec <- rep_len( paste0("iid_", 1:(n/10) ), n ) ## individual ids
marker_names <- c("TNFa", "IL2", "IL4", "IL6")

## Generate n sets of 'flow' data -- a list of matrices, each row
## is a cell, each column is fluorescence intensities on a particular
## channel / marker
data <- replicate(n, {
    nrow <- round(runif(1) * 1E4 + 1000)
ncol <- k
vals <- rexp(nrow * ncol, runif(1, 1E-5, 1E-3))
output <- matrix(vals, nrow, ncol)
colnames(output) <- marker_names
return(output)
})
names(data) <- sid_vec

## Put it into a GatingSet
fs <- flowSet(lapply(data, flowFrame))
gs <- GatingSet(fs)

## Add some dummy metadata
meta <- pData(gs)
meta$PTID <- 1:10
pData(gs) <- meta
gate <- rectangleGate(list('TNFa' = c(-Inf, Inf)))
add(gs, gate, parent="root", name="dummy")

## Add dummy gate
invisible(lapply(marker_names, function(marker) {
  .gate <- setNames(list(c(rexp(1, runif(1, 1E-5, 1E-3)), Inf)), marker)
  gate <- rectangleGate(.gate = .gate)
  add(gs, gate, parent="dummy", name=paste0(marker, "+"))
}))
recompute(gs)

## Map node names to channel names
map=list(
  "TNFa+"="TNFa",
  "IL2+"="IL2",
  "IL4+"="IL4",
  "IL6+"="IL6"
)

## Pull out the data as a COMPASS-friendly dataset
node <- "dummy"
map <- map
system.time(
  output <- GetThresholdedIntensities(gs, "dummy", map)
)

system.time(
  output <- COMPASSContainerFromGatingSet(gs, "dummy", individual_id="PTID")
)
str(output)
melt_  

Description  
Returns the markers associated with an experiment.

Usage  
markers(object)

Arguments  
object  An R object.

melt_  Make a 'Wide' data set 'Long'

Description  
Inspired by reshape2::melt, we melt data.frames and matrices. This function is built for speed.

Usage  
melt_(data, ...)

## S3 method for class 'data.frame'
melt_(data, id.vars, measure.vars,  
   variable.name = "variable", ..., value.name = "value")

## S3 method for class 'matrix'
melt_(data, ...)

Arguments  
data  The data.frame to melt.
...  Arguments passed to other methods.
id.vars  Vector of id variables. Can be integer (variable position) or string (variable name). If blank, we use all variables not in measure.vars.
measure.vars  Vector of measured variables. Can be integer (variable position) or string (variable name). If blank, we use all variables not in id.vars.
variable.name  Name of variable used to store measured variable names.
value.name  Name of variable used to store values.

Details  
If items to be stacked are not of the same internal type, they will be promoted in the order logical > integer > numeric > character.
merge.COMPASSContainer

*Merge Two COMPASSContainers*

**Description**

This function merges two COMPASSContainers.

**Usage**

```r
## S3 method for class 'COMPASSContainer'
merge(x, y, ...)
```

**Arguments**

- `x`: A COMPASSContainer.
- `y`: A COMPASSContainer.
- `...`: other arguments passed to 'COMPASSContainer' call.

**Examples**

```r
## Chop the example COMPASSContainer into two, then merge it back together
CC1 <- subset(CC, trt == "Control")
CC2 <- subset(CC, trt == "Treatment")
merged <- merge(CC1, CC2)
res <- identical(CC, merge(CC1, CC2)) ## should return TRUE in this case
stopifnot( isTRUE(res) )
```

---

**metadata**

*Metadata*

**Description**

Functions for getting and setting the metadata associated with an object.

**Usage**

```r
metadata(x)
```

```r
## S3 method for class 'COMPASSContainer'
metadata(x)
```

```r
## S3 method for class 'COMPASSResult'
metadata(x)
```

```r
metadata(x) <- value
```

```r
## S3 replacement method for class 'COMPASSContainer'
metadata(x) <- value
```
Arguments

x  An R object.
value  An R object appropriate for storing metadata in object x; typically a data.frame.

pheatmap  A function to draw clustered heatmaps.

Description

A function to draw clustered heatmaps where one has better control over some graphical parameters such as cell size, etc.

Usage

pheatmap(mat, color = colorRampPalette(rev(brewer.pal(n = 7, name = "RdYlBu")))(100), kmeans_k = NA, breaks = NA, border_color = "grey60", cellwidth = NA, cellheight = NA, scale = "none", cluster_rows = TRUE, cluster_cols = TRUE, clustering_distance_rows = "euclidean", clustering_distance_cols = "euclidean", clustering_method = "complete", treeheight_row = ifelse(cluster_rows, 50, 0), treeheight_col = ifelse(cluster_cols, 50, 0), legend = TRUE, legend_breaks = NA, legend_labels = NA, annotation = NA, annotation_colors = NA, annotation_legend = TRUE, drop_levels = TRUE, show_rownames = TRUE, show_colnames = TRUE, main = NA, fontsize = 10, fontsize_row = fontsize, fontsize_col = fontsize, display_numbers = FALSE, number_format = "%.2f", fontsize_number = 0.8 * fontsize, filename = NA, width = NA, height = NA, row_annotation = NA, row_annotation_legend = TRUE, row_annotation_colors = NA, cytokine_annotation = NA, headerplot = NA, polar = FALSE, order_by_max_functionality = TRUE, ...)

Arguments

mat  numeric matrix of the values to be plotted.
color  vector of colors used in heatmap.
kmeans_k  the number of kmeans clusters to make, if we want to aggregate the rows before drawing heatmap. If NA then the rows are not aggregated.
brakes  a sequence of numbers that covers the range of values in mat and is one element longer than color vector. Used for mapping values to colors. Useful, if needed to map certain values to certain colors, to certain values. If value is NA then the breaks are calculated automatically.
border_color  color of cell borders on heatmap, use NA if no border should be drawn.
cellwidth  individual cell width in points. If left as NA, then the values depend on the size of plotting window.
cellheight  individual cell height in points. If left as NA, then the values depend on the size of plotting window.
scale  character indicating if the values should be centered and scaled in either the row direction or the column direction, or none. Corresponding values are "row", "column" and "none"
cluster_rows boolean values determining if rows should be clustered.
cluster_cols boolean values determining if columns should be clustered.
clustering_distance_rows distance measure used in clustering rows. Possible values are "correlation" for Pearson correlation and all the distances supported by dist, such as "euclidean", etc. If the value is none of the above it is assumed that a distance matrix is provided.
clustering_distance_cols distance measure used in clustering columns. Possible values the same as for clustering_distance_rows.
clustering_method clustering method used. Accepts the same values as hclust.
treeheight_row the height of a tree for rows, if these are clustered. Default value 50 points.
treeheight_col the height of a tree for columns, if these are clustered. Default value 50 points.
legend logical to determine if legend should be drawn or not.
legend_breaks vector of breakpoints for the legend.
legend_labels vector of labels for the legend_breaks.
annotation data frame that specifies the annotations shown on top of the columns. Each row defines the features for a specific column. The columns in the data and rows in the annotation are matched using corresponding row and column names. Note that color schemes takes into account if variable is continuous or discrete.
annotation_colors list for specifying annotation track colors manually. It is possible to define the colors for only some of the features. Check examples for details.
annotation_legend boolean value showing if the legend for annotation tracks should be drawn.
drop_levels logical to determine if unused levels are also shown in the legend
show_rownames boolean specifying if column names are be shown.
show_colnames boolean specifying if column names are be shown.
main the title of the plot
fontsize base fontsize for the plot
fontsize_row fontsize for rownames (Default: fontsize)
fontsize_col fontsize for colnames (Default: fontsize)
display_numbers logical determining if the numeric values are also printed to the cells.
number_format format strings (C printf style) of the numbers shown in cells. For example "%.2f" shows 2 decimal places and "%e" shows exponential notation (see more in gettextf).
fontsize_number fontsize of the numbers displayed in cells
filename file path where to save the picture. Filetype is decided by the extension in the path. Currently following formats are supported: png, pdf, tiff, bmp, jpeg. Even if the plot does not fit into the plotting window, the file size is calculated so that the plot would fit there, unless specified otherwise.
width manual option for determining the output file width in inches.
height manual option for determining the output file height in inches.
row_annotation  data frame that specifies the annotations shown on the rows. Each row defines the features for a specific row. The rows in the data and rows in the annotation are matched using corresponding row names. The category labels are given by the data frame column names.

row_annotation_legend
same interpretation as the column parameters.

row_annotation_colors
same interpretation as the column parameters

cytokine_annotation
A data.frame of factors, with either levels 0 = unexpressed, 1 = expressed, or optionally with a third level -1 = 'left out'. of the categories for each column. They will be colored by their degree of functionality and ordered by degree of functionality and by amount of expression if column clustering is not done.

headerplot
is a list with two components, order and data. Order tells how to reorder the columns of the matrix.

polar
Boolean; if TRUE we draw a polar legend. Primarily for internal use. Data is some summary statistic over the columns which will be plotted in the header where the column cluster tree usually appears. Cytokine ordering is ignored when the headerplot argument is passed.

order_by_max_functionality
Boolean; re-order the cytokine labels by maximum functionality?

... graphical parameters for the text used in plot. Parameters passed to grid.text, see gpar.

Details

The function also allows to aggregate the rows using kmeans clustering. This is advisable if number of rows is so big that R cannot handle their hierarchical clustering anymore, roughly more than 1000. Instead of showing all the rows separately one can cluster the rows in advance and show only the cluster centers. The number of clusters can be tuned with parameter kmeans_k.

Value

Invisibly a list of components

- tree_row the clustering of rows as hclust object
- tree_col the clustering of columns as hclust object
- kmeans the kmeans clustering of rows if parameter kmeans_k was specified

Author(s)

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Examples

# Generate some data
test = matrix(rnorm(200), 20, 10)
test[1:10, seq(1, 10, 2)] = test[1:10, seq(1, 10, 2)] + 3
test[11:20, seq(2, 10, 2)] = test[11:20, seq(2, 10, 2)] + 2
test[15:20, seq(2, 10, 2)] = test[15:20, seq(2, 10, 2)] + 4
colnames(test) = paste("Test", 1:10, sep = "")
rownames(test) = paste("Gene", 1:20, sep = "")

# Draw heatmaps
pheatmap(test)

pheatmap(test, kmeans_k = 2)
pheatmap(test, scale = "row", clustering_distance_rows = "correlation")
pheatmap(test, color = colorRampPalette(c("navy", "white", "firebrick3"))(50))
pheatmap(test, cluster_row = FALSE)
pheatmap(test, legend = FALSE)
pheatmap(test, display_numbers = TRUE)
pheatmap(test, display_numbers = TRUE, number_format = "%.1e")
pheatmap(test, cluster_row = FALSE, legend_breaks = -1:4, legend_labels = c("0", "1e-4", "1e-3", "1e-2", "1e-1", "1"))
pheatmap(test, cellwidth = 15, cellheight = 12, main = "Example heatmap")

# Generate column annotations
annotation = data.frame(Var1 = factor(1:10 %% 2 == 0, labels = c("Class1", "Class2")), Var2 = 1:10)

annotation$Var1 = factor(annotation$Var1, levels = c("Class1", "Class2", "Class3"))
rownames(annotation) = paste("Test", 1:10, sep = "")

pheatmap(test, annotation = annotation)
pheatmap(test, annotation = annotation, annotation_legend = FALSE)
pheatmap(test, annotation = annotation, annotation_legend = FALSE, drop_levels = FALSE)

# Specify colors
Var1 = c("navy", "darkgreen")
names(Var1) = c("Class1", "Class2")
Var2 = c("lightgreen", "navy")

ann_colors = list(Var1 = Var1, Var2 = Var2)

#Specify row annotations
row_ann <- data.frame(foo=gl(2,nrow(test)/2), Bar=relevel(gl(2,nrow(test)/2),"2"))
rownames(row_ann) <- rownames(test)
pheatmap(test, annotation = annotation, annotation_legend = FALSE, drop_levels = FALSE, row_annotation = row_ann)

#Using cytokine annotations
M<-matrix(rnorm(8*20),ncol=8)
row_annotation<-data.frame(A=gl(4,nrow(M)/4),B=gl(4,nrow(M)/4))

eg=expand.grid(factor(c(0,1)),factor(c(0,1)),factor(c(0,1)))
colnames(eeg)<-c("IFNg","TNF\alpha","IL2")
rownames(eeg)<-apply(eeg,1,function(x)paste0(x,collapse=""))
colnames(M)<-1:nrow(M)
colnames(M)<-rownames(M)
cytokine_annotation=eeg

pheatmap(M,annotation=annotation,row_annotation=row_annotation,annotation_legend=FALSE,row_annotation_legend=FALSE,cluster_rows=FALSE,cluster_cols=FALSE,legend_breaks = -1:4, legend_labels = c("0", "1e-4", "1e-3", "1e-2", "1e-1", "1"))

# Specifying clustering from distance matrix
drows = dist(test, method = "minkowski")
dcols = dist(t(test), method = "minkowski")
pheatmap(test, clustering_distance_rows = drows, clustering_distance_cols = dcols)
Description

This function can be used to visualize the mean probability of response; that is, the probability that there is a difference in response between samples subjected to the 'treatment' condition, and samples subjected to the 'control' condition.

Usage

## S3 method for class 'COMPASSResult'
plot(x, y, subset = NULL, threshold = 0.01,
     minimum_dof = 1, maximum_dof = Inf, must_express = NULL, row_annotation,
     palette = colorRampPalette(brewer.pal(10, "Purples"))(20),
     show_rownames = FALSE, show_colnames = FALSE, measure = NULL,
     order_by = FunctionalityScore, order_by_max_functionality = TRUE,
     markers = NULL, ...)

Arguments

x An object of class COMPASSResult.

y This argument gets passed to row_annotation, if row_annotation is missing. It can be used to group rows (individuals) by different conditions as defined in the metadata.

subset An R expression, evaluated within the metadata, used to determine which individuals should be kept.

threshold A numeric threshold for filtering under-expressed categories. Any categories with mean score < threshold are removed.

minimum_dof The minimum degree of functionality for the categories to be plotted.

maximum_dof The maximum degree of functionality for the categories to be plotted.

must_express A character vector of markers that should be included in each subset plotted. For example, must_express=c("TNFa & IFNg") says we include only subsets that are positive for both TNFa or IFNg, while must_express=c("TNFa", "IFNg") says we should keep subsets which are positive for either TNFa or IFNg.

row_annotation A vector of names, pulled from the metadata, to be used for row annotation.

palette The colour palette to be used.

show_rownames Boolean; if TRUE we display row names (i.e., the individual ids).

show_colnames Boolean; if TRUE we display column names (i.e., the column name associated with a cytokine; typically not needed)

measure Optional. By default, we produce a heatmap of the mean gammas produced in a model fit. We can override this by supplying a matrix of suitable dimension as well; these can be generated with the Posterior* functions – see Posterior for examples.

order_by Order rows within a group. This should be a function; e.g. FunctionalityScore, mean, median, and so on. Set this to NULL to preserve the original ordering of the data.
**plot2**

Plot a pair of COMPASSResults

**Description**

This function can be used to visualize the mean probability of response – that is, the probability that there is a difference in response between samples subjected to the 'treatment' condition, and samples subjected to the 'control' condition.

**Usage**

```r
plot2(x, y, subset, threshold = 0.01, minimum_dof = 1, maximum_dof = Inf,
      must_express = NULL, row_annotation = NULL, palette = NA,
      show_rownames = FALSE, show_colnames = FALSE, ...)
```

**Arguments**

- `x` An object of class COMPASSResult.
- `y` An object of class COMPASSResult.
- `subset` An R expression, evaluated within the metadata, used to determine which individuals should be kept.
- `threshold` A numeric threshold for filtering under-expressed categories. Any categories with mean score < threshold are removed.
- `minimum_dof` The minimum degree of functionality for the categories to be plotted.
- `maximum_dof` The maximum degree of functionality for the categories to be plotted.
- `must_express` A character vector of markers that should be included in each subset plotted. For example, `must_express=c("TNFa & IFNg")` says we include only subsets that are positive for both TNFa or IFNg, while `must_express=c("TNFa", "IFNg")` says we should keep subsets which are positive for either TNFa or IFNg.
- `row_annotation` A vector of names, pulled from the metadata, to be used for row annotation.
- `palette` The colour palette to be used.
- `show_rownames` Boolean; if TRUE we display row names (ie, the individual ids).

**Value**

The plot as a grid object (grob). It can be redrawn with e.g. `grid::grid.draw()`.

**Examples**

```r
## visualize the mean probability of reponse
plot(CR)

## visualize the proportion of cells belonging to a category
plot(CR, measure=PosteriorPs(CR))
```
**PolyfunctionalityScore**

**show_colnames** Boolean: if TRUE we display column names (ie, the column name associated with a cytokine; typically not needed)

... Optional arguments passed to `pheatmap`.

**Value**

The plot as a grid object (grob). It can be redrawn with e.g. `grid::grid.draw()`.

---

**PolyfunctionalityScore**

*Compute the Polyfunctionality Score for each subject fit in a COMPASS model*

---

**Description**

Computes the Polyfunctionality score for each observation from the gamma matrix of a COMPASS model fit. The scores are normalized to one.

**Usage**

```r
PolyfunctionalityScore(x, degree, n, markers = NULL)
```

## S3 method for class `COMPASSResult`

```r
PolyfunctionalityScore(x, degree, n, markers = NULL)
```

## Default S3 method:

```r
PolyfunctionalityScore(x, degree, n, markers = NULL)
```

**Arguments**

- **x** An object of class `COMPASSResult`, as returned by `COMPASS`. Alternatively, a matrix of functionality scores.
- **degree** A vector of weights. If missing, this is the 'degree of functionality', that is, the number of markers expressed in a particular category.
- **n** The total number of markers. This is inferred when `x` is a `COMPASSResult`, and is unused in that case.
- **markers** A character specifying the markers for which to compute the score. Must match names in `markers()`.

**Value**

A numeric vector of polyfunctionality scores.

**Examples**

```r
PolyfunctionalityScore(CR)
```
Posterior

Retrieve Posterior Measures from a COMPASS fit

Description

These functions can be used to retrieve different posterior measures from a COMPASS fit object.

Usage

Posterior(x)
PosteriorDiff(x)
PosteriorLogDiff(x)
PosteriorPs(x)
PosteriorPu(x)

Arguments

x An object of class COMPASSResult.

Details

The posterior items retrieved are described as follows:

PosteriorPs: The posterior probability that the samples subjected to the 'treatment', or 'stimulated', condition responded.
PosteriorPu: The posterior probability that the samples subjected to the 'control', or 'unstimulated', condition responded.
PosteriorDiff: The difference in posterior response rates, as described above.
PosteriorLogDiff: The difference in the log response rates, as described above.

Examples

Posterior(CR)
PosteriorPs(CR)
PosteriorPu(CR)
PosteriorDiff(CR)
PosteriorLogDiff(CR)
**print.COMPASSContainer**

*Print a COMPASSContainer Object*

**Description**

This function prints a COMPASSContainer object, giving basic information about the object and the data it encapsulates.

**Usage**

```r
## S3 method for class 'COMPASSContainer'
print(x, ...)
```

**Arguments**

- `x` An object of class COMPASSContainer.
- `...` Optional arguments passed to `cat`.

**Examples**

```r
print(CC)
```

---

**print.COMPASSResult** *Print a COMPASSResult Object*

**Description**

This function prints basic information about the model fit by a COMPASS call.

**Usage**

```r
## S3 method for class 'COMPASSResult'
print(x, ...)
```

**Arguments**

- `x` An object of class COMPASSResult.
- `...` Optional arguments; currently unused.

**Examples**

```r
print(CR)
```
scores

Fetch the table of scores and metadata from a COMPASSResult Object

Description

This function extracts the functionality and polyfunctionality scores from a COMPASS result merged with the sample metadata table, accounting for any dropped samples due to filtering.

Usage

scores(x, markers = NULL)

Arguments

x
A COMPASSResult object.

markers
A character vector of markers for which to compute the scores. Defaults to all markers. Must match the names returned by markers().

Examples

scores(CR)

shinyCOMPASS

Start a Shiny Application for Visualizing COMPASS Results

Description

This function takes a COMPASSResult object, and generates a local Shiny application for visualizing the results.

Usage

shinyCOMPASS(x, dir = NULL, meta.vars, facet1 = "None", facet2 = "None", facet3 = "None", main = "Heatmap of Ag-Specificity Posterior Probabilities", stimulation = NULL, launch = TRUE, ...)

Arguments

x
An object of class COMPASSResult.

dir
A location to write out the .rds files that will be loaded and used by the Shiny application.

meta.vars
A character vector of column names that should be used for potential facetting in the Shiny app. By default, we take all metadata variables; you may want to limit this if you know certain variables are not of interest.

facet1, facet2, facet3
Default values for facets in the Shiny app. Each should be the name of a single vector in the metadata.
**shinyCOMPASSDeps**

```
shinyCOMPASSDeps
```

### Description

This function can be used to identify the packages still needed in order to launch the Shiny app.

### Usage

```
shinyCOMPASSDeps(verbos e = TRUE)
```

### Arguments

- `verbose`  
  Boolean; if TRUE we print installation instructions to the screen.

### Examples

```
shinyCOMPASSDeps()
```
Description

This function fits the COMPASS model from a user-provided set of stimulated / unstimulated matrices. See the NOTE for important details.

Usage

```r
SimpleCOMPASS(n_s, n_u, meta, individual_id, sample_id, iterations = 10000, replications = 8, verbose = TRUE)
```

Arguments

- `n_s`: The cell counts for stimulated cells.
- `n_u`: The cell counts for unstimulated cells.
- `meta`: A data.frame of metadata, describing the individuals in the experiment. Each row in `meta` should correspond to a row in `data`. There should be one row for each sample; i.e., one row for each element of `n_s` and `n_u`.
- `individual_id`: The name of the vector in `meta` that denotes the individuals from which samples were drawn.
- `sample_id`: The name of the vector in `meta` that denotes the samples. This vector should contain all of the names in the `data` input.
- `iterations`: The number of iterations (per 'replication') to perform.
- `replications`: The number of 'replications' to perform. In order to conserve memory, we only keep the model estimates from the last replication.
- `verbose`: Boolean; if `TRUE` we output progress information.

Value

A list with class COMPASSResult with two components, the `fit` containing parameter estimates and parameter acceptance rates, and `data` containing the generated data used as input for the model.

Note

`n_s` and `n_u` counts matrices should contain ALL $2^M$ possible combinations of markers, even if they are 0 for some combinations. The code expects the marker combinations to be named in the following way: "M1&M2&M3" means the combination represents cells expressing marker "M1" and "M2" and not "M3". For 3 markers, there should be 8 such combinations, such that `n_s` and `n_u` have 8 columns.

Examples

```r
## Not run:
set.seed(123)
n <- 10 ## number of samples
k <- 3 ## number of markers

## generate some sample data
```
subset.COMPASSContainer <- function(x, subset, ...) {
  ## S3 method for class 'COMPASSContainer'
  subset(x, subset, ...)

  Args:
  x: A COMPASSContainer.
  subset: A logical expression, evaluated within the metadata, indicating which entries to keep.
  ...: other arguments passed to 'COMPASSContainer' call.

  Examples:
  subset(CC, iid == "iid_1")
**summary.COMPASSContainer**  
*Summarize a COMPASSContainer Object*

**Description**

This function prints summary information about a COMPASSContainer object – the number of samples, basic information about the metadata, and so on.

**Usage**

```r
## S3 method for class 'COMPASSContainer'
summary(object, ...)
```

**Arguments**

- `object` An object of class COMPASSContainer.
- `...` Optional arguments; currently ignored.

**Examples**

```r
summary(CC)
```

---

**summary.COMPASSResult**  
*Summarize a COMPASSResult Object*

**Description**

This function prints basic information about the model fit by a COMPASS call.

**Usage**

```r
## S3 method for class 'COMPASSResult'
summary(object, ...)
```

**Arguments**

- `object` An object of class COMPASSResult.
- `...` Optional arguments; currently unused.

**Examples**

```r
print(CR)
```
**TotalCellCounts**  
*Compute Total Cell Counts*

**Description**

This function is used to compute total cell counts, per individual, from a COMPASSContainer.

**Usage**

```r
TotalCellCounts(data, subset, aggregate = TRUE)
```

**Arguments**

- `data`: A COMPASSContainer.
- `subset`: An expression, evaluated within the metadata, defining the subset of data over which the counts are computed. If left unspecified, the counts are computed over all samples.
- `aggregate`: Boolean; if TRUE we sum over the individual, to get total counts across samples for each individual.

**Examples**

```r
TotalCellCounts(CC, trt == "Treatment")
TotalCellCounts(CC, trt == "Control")
TotalCellCounts(CC)
```

---

**transpose_list**  
*Transpose a List*

**Description**

Transpose a matrix-like list.

**Usage**

```r
transpose_list(x)
```

**Arguments**

- `x`: An R list.

**Examples**

```r
l <- list( 1:3, 4:6, 7:9 )
stopifnot( identical(  
   transpose_list( transpose_list(l) ), l  
 ) )
```
UniqueCombinations  Generate Unique Combinations

Description
Generate all possible unique combinations of x. Primarily used as a helper function for CellCounts, but may be occasionally useful to the end user.

Usage
UniqueCombinations(x, as.matrix)

## S3 method for class 'COMPASSContainer'
UniqueCombinations(x, as.matrix = FALSE)

## Default S3 method:
UniqueCombinations(x, as.matrix = FALSE)

Arguments
x  Either a COMPASSContainer, or a list of matrices.

as.matrix  Boolean; if TRUE we return results as a matrix; otherwise, we return the results as a list.

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