Package 'scGPS'

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Type Package

Title A complete analysis of single cell subpopulations, from identifying subpopulations to analysing their relationship (scGPS = single cell Global Predictions of Subpopulation)

Version 1.19.0

Description The package implements two main algorithms to answer two key questions: a SCORE (Stable Clustering at Optimal REsolution) to find subpopulations, followed by scGPS to investigate the relationships between subpopulations.

Encoding UTF-8

LazyData true

License GPL-3

BugReports https://github.com/IMB-Computational-Genomics-Lab/scGPS/issues

url https://github.com/IMB-Computational-Genomics-Lab/scGPS/

RoxygenNote 7.1.1

Depends R (>= 3.6), SummarizedExperiment, dynamicTreeCut, SingleCellExperiment

biocViews SingleCell, Clustering, DataImport, Sequencing, Coverage

Imports glmnet (> 2.0), caret (>= 6.0), ggplot2 (>= 2.2.1), fastcluster, dplyr, Rcpp, RcppArmadillo, RcppParallel, grDevices, graphics, stats, utils, DESeq2, locfit

Suggests Matrix (>= 1.2), testthat, knitr, parallel, rmarkdown, RColorBrewer, ReactomePA, clusterProfiler, cowplot, org.Hs.eg.db, reshape2, xlsx, dendextend, networkD3, Rtsne, BiocParallel, e1071, WGCNA, devtools, DOSE

VignetteBuilder knitr

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Contents

`add_import` *add_import*

Description

import packages to namespace

`annotate_clusters` *annotate_clusters functionally annotates the identified clusters*

Description

often we need to label clusters with unique biological characters. One of the common approach to annotate a cluster is to perform functional enrichment analysis. The annotate implements ReactomePA and clusterProfiler for this analysis type in R. The function require installation of several databases as described below.

Usage

```
annotate_clusters(
  DEgeneList,
  pvalueCutoff = 0.05,
  gene_symbol = TRUE,
  species = "human"
)
```

Arguments

`DEgeneList`	is a vector of gene symbols, convertable to ENTREZID
`pvalueCutoff`	is a numeric of the cutoff p value
`gene_symbol`	logical of whether the geneList is a gene symbol
`species`	is the selection of 'human' or 'mouse', default to 'human' genes

Value

write enrichment test output to a file and an enrichment test object for plotting

Examples

```
genes <-training_gene_sample
genes <-genes$Merged_unique[seq_len(50)]
enrichment_test <- annotate_clusters(genes, pvalueCutoff=0.05,
    gene_symbol=TRUE, species = 'human')
clusterProfiler::dotplot(enrichment_test, showCategory=15)
```

`bootstrap_parallel` *BootStrap runs for both scGPS training and prediction with parallel option*

Description

same as bootstrap_prediction, but with an multicore option

Usage

```
bootstrap_parallel(
  ncores = 4,
  nboots = 1,
  genes = genes,
  mixedpop1 = mixedpop1,
  mixedpop2 = mixedpop2,
  c_selectID,
  listData = list(),
  cluster_mixedpop1 = NULL,
  cluster_mixedpop2 = NULL
)
```

Arguments

`ncores`	a number specifying how many cpus to be used for running
`nboots`	a number specifying how many bootstraps to be run
`genes`	a gene list to build the model
`mixedpop1`	a SingleCellExperiment object from a mixed population for training
`mixedpop2`	a SingleCellExperiment object from a target mixed population for prediction
`c_selectID`	the root cluster in mixedpop1 to becompared to clusters in mixedpop2
`listData`	a `list` object, which contains trained results for the first mixed population
`cluster_mixedpop1`	a vector of cluster assignment for mixedpop1
`cluster_mixedpop2`	a vector of cluster assignment for mixedpop2

Value

a `list` with prediction results written in to the index `out_idx`

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
#prl_boots <- bootstrap_parallel(ncores = 4, nboots = 1, genes=genes,
#    mixedpop1 = mixedpop2, mixedpop2 = mixedpop2,  c_selectID=1,
#    listData =list())
#prl_boots[[1]]$ElasticNetPredict
#prl_boots[[1]]$LDAPredict
```

---

bootstrap_prediction *BootStrap runs for both scGPS training and prediction*

Description

ElasticNet and LDA prediction for each of all the subpopulations in the new mixed population after training the model for a subpopulation in the first mixed population. The number of bootstraps to be run can be specified.

Usage

```
bootstrap_prediction(
  nboots = 1,
  genes = genes,
  mixedpop1 = mixedpop1,
  mixedpop2 = mixedpop2,
  c_selectID = NULL,
  listData = list(),
  cluster_mixedpop1 = NULL,
  cluster_mixedpop2 = NULL,
  trainset_ratio = 0.5,
  LDA_run = TRUE,
  verbose = FALSE,
  log_transform = FALSE
)
```

Arguments

nboots	a number specifying how many bootstraps to be run
genes	a gene list to build the model
mixedpop1	a SingleCellExperiment object from a mixed population for training
mixedpop2	a SingleCellExperiment object from a target mixed population for prediction
c_selectID	the root cluster in mixedpop1 to becompared to clusters in mixedpop2
listData	a list object, which contains trained results for the first mixed population
cluster_mixedpop1	a vector of cluster assignment for mixedpop1
cluster_mixedpop2	a vector of cluster assignment for mixedpop2
trainset_ratio	a number specifying the proportion of cells to be part of the training subpopulation
LDA_run	logical, if the LDA prediction is added to compare to ElasticNet
verbose	a logical whether to display additional messages
log_transform	boolean whether log transform should be computed

Value

a list with prediction results written in to the index out_idx

Author(s)

Quan Nguyen, 2017-11-25

See Also

bootstrap_parallel for parallel options

Examples

```
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
cluster_mixedpop1 <- colData(mixedpop1)[,1]
cluster_mixedpop2 <- colData(mixedpop2)[,1]
c_selectID <- 2
test <- bootstrap_prediction(nboots = 1, mixedpop1 = mixedpop1,
    mixedpop2 = mixedpop2, genes=genes, listData =list(),
    cluster_mixedpop1 = cluster_mixedpop1,
    cluster_mixedpop2 = cluster_mixedpop2, c_selectID = c_selectID)
names(test)
```

```
test$ElasticNetPredict
test$LDAPredict
```

`calcDist` *Compute Euclidean distance matrix by rows*

Description

Compute Euclidean distance matrix by rows

Usage

```
calcDist(x)
```

Arguments

x	A numeric matrix

Value

a distance matrix

Examples

```
mat_test <-matrix(rnbinom(1000,mu=0.01, size=10),nrow=1000)
calcDist(mat_test)
```

`calcDistArma` *Compute Euclidean distance matrix by rows*

Description

Compute Euclidean distance matrix by rows

Usage

```
calcDistArma(x)
```

Arguments

x	A numeric matrix

Value

a distance matrix

Examples

```
mat_test <-matrix(rnbinom(1000,mu=0.01, size=10),nrow=1000)
#library(microbenchmark)
#microbenchmark(calcDistArma(mat_test), dist(mat_test), times=3)
```

`clustering` *HC clustering for a number of resolutions*

Description

performs 40 clustering runs or more depending on windows

Usage

```
clustering(
  object = NULL,
  ngenes = 1500,
  windows = seq(from = 0.025, to = 1, by = 0.025),
  remove_outlier = c(0),
  nRounds = 1,
  PCA = FALSE,
  nPCs = 20,
  verbose = FALSE,
  log_transform = FALSE
)
```

Arguments

`object`	is a SingleCellExperiment object from the train mixed population
`ngenes`	number of top variable genes to be used
`windows`	a numeric specifying the number of windows to test
`remove_outlier`	a vector containing IDs for clusters to be removed the default vector contains 0, as 0 is the cluster with singletons
`nRounds`	number of iterations to remove a selected clusters
`PCA`	logical specifying if PCA is used before calculating distance matrix
`nPCs`	number of principal components from PCA dimensional reduction to be used
`verbose`	a logical whether to display additional messages
`log_transform`	boolean whether log transform should be computed

Value

clustering results

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
test <-clustering(mixedpop2, remove_outlier = c(0))
```

---

clustering_bagging *HC clustering for a number of resolutions*

Description

subsamples cells for each bagging run and performs 40 clustering runs or more depending on windows.

Usage

```
clustering_bagging(
  object = NULL,
  ngenes = 1500,
  bagging_run = 20,
  subsample_proportion = 0.8,
  windows = seq(from = 0.025, to = 1, by = 0.025),
  remove_outlier = c(0),
  nRounds = 1,
  PCA = FALSE,
  nPCs = 20,
  log_transform = FALSE
)
```

Arguments

object	is a SingleCellExperiment object from the train mixed population.
ngenes	number of genes used for clustering calculations.
bagging_run	an integer specifying the number of bagging runs to be computed.
subsample_proportion	a numeric specifying the proportion of the tree to be chosen in subsampling.
windows	a numeric vector specifying the rages of each window.
remove_outlier	a vector containing IDs for clusters to be removed the default vector contains 0, as 0 is the cluster with singletons.
nRounds	a integer specifying the number rounds to attempt to remove outliers.
PCA	logical specifying if PCA is used before calculating distance matrix.
nPCs	an integer specifying the number of principal components to use.
log_transform	boolean whether log transform should be computed

Value

a list of clustering results containing each bagging run as well as the clustering of the original tree and the tree itself.

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
test <-clustering_bagging(mixedpop2, remove_outlier = c(0),
    bagging_run = 2, subsample_proportion = .7)
```

CORE_bagging *Main clustering SCORE (CORE V2.0) Stable Clustering at Optimal REsolution with bagging and bootstrapping*

Description

CORE is an algorithm to generate reproduciable clustering, CORE is first implemented in ascend R package. Here, CORE V2.0 uses bagging analysis to find a stable clustering result and detect rare clusters mixed population.

Usage

```
CORE_bagging(
  mixedpop = NULL,
  bagging_run = 20,
  subsample_proportion = 0.8,
  windows = seq(from = 0.025, to = 1, by = 0.025),
  remove_outlier = c(0),
  nRounds = 1,
  PCA = FALSE,
  nPCs = 20,
  ngenes = 1500,
  log_transform = FALSE
)
```

Arguments

mixedpop	is a SingleCellExperiment object from the train mixed population.
bagging_run	an integer specifying the number of bagging runs to be computed.
subsample_proportion	a numeric specifying the proportion of the tree to be chosen in subsampling.

windows	a numeric vector specifying the ranges of each window.
remove_outlier	a vector containing IDs for clusters to be removed the default vector contains 0, as 0 is the cluster with singletons.
nRounds	an integer specifying the number rounds to attempt to remove outliers.
PCA	logical specifying if PCA is used before calculating distance matrix.
nPCs	an integer specifying the number of principal components to use.
ngenes	number of genes used for clustering calculations.
log_transform	boolean whether log transform should be computed

Value

a `list` with clustering results of all iterations, and a selected optimal resolution

Author(s)

Quan Nguyen, 2018-05-11

Examples

```
day5 <- day_5_cardio_cell_sample
cellnames<-colnames(day5$dat5_counts)
cluster <-day5$dat5_clusters
cellnames <- data.frame('cluster' = cluster, 'cellBarcodes' = cellnames)
#day5$dat5_counts needs to be in a matrix format
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
test <- CORE_bagging(mixedpop2, remove_outlier = c(0), PCA=FALSE,
    bagging_run = 2, subsample_proportion = .7)
```

CORE_clustering *Main clustering CORE V2.0 updated*

Description

CORE is an algorithm to generate reproduciable clustering, CORE is first implemented in ascend R package. Here, CORE V2.0 introduces several new functionalities, including three key features: fast (and more memory efficient) implementation with C++ and paralellisation options allowing clustering of hundreds of thousands of cells (ongoing development), outlier revomal important if singletons exist (done), a number of dimensionality reduction methods including the imputation implementation (CIDR) for confirming clustering results (done), and an option to select the number of optimisation tree height windows for increasing resolution

Usage

```
CORE_clustering(
  mixedpop = NULL,
  windows = seq(from = 0.025, to = 1, by = 0.025),
  remove_outlier = c(0),
  nRounds = 1,
  PCA = FALSE,
  nPCs = 20,
  ngenes = 1500,
  verbose = FALSE,
  log_transform = FALSE
)
```

Arguments

mixedpop	is a SingleCellExperiment object from the train mixed population
windows	a numeric specifying the number of windows to test
remove_outlier	a vector containing IDs for clusters to be removed the default vector contains 0, as 0 is the cluster with singletons.
nRounds	an integer specifying the number rounds to attempt to remove outliers.
PCA	logical specifying if PCA is used before calculating distance matrix
nPCs	an integer specifying the number of principal components to use.
ngenes	number of genes used for clustering calculations.
verbose	a logical whether to display additional messages
log_transform	boolean whether log transform should be computed

Value

a `list` with clustering results of all iterations, and a selected optimal resolution

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day5 <- day_5_cardio_cell_sample
#day5$dat5_counts needs to be in a matrix format
cellnames <- colnames(day5$dat5_counts)
cluster <-day5$dat5_clusters
cellnames <-data.frame('Cluster'=cluster, 'cellBarcodes' = cellnames)
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
test <- CORE_clustering(mixedpop2, remove_outlier = c(0), PCA=FALSE, nPCs=20,
    ngenes=1500)
```

CORE_subcluster *sub_clustering (optional) after running CORE 'test'*

Description

CORE_subcluster allows re-cluster the CORE clustering result

Usage

```
CORE_subcluster(
  mixedpop = NULL,
  windows = seq(from = 0.025, to = 1, by = 0.025),
  select_cell_index = NULL,
  ngenes = 1500
)
```

Arguments

mixedpop	is a SingleCellExperiment object from the train mixed population
windows	a numeric specifying the number of windows to test
select_cell_index	a vector containing indexes for cells in selected clusters to be reclustered
ngenes	number of genes used for clustering calculations.

Value

a `list` with clustering results of all iterations, and a selected optimal resolution

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
test <- CORE_clustering(mixedpop2,remove_outlier= c(0))
```

`day_2_cardio_cell_sample`

One of the two example single-cell count matrices to be used for training **scGPS** *model*

Description

The count data set contains counts for 16990 genes for 590 cells randomly subsampled from day-2 cardio-differentiation population. The vector of clustering information contains corresponding to cells in the count matrix

Usage

```
day_2_cardio_cell_sample
```

Format

a list instance, containing a count matrix and a vector with clustering information

Value

a list, with the name day2

Author(s)

Quan Nguyen, 2017-11-25

Source

Dr Joseph Powell's laboratory, IMB, UQ

`day_5_cardio_cell_sample`

One of the two example single-cell count matrices to be used for **scGPS** *prediction*

Description

The count data set contains counts for 17402 genes for 983 cells (1 row per gene) randomly subsampled from day-5 cardio-differentiation population The vector of clustering information contains corresponding to cells in the count matrix

Usage

```
day_5_cardio_cell_sample
```

Format

a list instance, containing a count matrix and a vector with clustering information.

Value

a list, with the name day5

Author(s)

Quan Nguyen, 2017-11-25

Source

Dr Joseph Powell's laboratory, IMB, UQ

---

distvec *Compute Distance between two vectors*

Description

Compute Distance between two vectors

Usage

```
distvec(x, y)
```

Arguments

x	A numeric vector
y	A numeric vector

Value

a numeric distance

Examples

```
x <-matrix(rnbinom(1000,mu=0.01, size=10),nrow=1000)
x <- x[1,]
y <-matrix(rnbinom(1000,mu=0.01, size=10),nrow=1000)
y <- y[1,]
distvec(x, y)
```

find_markers *find marker genes*

Description

Find DE genes from comparing one clust vs remaining

Usage

```
find_markers(
  expression_matrix = NULL,
  cluster = NULL,
  selected_cluster = NULL,
  fitType = "local",
  dispersion_method = "per-condition",
  sharing_Mode = "maximum"
)
```

Arguments

expression_matrix	is a normalised expression matrix.
cluster	corresponding cluster information in the expression_matrix by running CORE clustering or using other methods.
selected_cluster	a vector of unique cluster ids to calculate
fitType	string specifying 'local' or 'parametric' for DEseq dispersion estimation
dispersion_method	one of the options c('pooled', 'pooled-CR', per-condition', 'blind')
sharing_Mode	one of the options c("maximum", "fit-only", "gene-est-only")

Value

a `list` containing sorted DESeq analysis results

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
# depending on the data, the DESeq::estimateDispersions function requires
# suitable fitType
# and dispersion_method options
```

```
DEgenes <- find_markers(expression_matrix=assay(mixedpop1),
                        cluster = colData(mixedpop1)[,1],
                        selected_cluster=c(1), #can also run for more
                        #than one clusters, e.g.selected_cluster = c(1,2)
                        fitType = "parametric",
                        dispersion_method = "blind",
                        sharing_Mode="fit-only"
                        )
names(DEgenes)
```

`find_optimal_stability` *Find the optimal cluster*

Description

from calculated stability based on Rand indexes for consecutive clustering run, find the resolution (window), where the stability is the highest

Usage

```
find_optimal_stability(
  list_clusters,
  run_RandIdx,
  bagging = FALSE,
  windows = seq(from = 0.025, to = 1, by = 0.025)
)
```

Arguments

`list_clusters`	is a `list` object containing 40 clustering results
`run_RandIdx`	is a `data frame` object from iterative clustering runs
`bagging`	is a logical that is true if bagging is to be performed, changes return
`windows`	a numeric vector specifying the ranges of each window.

Value

bagging == FALSE => a `list` with optimal stability, cluster count and summary stats bagging == TRUE => a `list` with high res cluster count, optimal cluster count and keystats

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
cluster_all <-clustering(object=mixedpop2)
stab_df <- find_stability(list_clusters=cluster_all$list_clusters,
                          cluster_ref = cluster_all$cluster_ref)
optimal_stab <- find_optimal_stability(list_clusters =
    cluster_all$list_clusters, stab_df, bagging = FALSE)
```

---

find_stability *Calculate stability index*

Description

from clustering results, compare similarity between clusters by adjusted Randindex

Usage

```
find_stability(list_clusters = NULL, cluster_ref = NULL)
```

Arguments

list_clusters	is a object from the iterative clustering runs
cluster_ref	is a object from the reference cluster

Value

a data frame with stability scores and rand_index results

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
cluster_all <-clustering(object=mixedpop2)
stab_df <- find_stability(list_clusters=cluster_all$list_clusters,
                          cluster_ref = cluster_all$cluster_ref)
```

`mean_cpp` *Calculate mean*

Description

Calculate mean

Usage

```
mean_cpp(x)
```

Arguments

`x`	integer.

Value

a scalar value

Examples

```
mean_cpp(seq_len(10^6))
```

`new_scGPS_object` *new_scGPS_object*

Description

`new_scGPS_object` generates a scGPS object in the SingleCellExperiment class for use with the scGPS package. This object contains an expression matrix, associated metadata (cells, genes, clusters). The data are expected to be normalised counts.

Usage

```
new_scGPS_object(
  ExpressionMatrix = NULL,
  GeneMetadata = NULL,
  CellMetadata = NULL,
  LogMatrix = NULL
)
```

Arguments

ExpressionMatrix	An expression matrix in data.frame or matrix format. Rows should represent a transcript and its normalised counts, while columns should represent individual cells.
GeneMetadata	A data frame or vector containing gene identifiers used in the expression matrix. The first column should hold the gene identifiers you are using in the expression matrix. Other columns contain information about the genes, such as their corresponding ENSEMBL transcript identifiers.
CellMetadata	A data frame containing cell identifiers (usually barcodes) and an integer representing which batch they belong to. The column containing clustering information needs to be the first column in the CellMetadata dataframe If clustering information is not available, users can run CORE function and add the information to the scGPS before running scGPS prediction
LogMatrix	optional input for a log matrix of the data. If no log matrix is supplied one will be created for the object

Value

This function generates an scGPS object belonging to the SingleCellExperiment.

Author(s)

Quan Nguyen, 2018-04-06

See Also

SingleCellExperiment

Examples

```
day2 <- day_2_cardio_cell_sample
t <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
colData(t); show(t); colnames(t)
```

---

new_summarized_scGPS_object

new_summarized_scGPS_object

Description

new_scGPS_object generates a scGPS object in the SingleCellExperiment class for use with the scGPS package. This object contains an expression matrix, associated metadata (cells, genes, clusters). The data are expected to be normalised counts.

Usage

```
new_summarized_scGPS_object(
  ExpressionMatrix = NULL,
  GeneMetadata = NULL,
  CellMetadata = NULL
)
```

Arguments

ExpressionMatrix	An expression dataset in matrix format. Rows should represent a transcript and its normalised counts, while columns should represent individual cells.
GeneMetadata	A data frame or vector containing gene identifiers used in the expression matrix. The first column should hold the cell identifiers you are using in the expression matrix. Other columns contain information about the genes, such as their corresponding ENSEMBL transcript identifiers.
CellMetadata	A data frame containing cell identifiers (usually barcodes) and clustering information (the first column of the data frame contains clustering information). The column containing clustering information needs to be named as 'Cluster'. If clustering information is not available, users can run CORE function and add the information to the scGPS before running scGPS prediction

Value

This function generates an scGPS object belonging to the SingleCellExperiment.

Author(s)

Quan Nguyen, 2017-11-25

See Also

SingleCellExperiment

Examples

```
day2 <- day_2_cardio_cell_sample
t <-new_summarized_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
colData(t); show(t); colnames(t)
```

PCA *PCA*

Description

Select top variable genes and perform prcomp

Usage

```
PCA(expression.matrix = NULL, ngenes = 1500, scaling = TRUE, npcs = 50)
```

Arguments

expression.matrix	An expression matrix, with genes in rows
ngenes	number of genes used for clustering calculations.
scaling	a logical of whether we want to scale the matrix
npcs	an integer specifying the number of principal components to use.

Value

a list containing PCA results and variance explained

Examples

```
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
t <-PCA(expression.matrix=assay(mixedpop1))
```

plot_CORE *Plot dendrogram tree for CORE result*

Description

This function plots CORE and all clustering results underneath

Usage

```
plot_CORE(original.tree, list_clusters = NULL, color_branch = NULL)
```

Arguments

original.tree	the original dendrogram before clustering
list_clusters	a list containing clustering results for each of the
color_branch	is a vector containing user-specified colors (the number of unique colors should be equal or larger than the number of clusters). This parameter allows better selection of colors for the display.

Value

a plot with clustering bars underneath the tree

Examples

```
day5 <- day_5_cardio_cell_sample
cellnames <- colnames(day5$dat5_counts)
cluster <-day5$dat5_clusters
cellnames <-data.frame('Cluster'=cluster, 'cellBarcodes' = cellnames)
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = cellnames)
CORE_cluster <- CORE_clustering(mixedpop2, remove_outlier = c(0))
plot_CORE(CORE_cluster$tree, CORE_cluster$Cluster)
```

---

plot_optimal_CORE *plot one single tree with the optimal clustering result*

Description

after an optimal cluster has been identified, users may use this function to plot the resulting dendrogram with the branch colors represent clutering results

Usage

```
plot_optimal_CORE(
  original_tree,
  optimal_cluster = NULL,
  shift = -100,
  values = NULL
)
```

Arguments

original_tree	a dendrogram object
optimal_cluster	a vector of cluster IDs for cells in the dendrogram
shift	a numer specifying the gap between the dendrogram and the colored
values	a vector containing color values of the branches and the colored bar underneath the tree bar underneath the dendrogram. This parameter allows better selection of colors for the display.

Value

a plot with colored braches and bars for the optimal clustering result

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
CORE_cluster <- CORE_clustering(mixedpop2, remove_outlier = c(0))
key_height <- CORE_cluster$optimalClust$KeyStats$Height
optimal_res <- CORE_cluster$optimalClust$OptimalRes
optimal_index = which(key_height == optimal_res)
plot_optimal_CORE(original_tree= CORE_cluster$tree,
    optimal_cluster = unlist(CORE_cluster$Cluster[optimal_index]),
    shift = -2000)
```

---

plot_reduced *plot reduced data*

Description

plot PCA, tSNE, and CIDR reduced datasets

Usage

```
plot_reduced(
  reduced_dat,
  color_fac = NULL,
  dims = c(1, 2),
  dimNames = c("Dim1", "Dim2"),
  palletes = NULL,
  legend_title = "Cluster"
)
```

Arguments

reduced_dat	is a matrix with genes in rows and cells in columns
color_fac	is a vector of colors corresponding to clusters to determine colors of scattered plots
dims	an integer of the number of dimestions
dimNames	a vector of the names of the dimensions

palletes	can be a customised color pallete that determine colors for density plots, if NULL it will use RColorBrewer colorRampPalette(RColorBrewer::brewer.pal(sample_num, 'Set1'))(sample_num)
legend_title	title of the plot's legend

Value

a matrix with the top 20 CIDR dimensions

Examples

```
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
#CIDR_dim <-CIDR(expression.matrix=assay(mixedpop1))
#p <- plot_reduced(CIDR_dim, color_fac = factor(colData(mixedpop1)[,1]),
#     palletes = seq_len(length(unique(colData(mixedpop1)[,1]))))
#plot(p)
tSNE_dim <-tSNE(expression.mat=assay(mixedpop1))
p2 <- plot_reduced(tSNE_dim, color_fac = factor(colData(mixedpop1)[,1]),
    palletes = seq_len(length(unique(colData(mixedpop1)[,1]))))
plot(p2)
```

---

predicting *Main prediction function applying the optimal ElasticNet and LDA models*

Description

Predict a new mixed population after training the model for a subpopulation in the first mixed population. All subpopulations in the new target mixed population will be predicted, where each targeted subpopulation will have a transition score from the orginal subpopulation to the new subpopulation.

Usage

```
predicting(
  listData = NULL,
  cluster_mixedpop2 = NULL,
  mixedpop2 = NULL,
  out_idx = NULL,
  standardize = TRUE,
  LDA_run = FALSE,
  c_selectID = NULL,
  log_transform = FALSE
)
```

Arguments

`listData`	a `list` object containing trained results for the selected subpopulation in the first mixed population
`cluster_mixedpop2`	a vector of cluster assignment for mixedpop2
`mixedpop2`	a SingleCellExperiment object from the target mixed population of importance, e.g. differentially expressed genes that are most significant
`out_idx`	a number to specify index to write results into the list output. This is needed for running bootstrap.
`standardize`	a logical of whether to standardize the data
`LDA_run`	logical, if the LDA prediction is added to compare to ElasticNet, the LDA model needs to be trained from the training before inputting to this prediction step
`c_selectID`	a number to specify the trained cluster used for prediction
`log_transform`	boolean whether log transform should be computed

Value

a `list` with prediction results written in to the index `out_idx`

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
c_selectID<-1
out_idx<-1
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
listData  <- training(genes,
    cluster_mixedpop1 = colData(mixedpop1)[, 1], mixedpop1 = mixedpop1,
    mixedpop2 = mixedpop2, c_selectID, listData =list(), out_idx=out_idx)
listData  <- predicting(listData =listData,  mixedpop2 = mixedpop2,
    out_idx=out_idx, cluster_mixedpop2 = colData(mixedpop2)[, 1],
    c_selectID = c_selectID)
```

PrinComp_cpp *Principal component analysis*

Description

This function provides significant speed gain if the input matrix is big

Usage

```
PrinComp_cpp(X)
```

Arguments

X	an R matrix (expression matrix), rows are genes, columns are cells

Value

a list with three list pca lists

Examples

```
mat_test <-matrix(rnbinom(1000000,mu=0.01, size=10),nrow=1000)
#library(microbenchmark)
#microbenchmark(PrinComp_cpp(mat_test), prcomp(mat_test), times=3)
```

rand_index *Calculate rand index*

Description

Comparing clustering results Function for calculating randindex (adapted from the function by Steve Horvath and Luohua Jiang, UCLA, 2003)

Usage

```
rand_index(tab, adjust = TRUE)
```

Arguments

tab	a table containing different clustering results in rows
adjust	a logical of whether to use the adjusted rand index

Value

a rand_index value

Author(s)

Quan Nguyen and Michael Thompson, 2018-05-11

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
cluster_all <-clustering(object=mixedpop2)

rand_index(table(unlist(cluster_all$list_clusters[[1]]),
cluster_all$cluster_ref))
```

---

rcpp_Eucl_distance_NotPar

Function to calculate Eucledean distance matrix without parallelisation

---

Description

Function to calculate Eucledean distance matrix without parallelisation

Usage

```
rcpp_Eucl_distance_NotPar(mat)
```

Arguments

mat	an R matrix (expression matrix), with cells in rows and genes in columns

Value

a distance matrix

Examples

```
mat_test <-matrix(rnbinom(100000,mu=0.01, size=10),nrow=1000)
#library(microbenchmark)
#microbenchmark(rcpp_Eucl_distance_NotPar(mat_test), dist(mat_test), times=3)
```

rcpp_parallel_distance *distance matrix using C++*

Description

This function provides fast and memory efficient distance matrix calculation

Usage

```
rcpp_parallel_distance(mat)
```

Arguments

mat	an R matrix (expression matrix), rows are genes, columns are cells

Value

a distance matrix

Examples

```
mat_test <-matrix(rnbinom(1000000,mu=0.01, size=10),nrow=10000)
#library(microbenchmark)
#microbenchmark(rcpp_parallel_distance(mat_test), dist(mat_test), times=3)
```

reformat_LASSO *summarise bootstrap runs for Lasso model, from* n *bootstraps*

Description

the training and prediction results from bootstrap were written to the object LSOLDA_dat, the reformat_LASSO summarises prediction for n bootstrap runs

Usage

```
reformat_LASSO(
  c_selectID = NULL,
  mp_selectID = NULL,
  LSOLDA_dat = NULL,
  nPredSubpop = NULL,
  Nodes_group = "#7570b3",
  nboots = 2
)
```

Arguments

c_selectID	is the original cluster to be projected
mp_selectID	is the target mixedpop to project to
LSOLDA_dat	is the results from the bootstrap
nPredSubpop	is the number of clusters in the target mixedpop row_cluster <-length(unique(target_cluster))
Nodes_group	string representation of hexidecimal color code for node
nboots	is an integer for how many bootstraps are run

Value

a dataframe containg information for the Lasso prediction results, each column contains prediction results for all subpopulations from each bootstrap run

Examples

```
c_selectID<-1
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
LSOLDA_dat <- bootstrap_prediction(nboots = 2, mixedpop1 = mixedpop1,
    mixedpop2 = mixedpop2, genes=genes, c_selectID, listData =list(),
    cluster_mixedpop1 = colData(mixedpop1)[,1],
    cluster_mixedpop2=colData(mixedpop2)[,1])
reformat_LASSO(LSOLDA_dat=LSOLDA_dat,
    nPredSubpop=length(unique(colData(mixedpop2)[,1])), c_selectID = 1,
    mp_selectID =2, nboots = 2)
```

---

subset_cpp *Subset a matrix*

Description

Subset a matrix

Usage

```
subset_cpp(m1in, rowidx_in, colidx_in)
```

Arguments

m1in	an R matrix (expression matrix)
rowidx_in	a numeric vector of rows to keep
colidx_in	a numeric vector of columns to keep

Value

a subsetted matrix

Examples

```
mat_test <-matrix(rnbinom(1000000,mu=0.01, size=10),nrow=100)
subset_mat <- subset_cpp(mat_test, rowidx_in=c(1:10), colidx_in=c(100:500))
dim(subset_mat)
```

---

sub_clustering *sub_clustering for selected cells*

Description

performs 40 clustering runs or more depending on windows

Usage

```
sub_clustering(
  object = NULL,
  ngenes = 1500,
  windows = seq(from = 0.025, to = 1, by = 0.025),
  select_cell_index = NULL
)
```

Arguments

object	is a SingleCellExperiment object from the train mixed population
ngenes	number of genes used for clustering calculations.
windows	a numeric vector specifying the ranges of each window.
select_cell_index	a vector containing indexes for cells in selected clusters to be reclustered

Value

clustering results

Author(s)

Quan Nguyen, 2018-01-31

Examples

```
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_summarized_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
test_sub_clustering <-sub_clustering(mixedpop2,
    select_cell_index = c(seq_len(100)))
```

---

summary_accuracy *get percent accuracy for Lasso model, from* n *bootstraps*

Description

The training results from training were written to

Usage

```
summary_accuracy(object = NULL)
```

Arguments

object	is a list containing the training results from the summary_accuracy summarise n bootstraps

Value

a vector of percent accuracy for the selected subpopulation

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
c_selectID<-1
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
LSOLDA_dat <- bootstrap_prediction(nboots = 1,mixedpop1 = mixedpop1,
    mixedpop2 = mixedpop2, genes=genes, c_selectID, listData =list(),
    cluster_mixedpop1 = colData(mixedpop1)[,1],
    cluster_mixedpop2=colData(mixedpop2)[,1])
summary_accuracy(LSOLDA_dat)
summary_deviance(LSOLDA_dat)
```

summary_deviance *get percent deviance explained for Lasso model, from* n *bootstraps*

Description

the training results from training were written to the object LSOLDA_dat, the summary_devidance summarises deviance explained for n bootstrap runs and also returns the best deviance matrix for plotting, as well as the best matrix with Lasso genes and coefficients

Usage

```
summary_deviance(object = NULL)
```

Arguments

object	is a list containing the training results from training

Value

a list containing three elements, with a vector of percent maximum deviance explained, a dataframe containg information for the full deviance, and a dataframe containing gene names and coefficients of the best model

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
c_selectID<-1
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo,
                    CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
LSOLDA_dat <- bootstrap_prediction(nboots = 2,mixedpop1 = mixedpop1,
    mixedpop2 = mixedpop2, genes=genes, c_selectID, listData =list(),
    cluster_mixedpop1 = colData(mixedpop1)[,1],
    cluster_mixedpop2=colData(mixedpop2)[,1])
summary_deviance(LSOLDA_dat)
```

summary_prediction_lasso *get percent deviance explained for Lasso model, from* n *bootstraps*

Description

the training results from `training` were written to the object `LSOLDA_dat`, the `summary_prediction` summarises prediction for n bootstrap runs

Usage

```
summary_prediction_lasso(LSOLDA_dat = NULL, nPredSubpop = NULL)
```

Arguments

`LSOLDA_dat`	is a list containing the training results from `training`
`nPredSubpop`	is the number of subpopulations in the target mixed population

Value

a dataframe containg information for the Lasso prediction results, each column contains prediction results for all subpopulations from each bootstrap run

Examples

```
c_selectID<-1
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
LSOLDA_dat <- bootstrap_prediction(nboots = 1,mixedpop1 = mixedpop1,
    mixedpop2 = mixedpop2, genes=genes, c_selectID, listData =list(),
    cluster_mixedpop1 = colData(mixedpop1)[,1],
    cluster_mixedpop2=colData(mixedpop2)[,1])
summary_prediction_lasso(LSOLDA_dat=LSOLDA_dat, nPredSubpop=4)
```

summary_prediction_lda *get percent deviance explained for LDA model, from* n *bootstraps*

Description

the training results from `training` were written to the object `LSOLDA_dat`, the `summary_prediction` summarises prediction explained for `n` bootstrap runs and also returns the best deviance matrix for plotting, as well as the best matrix with Lasso genes and coefficients

Usage

```
summary_prediction_lda(LSOLDA_dat = NULL, nPredSubpop = NULL)
```

Arguments

`LSOLDA_dat`	is a list containing the training results from `training`
`nPredSubpop`	is the number of subpopulations in the target mixed population

Value

a dataframe containg information for the LDA prediction results, each column contains prediction results for all subpopulations from each bootstrap run

Examples

```
c_selectID<-1
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
    GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
LSOLDA_dat <- bootstrap_prediction(nboots = 1,mixedpop1 = mixedpop1,
mixedpop2 = mixedpop2, genes=genes, c_selectID, listData =list(),
    cluster_mixedpop1 = colData(mixedpop1)[,1],
    cluster_mixedpop2=colData(mixedpop2)[,1])
summary_prediction_lda(LSOLDA_dat=LSOLDA_dat, nPredSubpop=4)
```

top_var *select top variable genes*

Description

subset a matrix by top variable genes

Usage

```
top_var(expression.matrix = NULL, ngenes = 1500)
```

Arguments

expression.matrix	is a matrix with genes in rows and cells in columns
ngenes	number of genes used for clustering calculations.

Value

a subsetted expression matrix with the top n most variable genes

Examples

```
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
SortedExprsMat <-top_var(expression.matrix=assay(mixedpop1))
```

tp_cpp *Transpose a matrix*

Description

Transpose a matrix

Usage

```
tp_cpp(X)
```

Arguments

X	an R matrix (expression matrix)

Value

a transposed matrix

Examples

```
mat_test <-matrix(rnbinom(1000000,mu=0.01, size=10),nrow=100)
tp_mat <- tp_cpp(mat_test)
```

`training` *Main model training function for finding the best model that characterises a subpopulation*

Description

Training a haft of all cells to find optimal ElasticNet and LDA models to predict a subpopulation

Usage

```
training(
  genes = NULL,
  cluster_mixedpop1 = NULL,
  mixedpop1 = NULL,
  mixedpop2 = NULL,
  c_selectID = NULL,
  listData = list(),
  out_idx = 1,
  standardize = TRUE,
  trainset_ratio = 0.5,
  LDA_run = FALSE,
  log_transform = FALSE
)
```

Arguments

`genes`	a vector of gene names (for ElasticNet shrinkage); gene symbols must be in the same format with gene names in subpop2. Note that genes are listed by the order of importance, e.g. differentially expressed genes that are most significan, so that if the gene list contains too many genes, only the top 500 genes are used.
`cluster_mixedpop1`	a vector of cluster assignment in mixedpop1
`mixedpop1`	is a SingleCellExperiment object from the train mixed population
`mixedpop2`	is a SingleCellExperiment object from the target mixed population
`c_selectID`	a selected number to specify which subpopulation to be used for training
`listData`	list to store output in
`out_idx`	a number to specify index to write results into the list output. This is needed for running bootstrap.
`standardize`	a logical value specifying whether or not to standardize the train matrix
`trainset_ratio`	a number specifying the proportion of cells to be part of the training subpopulation
`LDA_run`	logical, if the LDA run is added to compare to ElasticNet
`log_transform`	boolean whether log transform should be computed

Value

a `list` with prediction results written in to the indexed `out_idx`

Author(s)

Quan Nguyen, 2017-11-25

Examples

```
c_selectID<-1
out_idx<-1
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
day5 <- day_5_cardio_cell_sample
mixedpop2 <-new_scGPS_object(ExpressionMatrix = day5$dat5_counts,
GeneMetadata = day5$dat5geneInfo, CellMetadata = day5$dat5_clusters)
genes <-training_gene_sample
genes <-genes$Merged_unique
listData  <- training(genes,
    cluster_mixedpop1 = colData(mixedpop1)[, 1],
    mixedpop1 = mixedpop1, mixedpop2 = mixedpop2, c_selectID,
    listData =list(), out_idx=out_idx, trainset_ratio = 0.5)
names(listData)
listData$Accuracy
```

`training_gene_sample` *Input gene list for training* **scGPS***, e.g. differentially expressed genes*

Description

Genes should be ordered from most to least important genes (1 row per gene)

Usage

```
training_gene_sample
```

Format

a list instance, containing a count matrix and a vector with clustering information.

Value

a vector containing gene symbols

Author(s)

Quan Nguyen, 2017-11-25

Source

Dr Joseph Powell's laboratory, IMB, UQ

`tSNE` *tSNE*

Description

calculate tSNE from top variable genes

Usage

```
tSNE(
  expression.mat = NULL,
  topgenes = 1500,
  scale = TRUE,
  thet = 0.5,
  perp = 30
)
```

Arguments

`expression.mat`	An expression matrix, with genes in rows
`topgenes`	number of genes used for clustering calculations.
`scale`	a logical of whether we want to scale the matrix
`thet`	numeric; Speed/accuracy trade-off (increase for less accuracy)
`perp`	numeric; Perplexity parameter (should not be bigger than 3 * perplexity < nrow(X) - 1, see details for interpretation)

Value

a tSNE reduced matrix containing three tSNE dimensions

Examples

```
day2 <- day_2_cardio_cell_sample
mixedpop1 <-new_scGPS_object(ExpressionMatrix = day2$dat2_counts,
    GeneMetadata = day2$dat2geneInfo, CellMetadata = day2$dat2_clusters)
t <-tSNE(expression.mat = assay(mixedpop1))
```

var_cpp *Calculate variance*

Description

Calculate variance

Usage

```
var_cpp(x, bias = TRUE)
```

Arguments

x	a vector of gene expression.
bias	degree of freedom

Value

a variance value

Examples

```
var_cpp(seq_len(10^6))
```

Index