

# Package ‘PhosR’

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**Type** Package

**Title** A set of methods and tools for comprehensive analysis of phosphoproteomics data

**Version** 1.20.0

**Description** PhosR is a package for the comprehensive analysis of phosphoproteomic data. There are two major components to PhosR: processing and downstream analysis. PhosR consists of various processing tools for phosphoproteomics data including filtering, imputation, normalisation, and functional analysis for inferring active kinases and signalling pathways.

**License** GPL-3 + file LICENSE

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## Contents

createFrequencyMat	3
frequencyScoring	3
getSPS	4
hSEGS	5
KinaseFamily	6
kinaseSubstrateHeatmap	6
kinaseSubstratePred	7
kinaseSubstrateProfile	9
kinaseSubstrateScore	10
matANOVA	11
meanAbundance	12
medianScaling	13
minmax	14
mIntersect	15
motif.human.list	16
motif.mouse.list	17
motif.rat.list	17
mSEGS	17
pathwayOverrepresent	18
pathwayRankBasedEnrichment	20
phosCollapse	21
phospho.cells.Ins	23
phospho.L6.ratio	24
phospho.L6.ratio.pe	24
phospho.liver.Ins.TC.ratio.RUV	25
phospho.liver.Ins.TC.ratio.RUV.pe	25
PhosphoExperiment-class	26
PhosphoSite.human	27
PhosphoSite.mouse	27
PhosphoSite.rat	28
plotKinaseNetwork	28
plotQC	29
plotSignalomeMap	31
PPE-accessors	31
PPE-operate	33
ptImpute	35
RUVphospho	36
scImpute	38
selectGrps	39
selectLocalisedSites	40
selectOverallPercent	41
selectTimes	41
Signalomes	43
siteAnnotate	44
SPSs	45
standardise	46
tImpute	47

---

createFrequencyMat      *Create frequency matrix*

---

**Description**

Create frequency matrix

**Usage**

```
createFrequencyMat(substrates.seq)
```

**Arguments**

substrates.seq    A substrate sequence

**Value**

A frequency matrix of amino acid from substrates.seq.

**Examples**

```
data("phospho_L6_ratio_pe")

# We will create a frequency matrix of Tfg S198 phosphosite.
idx = which(grepl("TFG\\;S198\\;", rownames(phospho.L6.ratio.pe)))
substrate.seq = Sequence(phospho.L6.ratio.pe)[idx]
freq.mat = createFrequencyMat(substrate.seq)
```

---

frequencyScoring      *Frequency scoring*

---

**Description**

Frequency scoring

**Usage**

```
frequencyScoring(sequence.list, frequency.mat)
```

**Arguments**

sequence.list    A vector list of sequences  
frequency.mat    A matrix output from 'createFrequencyMat'

**Value**

A vector of frequency score

**Examples**

```

data('phospho_L6_ratio_pe')
data('KinaseMotifs')

# Extracting first 10 sequences for demonstration purpose
seqs = Sequence(phospho.L6.ratio.pe)
seqs = seqs[seq(10)]

# extracting flanking sequences
seqWin = mapply(function(x) {
  mid <- (nchar(x)+1)/2
  substr(x, start=(mid-7), stop=(mid+7))
}, seqs)

# The first 10 for demonstration purpose
phospho.L6.ratio = SummarizedExperiment::assay(phospho.L6.ratio.pe,
  "Quantification")[seq(10),]

# minimum number of sequences used for compiling motif for each kinase.
numMotif=5

motif.mouse.list.filtered <-
  motif.mouse.list[which(motif.mouse.list$NumInputSeq >= numMotif)]

# scoring all phosphosites against all motifs
motifScoreMatrix <-
  matrix(NA, nrow=nrow(phospho.L6.ratio),
    ncol=length(motif.mouse.list.filtered))
rownames(motifScoreMatrix) <- rownames(phospho.L6.ratio)
colnames(motifScoreMatrix) <- names(motif.mouse.list.filtered)

# Scoring phosphosites against kinase motifs
for(i in seq_len(length(motif.mouse.list.filtered))) {
  motifScoreMatrix[,i] <-
    frequencyScoring(seqWin, motif.mouse.list.filtered[[i]])
  cat(paste(i, '.', sep=''))
}

```

---

getSPS

*Generate set of stable phosphoporylated sites*


---

**Description**

Generate set of stable phosphoporylated sites

**Usage**

```
getSPS(phosData, assays, conds, num)
```

**Arguments**

phosData            a list of users' PhosphoExperiment objects from which generate SPSs

assays	an assay to use for each dataset in phosData
conds	a list of vector contains the conditions labels for each sample in the phosphoExperiment objects
num	the number of identified SPSs, by default is 100

### Value

A vectors of stably phosphorylated sites

### Examples

```
library(stringr)

data("phospho_L6_ratio_pe")
data("phospho.liver.Ins.TC.ratio.RUV.pe")
data("phospho.cells.Ins.pe")

ppe1 <- phospho.L6.ratio.pe
ppe2 <- phospho.liver.Ins.TC.ratio.RUV.pe
ppe3 <- phospho.cells.Ins.pe
grp3 = gsub('_[0-9]{1}', '', colnames(ppe3))

cond.list <- list(grp1 = gsub("_.", "", colnames(ppe1)),
                 grp2 = stringr::str_sub(colnames(ppe2), end=-5),
                 grp3 = grp3)

ppe3 <- selectGrps(ppe3, grps = grp3, 0.5, n=1)
ppe3 <- tImpute(ppe3)

# convert matrix to ratio
FL83B.ratio <- SummarizedExperiment::assay(ppe3,"imputed")[, seq(12)] -
  rowMeans(
    SummarizedExperiment::assay(ppe3,"imputed")[,grep("FL83B_Control",
    colnames(ppe3))])
Hepa.ratio <- SummarizedExperiment::assay(ppe3,"imputed")[, seq(13,24,1)] -
  rowMeans(
    SummarizedExperiment::assay(ppe3, "imputed")[,grep("Hepa1.6_Control",
    colnames(ppe3))])
SummarizedExperiment::assay(ppe3, "Quantification") <-
  cbind(FL83B.ratio, Hepa.ratio)

ppe.list <- list(ppe1, ppe2, ppe3)

inhouse_SPSs <- getSPS(ppe.list, conds = cond.list)
```

---

hSEGs

*A list of Stably Expressed Genes (SEGs)*

---

### Description

A list of stably expressed genes (SEGs) in mouse and human identified from a collection of single-cell RNA-sequencing data. See Lin et al., Evaluating stably expressed genes in single cells, *Giga-Science*, 8(9):giz106, <https://doi.org/10.1093/gigascience/giz106> for more details

**Usage**

```
data(SEGs)
```

**Format**

An object of class character of length 1076.

---

KinaseFamily	<i>KinaseFamily</i>
--------------	---------------------

---

**Description**

A summary table of kinase family

**Usage**

```
data(KinaseFamily)
```

**Format**

An object of class matrix (inherits from array) with 425 rows and 6 columns.

---

kinaseSubstrateHeatmap	<i>Kinase-substrate annotation prioritisation heatmap</i>
------------------------	---

---

**Description**

Kinase-substrate annotation prioritisation heatmap

**Usage**

```
kinaseSubstrateHeatmap(
  phosScoringMatrices,
  top = 3,
  printPlot = NULL,
  filePath = "../kinaseSubstrateHeatmap.pdf",
  width = 10,
  height = 10
)
```

**Arguments**

phosScoringMatrices	a matrix returned from kinaseSubstrateScore.
top	the number of top ranked phosphosites for each kinase to be included in the heatmap. Default is 1.
printPlot	indicate whether the plot should be saved as a PDF in the specified directory. Default is NULL, otherwise specify TRUE.
filePath	path name to save the plot as a PDF file. Default saves in the working directory.
width	width of PDF.
height	height of PDF.

**Value**

a heatmap object.

**Examples**

```
data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

ppe <- phospho.L6.ratio.pe
sites = paste(sapply(GeneSymbol(ppe), function(x)x),";",
              sapply(Residue(ppe), function(x)x),
              sapply(Site(ppe), function(x)x),
              ";", sep = "")
grps = gsub("_."+", "", colnames(ppe))
design = model.matrix(~ grps - 1)
ctl = which(sites %in% SPSs)
ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)
aov <- matANOVA(mat=phosphoL6, grps = grps)
idx <- (aov < 0.05) & (rowSums(phosphoL6.mean > 0.5) > 0)
phosphoL6.reg <- phosphoL6[idx, ,drop = FALSE]

L6.phos.std <- standardise(phosphoL6.reg)

rownames(L6.phos.std) <- paste0(GeneSymbol(ppe), ";", Residue(ppe),
                               Site(ppe), ";")[idx]

L6.phos.seq <- Sequence(ppe)[idx]

L6.matrices <- kinaseSubstrateScore(PhosphoSite.mouse, L6.phos.std,
                                   L6.phos.seq, numMotif = 5, numSub = 1)

kinaseSubstrateHeatmap(L6.matrices)
kinaseSubstrateHeatmap(L6.matrices, printPlot=TRUE)
```

---

kinaseSubstratePred     *kinaseSubstratePred*

---

**Description**

A machine learning approach for predicting specific kinase for a given substrate. This prediction framework utilise adaptive sampling.

**Usage**

```
kinaseSubstratePred(
  phosScoringMatrices,
  ensembleSize = 10,
```

```

    top = 50,
    cs = 0.8,
    inclusion = 20,
    iter = 5,
    verbose = TRUE
  )

```

### Arguments

phosScoringMatrices An output of kinaseSubstrateScore.

ensembleSize An ensemble size.

top a number to select top kinase substrates.

cs Score threshold.

inclusion A minimal number of substrates required for a kinase to be selected.

iter A number of iterations for adaSampling.

verbose Default to TRUE to show messages during the progress. All messages will be suppressed if set to FALSE

### Value

Kinase prediction matrix

### Examples

```

data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

ppe <- phospho.L6.ratio.pe
sites = paste(sapply(GeneSymbol(ppe), function(x)x),";",
              sapply(Residue(ppe), function(x)x),
              sapply(Site(ppe), function(x)x),
              ";", sep = "")
grps = gsub("_.", "", colnames(ppe))
design = model.matrix(~ grps - 1)
ctl = which(sites %in% SPSs)
ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)
aov <- matANOVA(mat=phosphoL6, grps = grps)
idx <- (aov < 0.05) & (rowSums(phosphoL6.mean > 0.5) > 0)
phosphoL6.reg <- phosphoL6[idx, ,drop = FALSE]

L6.phos.std <- standardise(phosphoL6.reg)

rownames(L6.phos.std) <- paste0(GeneSymbol(ppe), ";", Residue(ppe),
                               Site(ppe), ";")[idx]

L6.phos.seq <- Sequence(ppe)[idx]

```

```
L6.matrices <- kinaseSubstrateScore(PhosphoSite.mouse, L6.phos.std,
  L6.phos.seq, numMotif = 5, numSub = 1)
set.seed(1)
L6.predMat <- kinaseSubstratePred(L6.matrices, top=30)
```

---

**kinaseSubstrateProfile**

*Kinase substrate profiling*

---

### Description

This function generates substrate profiles for kinases that have one or more substrates quantified in the phosphoproteome data.

### Usage

```
kinaseSubstrateProfile(substrate.list, mat)
```

### Arguments

`substrate.list` a list of kinases with each element containing an array of substrates.  
`mat` a matrix with rows correspond to phosphosites and columns correspond to samples.

### Value

Kinase profile list.

### Examples

```
data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

ppe <- phospho.L6.ratio.pe
sites = paste(sapply(GeneSymbol(ppe), function(x)x),";",
  sapply(Residue(ppe), function(x)x),
  sapply(Site(ppe), function(x)x),
  ";", sep = "")
grps = gsub("_."+ , "" , colnames(ppe))
design = model.matrix(~ grps - 1)
ctl = which(sites %in% SPSs)
ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)
aov <- matANOVA(mat=phosphoL6, grps = grps)
idx <- (aov < 0.05) & (rowSums(phosphoL6.mean > 0.5) > 0)
phosphoL6.reg <- phosphoL6[idx, ,drop = FALSE]

L6.phos.std <- standardise(phosphoL6.reg)

ks.profile.list <- kinaseSubstrateProfile(PhosphoSite.mouse, L6.phos.std)
```

---

kinaseSubstrateScore *Kinase substrate scoring*

---

### Description

This function generates substrate scores for kinases that pass filtering based on both motifs and dynamic profiles

### Usage

```
kinaseSubstrateScore(
  substrate.list,
  mat,
  seqs,
  numMotif = 5,
  numSub = 1,
  species = "mouse",
  verbose = TRUE
)
```

### Arguments

<code>substrate.list</code>	A list of kinases with each element containing an array of substrates.
<code>mat</code>	A matrix with rows correspond to phosphosites and columns correspond to samples.
<code>seqs</code>	An array containing aa sequences surrounding each of all phosphosites. Each sequence has length of 15 (-7, p, +7).
<code>numMotif</code>	Minimum number of sequences used for compiling motif for each kinase. Default is 5.
<code>numSub</code>	Minimum number of phosphosites used for compiling phosphorylation profile for each kinase. Default is 1.
<code>species</code>	Motif list species to be used. Currently there are mouse (default), human and rat.
<code>verbose</code>	Default to TRUE to show messages during the progress. All messages will be suppressed if set to FALSE

### Value

A list of 4 elements. `motifScoreMatrix`, `profileScoreMatrix`, `combinedScoreMatrix`, `ksActivityMatrix` (kinase activity matrix) and their weights.

### Examples

```
data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

ppe <- phospho.L6.ratio.pe
sites = paste(apply(GeneSymbol(ppe), function(x)x), ";",
  apply(Residue(ppe), function(x)x),
```

```

    sapply(Site(ppe), function(x)x,
           ",", sep = "")
  grps = gsub("_."+ , "", colnames(ppe))
  design = model.matrix(~ grps - 1)
  ctl = which(sites %in% SPSSs)
  ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

  phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

  # filter for up-regulated phosphosites
  phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)
  aov <- matANOVA(mat=phosphoL6, grps = grps)
  idx <- (aov < 0.05) & (rowSums(phosphoL6.mean > 0.5) > 0)
  phosphoL6.reg <- phosphoL6[idx, ,drop = FALSE]

  L6.phos.std <- standardise(phosphoL6.reg)

  rownames(L6.phos.std) <- paste0(GeneSymbol(ppe), ";", Residue(ppe),
                                  Site(ppe), ";")[idx]

  L6.phos.seq <- Sequence(ppe)[idx]

  L6.matrices <- kinaseSubstrateScore(PhosphoSite.mouse, L6.phos.std,
                                     L6.phos.seq, numMotif = 5, numSub = 1)

```

---

matANOVA

*ANOVA test*


---

### Description

Performs an ANOVA test and returns its adjusted p-value

### Usage

```
matANOVA(mat, grps)
```

### Arguments

mat	An p by n matrix where p is the number of phosphosites and n is the number of samples
grps	A vector of length n, with group or time point information of the samples

### Value

A vector of multiple testing adjusted p-values

### Examples

```

data('phospho_L6_ratio_pe')
data('SPSS')
data('PhosphoSitePlus')

grps = gsub('_."+', '', colnames(phospho.L6.ratio.pe))

```

```

# Construct a design matrix by condition
design = model.matrix(~ grps - 1)

# phosphoproteomics data normalisation using RUV
L6.sites = paste(sapply(GeneSymbol(phospho.L6.ratio.pe), function(x)paste(x)),
                 ";",
                 sapply(Residue(phospho.L6.ratio.pe), function(x)paste(x)),
                 sapply(Site(phospho.L6.ratio.pe), function(x)paste(x)),
                 ";", sep = "")
ctl = which(L6.sites %in% SPSs)
phospho.L6.ratio.pe = RUVphospho(phospho.L6.ratio.pe,
                                M = design, k = 3,ctl = ctl)
phosphoL6 = SummarizedExperiment::assay(phospho.L6.ratio.pe, "normalised")

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)
aov <- matANOVA(mat=phosphoL6, grps = grps)

```

---

meanAbundance	<i>Obtain average expression from replicates</i>
---------------	--

---

### Description

Obtain average expression from replicates

### Usage

```
meanAbundance(mat, grps)
```

### Arguments

mat	a matrix with rows correspond to phosphosites and columns correspond to samples.
grps	a string specifying the grouping (replciates).

### Value

a matrix with mean expression from replicates

### Examples

```

data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

grps = gsub('_', '+', '', colnames(phospho.L6.ratio.pe))

# Construct a design matrix by condition
design = model.matrix(~ grps - 1)

# phosphoproteomics data normalisation using RUV
L6.sites = paste(sapply(GeneSymbol(phospho.L6.ratio.pe), function(x)paste(x)),
                 ";",
                 sapply(Residue(phospho.L6.ratio.pe), function(x)paste(x)),

```

```

      sapply(Site(phospho.L6.ratio.pe), function(x)paste(x),
             ";", sep = "")
ctl = which(L6.sites %in% SPSs)
phospho.L6.ratio.pe = RUVphospho(phospho.L6.ratio.pe,
                                M = design, k = 3,ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(phospho.L6.ratio.pe, "normalised")
phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)

```

---

medianScaling

*Median centering and scaling*


---

## Description

Median centering and scaling of an input numeric matrix

## Usage

```
medianScaling(mat, scale = FALSE, grps = NULL, reorder = FALSE, assay = NULL)
```

## Arguments

mat	a matrix with rows correspond to phosphosites and columns correspond to samples.
scale	a boolean flag indicating whether to scale the samples.
grps	a string or factor specifying the grouping (replciates).
reorder	To reorder the columns by group (grps). By default (reorder=FALSE), original column order is maintained.
assay	an assay to be selected if mat is a PhosphoExperiment object.

## Value

A median scaled matrix

## Examples

```

data('phospho.cells.Ins.sample')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins, grps, 0.5, n=1)

set.seed(123)
phospho.cells.Ins.impute <-
  scImpute(phospho.cells.Ins.filtered,
           0.5,
           grps)[,colnames(phospho.cells.Ins.filtered)]

set.seed(123)
phospho.cells.Ins.impute[,seq(5)] <- ptImpute(
  phospho.cells.Ins.impute[,seq(6,10)],
  phospho.cells.Ins.impute[,seq(5)], percent1 = 0.6,
  percent2 = 0, paired = FALSE)

```

```
phospho.cells.Ins.ms <-
  medianScaling(phospho.cells.Ins.impute, scale = FALSE)
```

---

minmax

*Minmax scaling*


---

## Description

Perform a minmax standardisation to scale data into 0 to 1 range

## Usage

```
minmax(mat)
```

## Arguments

**mat** a matrix with rows correspond to phosphosites and columns correspond to condition

## Value

Minmax standardised matrix

## Examples

```
data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

ppe <- phospho.L6.ratio.pe
sites = paste(sapply(GeneSymbol(ppe), function(x)x),",",
  sapply(Residue(ppe), function(x)x),
  sapply(Site(ppe), function(x)x),
  ",", sep = "")
grps = gsub("_."+", """, colnames(ppe))
design = model.matrix(~ grp - 1)
ctl = which(sites %in% SPSs)
ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grp = grp)
aov <- matANOVA(mat=phosphoL6, grp = grp)
idx <- (aov < 0.05) & (rowSums(phosphoL6.mean > 0.5) > 0)
phosphoL6.reg <- phosphoL6[idx, ,drop = FALSE]

L6.phos.std <- standardise(phosphoL6.reg)

ks.profile.list <- kinaseSubstrateProfile(PhosphoSite.mouse, L6.phos.std)

data(KinaseMotifs)
```

```

numMotif = 5
numSub = 1

motif.mouse.list.filtered <-
  motif.mouse.list[which(motif.mouse.list$NumInputSeq >= numMotif)]
ks.profile.list.filtered <-
  ks.profile.list[which(ks.profile.list$NumSub >= numSub)]

# scoring all phosphosites against all motifs
motifScoreMatrix <-
  matrix(NA, nrow=nrow(L6.phos.std),
        ncol=length(motif.mouse.list.filtered))
rownames(motifScoreMatrix) <- rownames(L6.phos.std)
colnames(motifScoreMatrix) <- names(motif.mouse.list.filtered)

L6.phos.seq <- Sequence(ppe)[idx]

# extracting flanking sequences
seqWin = mapply(function(x) {
  mid <- (nchar(x)+1)/2
  substr(x, start=(mid-7), stop=(mid+7))
}, L6.phos.seq)

print('Scoring phosphosites against kinase motifs:')
for(i in seq_len(length(motif.mouse.list.filtered))) {
  motifScoreMatrix[,i] <-
    frequencyScoring(seqWin, motif.mouse.list.filtered[[i]])
  cat(paste(i, '.', sep=''))
}
motifScoreMatrix <- minmax(motifScoreMatrix)

```

---

mIntersect

*Multi-intersection, union*


---

### Description

A recursive loop for intersecting multiple sets.

### Usage

```

mIntersect(x, y, ...)
mUnion(x, y, ...)

```

### Arguments

x, y, ...            objects to find intersection/union.

### Value

An intersection/union of input parameters

**Examples**

```

data('phospho_liverInsTC_RUV_sample')
data('phospho_L6_ratio')

site1 <- gsub('~[STY]', ';',
             sapply(strsplit(rownames(phospho.L6_ratio), ';'),
                   function(x){paste(toupper(x[2]), x[3], sep=';')}))
site2 <- rownames(phospho.liver.Ins.TC.ratio.RUV)

# step 2: rank by fold changes
treatment.grps = split(seq(ncol(phospho.L6_ratio)),
                      gsub('_exp\\d+', '', colnames(phospho.L6_ratio)))
tmp <- do.call(
  cbind,
  lapply(treatment.grps, function(i){
    rowMeans(phospho.L6_ratio[,i])
  })
)
site1 <- t(sapply(split(data.frame(tmp), site1), colMeans))[, -1])

treatment.grps = split(
  seq(ncol(phospho.liver.Ins.TC.ratio.RUV)),
  gsub('(Intensity\\.)(.*)\\_Bio\\d+', '\\2',
       colnames(phospho.liver.Ins.TC.ratio.RUV))
)
tmp <- do.call(
  cbind,
  lapply(
    treatment.grps,
    function(i){
      rowMeans(phospho.liver.Ins.TC.ratio.RUV[,i])
    }
  )
)
site2 <- t(sapply(split(data.frame(tmp), site2), colMeans))

o <- mIntersect(site1, site2)

```

---

motif.human.list

*List of human kinase motifs*


---

**Description**

A list of human kinase motifs and their sequence probability matrix.

**Usage**

```
data(KinaseMotifs)
```

**Format**

An object of class list of length 380.

---

motif.mouse.list	<i>List of mouse kinase motifs</i>
------------------	------------------------------------

---

**Description**

A list of mouse kinase motifs and their sequence probability matrix.

**Usage**

```
data(KinaseMotifs)
```

**Format**

An object of class `list` of length 250.

---

motif.rat.list	<i>List of rat kinase motifs</i>
----------------	----------------------------------

---

**Description**

A list of rat kinase motifs and their sequence probability matrix.

**Usage**

```
data(KinaseMotifs)
```

**Format**

An object of class `list` of length 159.

---

mSEGs	<i>A list of Stably Expressed Genes (SEGs)</i>
-------	--

---

**Description**

A list of stably expressed genes (SEGs) in mouse and human identified from a collection of single-cell RNA-sequencing data. See Lin et al., Evaluating stably expressed genes in single cells, *Giga-Science*, 8(9):giz106, <https://doi.org/10.1093/gigascience/giz106> for more details

**Usage**

```
data(SEGs)
```

**Format**

An object of class `character` of length 916.

---

pathwayOverrepresent *phosphosite/Gene set over-representation analysis*

---

## Description

This function performs phosphosite (or gene) set over-representation analysis using Fisher's exact test.

## Usage

```
pathwayOverrepresent(geneSet, annotation, universe, alter = "greater")
```

## Arguments

geneSet	an array of gene or phosphosite IDs (IDs are gene symbols etc that match to your pathway annotation list).
annotation	a list of pathways with each element containing an array of gene or phosphosite IDs.
universe	the universe/background of all genes or phosphosites in your profiled dataset.
alter	test for enrichment ('greater', default), depletion ('less'), or 'two.sided'.

## Value

A matrix of pathways and their associated substrates and p-values.

## Examples

```
library(limma)
library(org.Rn.eg.db)
library(reactome.db)
library(annotate)

data('phospho_L6_ratio_pe')
data('SPSs')

ppe <- phospho.L6.ratio.pe
sites = paste(sapply(GeneSymbol(ppe), function(x)x),";",
              sapply(Residue(ppe), function(x)x),
              sapply(Site(ppe), function(x)x),
              ";", sep = "")
grps = gsub("_.", "", colnames(ppe))
design = model.matrix(~ grp - 1)
ctl = which(sites %in% SPSs)
ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

# fit linear model for each phosphosite
f <- grp
X <- model.matrix(~ f - 1)
fit <- lmFit(phosphoL6, X)
```

```

# extract top-ranked phosphosites for each condition compared to basal
table.AICAR <- topTable(eBayes(fit), number=Inf, coef = 1)
table.Ins <- topTable(eBayes(fit), number=Inf, coef = 3)
table.AICARIns <- topTable(eBayes(fit), number=Inf, coef = 2)

DE1.RUV <- c(sum(table.AICAR[, 'adj.P.Val'] < 0.05),
             sum(table.Ins[, 'adj.P.Val'] < 0.05),
             sum(table.AICARIns[, 'adj.P.Val'] < 0.05))

# extract top-ranked phosphosites for each group comparison
contrast.matrix1 <- makeContrasts(fAICARIns-fIns, levels=X)
contrast.matrix2 <- makeContrasts(fAICARIns-fAICAR, levels=X)
fit1 <- contrasts.fit(fit, contrast.matrix1)
fit2 <- contrasts.fit(fit, contrast.matrix2)
table.AICARInsVSIns <- topTable(eBayes(fit1), number=Inf)
table.AICARInsVSAICAR <- topTable(eBayes(fit2), number=Inf)

DE2.RUV <- c(sum(table.AICARInsVSIns[, 'adj.P.Val'] < 0.05),
             sum(table.AICARInsVSAICAR[, 'adj.P.Val'] < 0.05))

o <- rownames(table.AICARInsVSIns)
Tc <- cbind(table.Ins[o, 'logFC'], table.AICAR[o, 'logFC'],
           table.AICARIns[o, 'logFC'])
rownames(Tc) = gsub('(.*)([A-Z])([0-9]+)(;)', '\\1;\\3;', o)
colnames(Tc) <- c('Ins', 'AICAR', 'AICAR+Ins')

# summary phosphosite-level information to proteins for performing downstream
# gene-centric analyses.
Tc.gene <- phosCollapse(Tc, id=gsub(';+', '', rownames(Tc)),
                      stat=apply(abs(Tc), 1, max), by = 'max')
geneSet <- names(sort(Tc.gene[,1],
                    decreasing = TRUE))[seq(round(nrow(Tc.gene) * 0.1))]
#lapply(PhosphoSite.rat, function(x){gsub(';[STY]', ';', x)})

# Preparing Reactome annotation for our pathways analysis
pathways = as.list(reactomePATHID2EXTID)

path_names = as.list(reactomePATHID2NAME)
name_id = match(names(pathways), names(path_names))
names(pathways) = unlist(path_names)[name_id]

pathways = pathways[which(grepl("Rattus norvegicus", names(pathways),
                               ignore.case = TRUE))]

pathways = lapply(pathways, function(path) {
  gene_name = unname(getSYMBOL(path, data = "org.Rn.eg"))
  toupper(unique(gene_name))
})

# 1D gene-centric pathway analysis
path1 <- pathwayOverrepresent(geneSet, annotation=pathways,
                             universe = rownames(Tc.gene), alter = 'greater')

```

---

 pathwayRankBasedEnrichment

*Phosphosite/Gene set enrichment analysis*


---

## Description

This function performs phosphosite (or gene) set enrichment analysis using Wilcoxon Rank Sum test.

## Usage

```
pathwayRankBasedEnrichment(geneStats, annotation, alter = "greater")
```

## Arguments

geneStats	an array of statistics (e.g. log2 FC) of all quantified genes or phosphosite with names of the array as gene or phosphosite IDs.
annotation	a list of pathways with each element containing an array of gene IDs.
alter	test for enrichment ('greater', default), depletion ('less'), or 'two.sided'.

## Value

A matrix of pathways and their associated substrates and p-values.

## Examples

```
library(limma)

library(org.Rn.eg.db)
library(reactome.db)
library(annotate)

data('phospho_L6_ratio_pe')
data('SPSs')

ppe <- phospho.L6.ratio.pe
sites = paste(sapply(GeneSymbol(ppe), function(x)x),",",
              sapply(Residue(ppe), function(x)x),
              sapply(Site(ppe), function(x)x),
              ",", sep = "")
grps = gsub("_.", "", colnames(ppe))
design = model.matrix(~ grp - 1)
ctl = which(sites %in% SPSs)
ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

# fit linear model for each phosphosite
f <- grp
X <- model.matrix(~ f - 1)
fit <- lmFit(phosphoL6, X)

# extract top-ranked phosphosites for each condition compared to basal
```

```

table.AICAR <- topTable(eBayes(fit), number=Inf, coef = 1)
table.Ins <- topTable(eBayes(fit), number=Inf, coef = 3)
table.AICARIns <- topTable(eBayes(fit), number=Inf, coef = 2)

DE1.RUV <- c(sum(table.AICAR[, 'adj.P.Val'] < 0.05),
             sum(table.Ins[, 'adj.P.Val'] < 0.05),
             sum(table.AICARIns[, 'adj.P.Val'] < 0.05))

# extract top-ranked phosphosites for each group comparison
contrast.matrix1 <- makeContrasts(fAICARIns-fIns, levels=X)
contrast.matrix2 <- makeContrasts(fAICARIns-fAICAR, levels=X)
fit1 <- contrasts.fit(fit, contrast.matrix1)
fit2 <- contrasts.fit(fit, contrast.matrix2)
table.AICARInsVSIns <- topTable(eBayes(fit1), number=Inf)
table.AICARInsVSAICAR <- topTable(eBayes(fit2), number=Inf)

DE2.RUV <- c(sum(table.AICARInsVSIns[, 'adj.P.Val'] < 0.05),
             sum(table.AICARInsVSAICAR[, 'adj.P.Val'] < 0.05))

o <- rownames(table.AICARInsVSIns)
Tc <- cbind(table.Ins[o, 'logFC'], table.AICAR[o, 'logFC'],
           table.AICARIns[o, 'logFC'])
rownames(Tc) = gsub('(.*)([A-Z])([0-9]+)(;)', '\\1;\\3;', o)
colnames(Tc) <- c('Ins', 'AICAR', 'AICAR+Ins')

# summary phosphosite-level information to proteins for performing downstream
# gene-centric analyses.
Tc.gene <- phosCollapse(Tc, id=gsub(';+', '', rownames(Tc)),
                      stat=apply(abs(Tc), 1, max), by = 'max')

# Preparing Reactome annotation for our pathways analysis
pathways = as.list(reactomePATHID2EXTID)

path_names = as.list(reactomePATHID2NAME)
name_id = match(names(pathways), names(path_names))
names(pathways) = unlist(path_names)[name_id]

pathways = pathways[which(grepl("Rattus norvegicus", names(pathways),
                               ignore.case = TRUE))]

pathways = lapply(pathways, function(path) {
  gene_name = unname(getSYMBOL(path, data = "org.Rn.eg"))
  toupper(unique(gene_name))
})

# 1D gene-centric pathway analysis
path2 <- pathwayRankBasedEnrichment(Tc.gene[,1],
                                   annotation=pathways,
                                   alter = 'greater')

```

**Description**

Summarising phosphosite-level information to proteins for performing downstream gene-centric analyses.

**Usage**

```
phosCollapse(mat, id, stat, by='min')
```

**Arguments**

mat	a matrix with rows correspond to phosphosites and columns correspond to samples.
id	an array indicating the grouping of phosphosites etc.
stat	an array containing statistics of phosphosite such as phosphorylation levels.
by	how to summarise phosphosites using their statistics. Either by 'min' (default), 'max', or 'mid'.

**Value**

A matrix summarised to protein level

**Examples**

```
library(limma)

data('phospho_L6_ratio_pe')
data('SPSs')

grps = gsub('_+', '', colnames(phospho.L6.ratio.pe))

L6.sites = paste(sapply(GeneSymbol(phospho.L6.ratio.pe), function(x)paste(x)),
                ";",
                sapply(Residue(phospho.L6.ratio.pe), function(x)paste(x)),
                sapply(Site(phospho.L6.ratio.pe), function(x)paste(x)),
                ";", sep = "")

# Construct a design matrix by condition
design = model.matrix(~ grps - 1)

ctl = which(L6.sites %in% SPSs)
phospho.L6.ratio.pe = RUVphospho(phospho.L6.ratio.pe,
                                M = design, k = 3, ctl = ctl)

# fit linear model for each phosphosite
f <- grps
X <- model.matrix(~ f - 1)
fit <- lmFit(SummarizedExperiment::assay(phospho.L6.ratio.pe, "normalised"), X)

# extract top-ranked phosphosites for each condition compared to basal
table.AICAR <- topTable(eBayes(fit), number=Inf, coef = 1)
table.Ins <- topTable(eBayes(fit), number=Inf, coef = 3)
table.AICARIns <- topTable(eBayes(fit), number=Inf, coef = 2)

DE1.RUV <- c(sum(table.AICAR[, 'adj.P.Val'] < 0.05),
            sum(table.Ins[, 'adj.P.Val'] < 0.05),
```

```

sum(table.AICARIns[, 'adj.P.Val'] < 0.05))

# extract top-ranked phosphosites for each group comparison
contrast.matrix1 <- makeContrasts(fAICARIns-fIns, levels=X)
contrast.matrix2 <- makeContrasts(fAICARIns-fAICAR, levels=X)
fit1 <- contrasts.fit(fit, contrast.matrix1)
fit2 <- contrasts.fit(fit, contrast.matrix2)
table.AICARInsVSIns <- topTable(eBayes(fit1), number=Inf)
table.AICARInsVSAICAR <- topTable(eBayes(fit2), number=Inf)

DE2.RUV <- c(sum(table.AICARInsVSIns[, 'adj.P.Val'] < 0.05),
             sum(table.AICARInsVSAICAR[, 'adj.P.Val'] < 0.05))

o <- rownames(table.AICARInsVSIns)
Tc <- cbind(table.Ins[o, 'logFC'], table.AICAR[o, 'logFC'],
            table.AICARIns[o, 'logFC'])
rownames(Tc) = gsub('(.*)([A-Z])([0-9]+)(;)', '\\1;\\3;', o)
colnames(Tc) <- c('Ins', 'AICAR', 'AICAR+Ins')

# summary phosphosite-level information to proteins for performing downstream
# gene-centric analyses.
Tc.gene <- phosCollapse(Tc, id=gsub(';+', '', rownames(Tc)),
                       stat=apply(abs(Tc), 1, max), by = 'max')

```

---

phospho.cells.Ins      *phospho.cells.Ins*

---

## Description

A subset of phosphoproteomics dataset generated by Humphrey et al., [doi:10.1038/nbt.3327] from two mouse liver cell lines (Hepa1.6 and FL38B) that were treated with either PBS (mock) or insulin.

A phosphoproteome Object containing a subset of phosphoproteomics dataset generated by Humphrey et al., [doi:10.1038/nbt.3327] from two mouse liver cell lines (Hepa1.6 and FL38B) that were treated with either PBS (mock) or insulin.

## Usage

```
data(phospho.cells.Ins.sample)
```

```
data(phospho.cells.Ins.pe)
```

## Format

An object of class `matrix` (inherits from `array`) with 49617 rows and 24 columns.

An object of class `matrix` (inherits from `array`) with 49617 rows and 24 columns.

## Source

doi: 10.1038/nbt.3327 (PXD001792)

doi: 10.1038/nbt.3327 (PXD001792)

**References**

Humphrey et al., 2015, doi: 10.1038/nbt.3327

Humphrey et al., 2015, doi: 10.1038/nbt.3327

---

phospho.L6.ratio      *phospho.L6.ratio*

---

**Description**

An L6 myotube phosphoproteome dataset (accession number: PXD019127).

**Usage**

```
data(phospho_L6_ratio)
```

**Format**

An object of class `matrix` (inherits from `array`) with 6660 rows and 12 columns.

**Source**

PRIDE accession number: PXD001792

---

phospho.L6.ratio.pe      *phospho\_L6\_ratio\_pe*

---

**Description**

L6 myotube phosphoproteome dataset (accession number: PXD019127).

**Usage**

```
data(phospho_L6_ratio_pe)
```

**Format**

An `PhosphoExperiment` object

**Source**

PRIDE accession number: PXD001792

---

phospho.liver.Ins.TC.ratio.RUV  
*phospho\_liverInsTC\_RUV\_sample*

---

### Description

A subset of phosphoproteomics dataset integrated from two time-course datasets of early and intermediate insulin signalling in mouse liver upon insulin stimulation.

### Usage

```
data(phospho_liverInsTC_RUV_sample)
```

### Format

An object of class `matrix` (inherits from `array`) with 5000 rows and 90 columns.

### Source

PRIDE accession number: PXD001792

### References

Humphrey et al., 2015

---

phospho.liver.Ins.TC.ratio.RUV.pe  
*phospho.liver.Ins.TC.ratio.RUV.pe*

---

### Description

A subset of phosphoproteomics dataset integrated from two time-course datasets of early and intermediate insulin signalling in mouse liver upon insulin stimulation.

### Usage

```
data(phospho.liver.Ins.TC.ratio.RUV.pe)
```

### Format

A Phosphoproteome Object

### Source

PRIDE accession number: PXD001792

### References

Humphrey et al., 2015

---

 PhosphoExperiment-class

*The PhosphoExperiment class*


---

## Description

The PhosphoExperiment class

## Usage

```
PhosphoExperiment(
  ...,
  UniprotID = c(),
  GeneSymbol = c(),
  Site = c(),
  Residue = c(),
  Sequence = c(),
  Localisation = c()
)
```

## Arguments

...	Arguments parsed, identical to those used to create <a href="#">SummarizedExperiment</a> .
UniprotID	A character vector of Uniprot ID
GeneSymbol	A character vector of gene symbol
Site	A numeric vector of phosphorylation site
Residue	A character vector of site residue
Sequence	A character vector of sequences
Localisation	A localisation score.

## Examples

```
data(phospho_L6_ratio)
quant <- as.matrix(phospho.L6.ratio)
uniprot <- as.character(sapply(strsplit(rownames(quant), ";"),
  function(x) x[[2]]))
symbol <- as.character(sapply(strsplit(rownames(quant), ";"),
  function(x) x[[2]]))
site <- as.numeric(gsub("[STY]", "", sapply(strsplit(rownames(quant), ";"),
  function(x) x[[3]])))
res <- as.character(gsub("[0-9]", "", sapply(strsplit(rownames(quant), ";"),
  function(x) x[[3]])))
seq <- as.character(sapply(strsplit(rownames(quant), ";"),
  function(x) x[[4]]))
phosData <- PhosphoExperiment(assays = list(Quantification = quant),
  UniprotID = uniprot, Site = site, GeneSymbol = symbol, Residue = res,
  Sequence = seq)
```

---

PhosphoSite.human      *PhosphoSitePlus annotations for human*

---

**Description**

The data object contains the annotations of kinases and their corresponding substrates as phosphorylation sites in human. It is extracted from the PhosphoSitePlus database. For details of PhosphoSitePlus, please refer to the article: Hornbeck et al. Nucleic Acids Res. 40:D261-70, 2012

**Usage**

```
data(PhosphoSitePlus)
```

**Format**

An object of class list of length 379.

**Source**

<https://www.phosphosite.org>

---

PhosphoSite.mouse      *PhosphoSitePlus annotations for mouse*

---

**Description**

The data object contains the annotations of kinases and their corresponding substrates as phosphorylation sites in mouse. It is extracted from the PhosphoSitePlus database. For details of PhosphoSitePlus, please refer to the article: Hornbeck et al. Nucleic Acids Res. 40:D261-70, 2012

**Usage**

```
data(PhosphoSitePlus)
```

**Format**

An object of class list of length 260.

**Source**

<https://www.phosphosite.org>

---

PhosphoSite.rat	<i>PhosphoSitePlus annotations for rat</i>
-----------------	--

---

**Description**

The data object contains the annotations of kinases and their corresponding substrates as phosphorylation sites in rat. It is extracted from the PhosphoSitePlus database. For details of PhosphoSitePlus, please refer to the article: Hornbeck et al. Nucleic Acids Res. 40:D261-70, 2012

**Usage**

```
data(PhosphoSitePlus)
```

**Format**

An object of class list of length 158.

**Source**

<https://www.phosphosite.org>

---

plotKinaseNetwork	<i>Plot kinase network</i>
-------------------	----------------------------

---

**Description**

Plot kinase network

**Usage**

```
plotKinaseNetwork(KSR, predMatrix, threshold = 0.9, color,
type = NULL, verbose = FALSE)
```

**Arguments**

KSR	Kinase-substrate relationship scoring results
predMatrix	Output of kinaseSubstratePred function
threshold	Threshold used to select interconnected kinases for the expanded signalomes
color	A string specifying the color vector for nodes
type	A type (graph or chord) of plot. If NULL, network graph is plotted
verbose	Default to TRUE to show messages during the progress. All messages will be suppressed if set to FALSE

**Value**

a graphical plot

plotQC

*A set of function for data QC plot***Description**

The 'panel' parameter allows different type of visualisation for output object from PhosR. 'panel = "all"' is used to create a 2\*2 panel of plots including the following. 'panel = "quantify"' is used to visualise percentage of quantification after imputataion. 'panel = "dendrogram"' is used to visualise dendrogram (hierarchical clustering) of the input matrix. 'panel = "abundance"' is used to visualise abundance level of samples from the input matrix. 'panel = "pca"' is used to show PCA plot

**Usage**

```
plotQC(mat, grps, labels, panel =
c("quantify", "dendrogram", "abundance", "pca", "all"))
```

**Arguments**

mat	A p by n matrix, where p is the number of phosphosites and n is the number of samples.
grps	A vector of colours to be used in the plot. The length should be equal to the columns of the mat.
labels	A vector of sample names. Used the label points in PCA plot (panel=4)
panel	A type of plot to output. See description for details.

**Value**

A graphical plot

**Examples**

```
# Imputation
data('phospho.cells.Ins.sample')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins, grps, 0.5, n=1)

set.seed(123)
phospho.cells.Ins.impute <-
  scImpute(
    phospho.cells.Ins.filtered,
    0.5,
    grps)[,colnames(phospho.cells.Ins.filtered)]

set.seed(123)
phospho.cells.Ins.impute[,seq_len(5)] <- ptImpute(
  phospho.cells.Ins.impute[,seq(6,10)],
  phospho.cells.Ins.impute[,seq(5)],
  percent1 = 0.6, percent2 = 0, paired = FALSE)

phospho.cells.Ins.ms <- medianScaling(phospho.cells.Ins.impute,
  scale = FALSE)
```

```

p1 = plotQC(phospho.cells.Ins.filtered,
            labels=colnames(phospho.cells.Ins.filtered),
            panel = "quantify", grps = grps)
p2 = plotQC(phospho.cells.Ins.ms,
            labels=colnames(phospho.cells.Ins.ms),
            panel = "quantify", grps = grps)
ggpubr::ggarrange(p1, p2, nrow = 1)

# Batch correction
data('phospho_L6_ratio_pe')
data('SPSs')

grps = gsub('_', '+', '', rownames(
  SummarizedExperiment::colData(phospho.L6.ratio.pe)
))

# Cleaning phosphosite label
L6.sites = paste(sapply(GeneSymbol(phospho.L6.ratio.pe), function(x) paste(x)),
                ";",
                sapply(Residue(phospho.L6.ratio.pe), function(x) paste(x)),
                sapply(Site(phospho.L6.ratio.pe), function(x) paste(x)),
                ";", sep = "")
phospho.L6.ratio = t(sapply(split(data.frame(
  SummarizedExperiment::assay(phospho.L6.ratio.pe, "Quantification"),
  L6.sites), colMeans))
phospho.site.names = split(
  rownames(
    SummarizedExperiment::assay(phospho.L6.ratio.pe, "Quantification")
  ), L6.sites)

# Construct a design matrix by condition
design = model.matrix(~ grps - 1)

# phosphoproteomics data normalisation using RUV
ctl = which(rownames(phospho.L6.ratio) %in% SPSs)
phospho.L6.ratio.RUV = RUVphospho(phospho.L6.ratio, M = design, k = 3,
                                ctl = ctl)

# plot after batch correction
p1 = plotQC(phospho.L6.ratio, panel = "dendrogram", grps=grps,
            labels = colnames(phospho.L6.ratio))
p2 = plotQC(phospho.L6.ratio.RUV, grps=grps,
            labels = colnames(phospho.L6.ratio),
            panel="dendrogram")
ggpubr::ggarrange(p1, p2, nrow = 1)

p1 = plotQC(phospho.L6.ratio, panel = "pca", grps=grps,
            labels = colnames(phospho.L6.ratio)) +
  ggplot2::ggtitle('Before Batch correction')
p2 = plotQC(phospho.L6.ratio.RUV, grps=grps,
            labels = colnames(phospho.L6.ratio),
            panel="pca") +
  ggplot2::ggtitle('After Batch correction')
ggpubr::ggarrange(p1, p2, nrow = 1)

```

---

plotSignalomeMap	<i>Plot signalome map</i>
------------------	---------------------------

---

**Description**

Plot signalome map

**Usage**

```
plotSignalomeMap(signalomes, color)
```

**Arguments**

signalomes	output from ‘Signalomes’ function
color	a string specifying the color vector for kinases

**Value**

a ggplot object

---

PPE-accessors	<i>PhosphoExperiment object accessors</i>
---------------	---

---

**Description**

These are methods for getting for setting accessors of PhosphoExperiment object. This provides some convenience for users.

**Usage**

```
UniprotID(x, ...)
```

```
UniprotID(x) <- value
```

```
GeneSymbol(x, ...)
```

```
GeneSymbol(x) <- value
```

```
Site(x, ...)
```

```
Site(x) <- value
```

```
Residue(x, ...)
```

```
Residue(x) <- value
```

```
Sequence(x, ...)
```

```
Sequence(x) <- value
```

```

Localisation(x, ...)

Localisation(x) <- value

## S4 method for signature 'PhosphoExperiment'
UniprotID(x, withDimnames = TRUE)

## S4 method for signature 'PhosphoExperiment'
GeneSymbol(x, withDimnames = TRUE)

## S4 method for signature 'PhosphoExperiment'
Site(x, withDimnames = TRUE)

## S4 method for signature 'PhosphoExperiment'
Residue(x, withDimnames = TRUE)

## S4 method for signature 'PhosphoExperiment'
Sequence(x, withDimnames = TRUE)

## S4 method for signature 'PhosphoExperiment'
Localisation(x, withDimnames = TRUE)

## S4 replacement method for signature 'PhosphoExperiment'
UniprotID(x) <- value

## S4 replacement method for signature 'PhosphoExperiment'
GeneSymbol(x) <- value

## S4 replacement method for signature 'PhosphoExperiment'
Site(x) <- value

## S4 replacement method for signature 'PhosphoExperiment'
Residue(x) <- value

## S4 replacement method for signature 'PhosphoExperiment'
Sequence(x) <- value

## S4 replacement method for signature 'PhosphoExperiment'
Localisation(x) <- value

```

### Arguments

<code>x</code>	A <code>PhosphoExperiment</code> object to be assigned to.
<code>...</code>	Ignored for accessors.
<code>value</code>	A vector of values to set to respective accessor. See section Available methods for more details.
<code>withDimnames</code>	A <code>logical(1)</code> , indicating whether the names of the vector should be applied.

### Available methods

In the following code snippets, `ppe` is a `PhosphoExperiment` object.

UniprotID(ppe), UniprotID(ppe) <- value: Get or set a Uniprot ID, where value is a character vector

GeneSymbol(ppe), GeneSymbol(ppe) <- value: Get or set a gene symbol, where value is a character vector

Site(ppe), Site(ppe) <- value: Get or set a phosphorylation site, where value is a numeric vector

Residue(ppe), Residue(ppe) <- value: Get or set a residue of phosphorylation site, where value is a character

Sequence(ppe), Sequence(ppe) <- value: Get or set a sequence, where value is a character vector

Localisation(ppe), Localisation(ppe) <- localisation: Get or set a localisation score, where localisation is a numeric vector

### Author(s)

Taiyun Kim

### Examples

```
example(PhosphoExperiment, echo = FALSE)

UniprotID(phosData) <- uniprot
head(UniprotID(phosData))

GeneSymbol(phosData) <- symbol
head(GeneSymbol(phosData))

Site(phosData) <- site
head(Site(phosData))

Residue(phosData) <- res
head(Residue(phosData))

Sequence(phosData) <- seq
head(Sequence(phosData))

Localisation(phosData) <- rnorm(nrow(phosData))
head(Localisation(phosData))
```

---

PPE-operate

*PhosphoExperiment object subset, combine methods*

---

### Description

These are methods for combining or subsetting for PhosphoExperiment object. This provides some convenience for users.

**Usage**

```
## S4 method for signature 'PhosphoExperiment,ANY,ANY,ANY'
x[i, j, drop = TRUE]

## S4 replacement method for signature 'PhosphoExperiment,ANY,ANY,ANY'
x[i, j, ...] <- value

## S4 method for signature 'PhosphoExperiment'
rbind(..., deparse.level = 1)

## S4 method for signature 'PhosphoExperiment'
cbind(..., deparse.level = 1)
```

**Arguments**

x	A PhosphoExperiment object
i	For [,PhosphoExperiment[,PhosphoExperiment<-, i, j are subscripts that can act to subset the rows of x
j	For [,PhosphoExperiment[,PhosphoExperiment<-, i, j are subscripts that can act to subset the columns of x
drop	A logical(1), ignored by these methods
...	In cbind or rbind, a PhosphoExperiment objects
value	An object of a class specified in the S4 method signature.
deparse.level	See ?base::cbind for a description of this argument.

**Available methods**

In the following code snippets, ppe1 and ppe2 is a PhosphoExperiment object with matching colData. ppe3 and ppe4 is a PhosphoExperiment object with matching rowData.

```
rbind(ppe1, ppe2): Combine row-wise
cbind(ppe3, ppe4): Combine column-wise
```

**Author(s)**

Taiyun Kim

**See Also**

method rbind, cbind from [SummarizedExperiment](#) object.

**Examples**

```
example(PhosphoExperiment, echo = FALSE)

n = ncol(phosData)
ppe1 = phosData[,seq(round(n/2))]
ppe2 = phosData[,-seq(round(n/2))]

ppe = cbind(ppe1, ppe2)
identical(ppe, phosData)
```

```

ppe[,seq(round(n/2))] = ppe1
identical(ppe, phosData)

p = nrow(phosData)
ppe1 = phosData[seq(round(p/2)),]
ppe2 = phosData[-seq(round(p/2)),]

ppe = rbind(ppe1, ppe2)
identical(ppe, phosData)

ppe[seq(round(p/2)),] = ppe1
identical(ppe, phosData)

```

---

ptImpute

*Paired-tail (pt) based impute*


---

### Description

Impute the missing values for mat2 using tail imputation approach if mat1 has more than percent1 (percentage) of quantified values and mat2 has less than percent2 (percentage) quantified values, and vice versa if paired is set to be true. That is if mat2 has percentage of quantified values more than percent1 and mat1 has percentage quantified values less than percent2.

### Usage

```

ptImpute(
  mat1,
  mat2,
  percent1,
  percent2,
  m = 1.6,
  s = 0.6,
  paired = TRUE,
  verbose = TRUE,
  assay
)

```

### Arguments

mat1	a matrix (or PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to replicates within treatment1.
mat2	a matrix (or PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to replicates within treatment2.
percent1	a percent indicating minimum quantified percentages required for considering for imputation.
percent2	a percent indicating minimum quantified percentages required for considering for imputation.
m	a numeric number of for controlling mean downshifting.
s	a numeric number of for controlling standard deviation of downshifted sampling values.

paired	a flag indicating whether to impute for both treatment1 and treatment2 (default) or treatment2 only (if paired=FALSE).
verbose	Default to TRUE to show messages during the progress. All messages will be suppressed if set to FALSE
assay	an assay to be selected if mat is a PhosphoExperiment object.

**Value**

An imputed matrix

**Examples**

```

data('phospho.cells.Ins.sample')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins, grps, 0.5, n=1)

set.seed(123)
phospho.cells.Ins.impute <-
  scImpute(
    phospho.cells.Ins.filtered,
    0.5,
    grps[,colnames(phospho.cells.Ins.filtered)]

set.seed(123)
phospho.cells.Ins.impute[,seq(6)] <-
  ptImpute(phospho.cells.Ins.impute[,seq(7,12)],
phospho.cells.Ins.impute[,seq(6)], percent1 = 0.6, percent2 = 0,
  paired = FALSE)

# For PhosphoExperiment objects
# mat = PhosphoExperiment(
#   assay = phospho.cells.Ins.impute,
#   colData = S4Vectors::DataFrame(
#     groups = grps
#   )
# )
# SummarizedExperiment::assay(mat)[,seq(6)] <-
#   ptImpute(SummarizedExperiment::assay(mat)[,seq(7,12)],
#     SummarizedExperiment::assay(mat)[,seq(6)], percent1 = 0.6,
#     percent2 = 0, paired = FALSE)

```

**Description**

This is a wrapper implementation of RUVIII for phosphoproteomics data normalisation. This function will call `tailImpute` function to impute all the missing values (if there is any) in the phosphoproteomics data for applying RUVIII. It will then return the normalised values for quantified phosphosites and remove imputed values.

**Usage**

```
RUVphospho(
  mat,
  M,
  ctl,
  k = NULL,
  m = 1.6,
  s = 0.6,
  keepImpute = FALSE,
  assay = NULL,
  ...
)
```

**Arguments**

mat	a matrix (or PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to samples.
M	is the design matrix as defined in RUVIII.
ctl	is the stable phosphosites (or negative controls as defined in RUVIII).
k	is the number of unwanted factors as defined in RUVIII.
m	a numeric number for controlling mean downshifting.
s	a numeric number for controlling standard deviation of downshifted sampling values.
keepImpute	a boolean to keep the missing value in the returned matrix.
assay	an assay to be selected if mat is a PhosphoExperiment object.
...	additional parameters that may be passed to RUVIII.

**Value**

A normalised matrix.

**Examples**

```
data('phospho_L6_ratio_pe')
data('SPSs')

grps = gsub('_.+ ', '', colnames(phospho.L6.ratio.pe))

L6.sites = paste(sapply(GeneSymbol(phospho.L6.ratio.pe), function(x)paste(x)),
                ";",
                sapply(Residue(phospho.L6.ratio.pe), function(x)paste(x)),
                sapply(Site(phospho.L6.ratio.pe), function(x)paste(x)),
                ";", sep = "")

# Construct a design matrix by condition
design = model.matrix(~ grps - 1)

# phosphoproteomics data normalisation using RUV
ctl = which(L6.sites %in% SPSs)
phospho.L6.ratio.RUV = RUVphospho(
  SummarizedExperiment::assay(phospho.L6.ratio.pe, "Quantification"),
  M = design, k = 3, ctl = ctl)
```

---

 scImpute

*Site- and condition-specific (sc) impute*


---

### Description

Impute the missing values for a phosphosite across replicates within a single condition (or treatment) if there are  $n$  or more quantified values of that phosphosite in that condition.

### Usage

```
scImpute(mat, percent, grps, assay)
```

### Arguments

mat	a matrix (or PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to replicates within a condition.
percent	a percent from 0 to 1, specifying the percentage of quantified values in any treatment group.
grps	a string specifying the grouping (replciates).
assay	an assay to be selected if mat is a PhosphoExperiment object.

### Value

An imputed matrix. If param `mat` is a PhosphoExperiment object, a PhosphoExperiment object will be returned.

### Examples

```
data('phospho.cells.Ins.sample')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins, grps, 0.5, n=1)

set.seed(123)
phospho.cells.Ins.impute <-
  scImpute(phospho.cells.Ins.filtered,
    0.5,
    grps)[,colnames(phospho.cells.Ins.filtered)]

# for PhosphoExperiment Object
data('phospho.cells.Ins.pe')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins.pe))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins.pe, grps,
  0.5, n=1)

set.seed(123)
phospho.cells.Ins.impute <-
  scImpute(phospho.cells.Ins.filtered,
    0.5,
    grps)[,colnames(phospho.cells.Ins.filtered)]
```

---

selectGrps	<i>Select by treatment groups (replicate block)</i>
------------	---

---

### Description

Select phosphosites that have been quantified in a given percentage of treatment groups (e.g. 0.75 as 3 out of 4 replicates) in n groups.

### Usage

```
selectGrps(mat, grps, percent, n, assay)
```

### Arguments

mat	a matrix (PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to samples in replicates for different treatments.
grps	a string specifying the grouping (replicates).
percent	a percent from 0 to 1, specifying the percentage of quantified values in any treatment group.
n	an integer indicating n or more replicates pass the percentage filtering for a phosphosite to be included.
assay	an assay to be selected if mat is a PhosphoExperiment object.

### Value

a filtered matrix (or a PhosphoExperiment Object) with at least 'percent' quantification in one or more conditions. If an input mat is a SummarizedExperiment object, filtered SummarizedExperiment object will be returned.

### Author(s)

Pengyi Yang, Taiyun Kim

### Examples

```
data('phospho.cells.Ins.sample')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins, grps, 0.5, n=1)

# For PhosphoExperiment object
data('phospho.cells.Ins.pe')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins.pe))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins.pe, grps, 0.5, n=1)
```

---

selectLocalisedSites *Select phosphosites by localisation score*

---

### Description

Select phosphosites with a localisation score higher than the pre-defined probability score (default score = 0.75)

### Usage

```
selectLocalisedSites(mat, loc=NULL, prob = 0.75)
```

### Arguments

mat	a matrix (or PhosphoExperiment object) with rows corresponding to phosphosites and columns corresponding to samples in replicates for different treatments.
loc	a vector of localisation scores
prob	a percent from 0 to 1, specifying the localisation probability of quantified values in across all samples for retaining a phosphosite for subsequent analysis.

### Value

a filtered matrix

### Examples

```
data('phospho.cells.Ins.pe')
ppe <- phospho.cells.Ins.pe
ppe_mat <- as.data.frame(SummarizedExperiment::assay(ppe))
# Before filtering
dim(ppe)
dim(ppe_mat)

# Generate arbitrary localisation probabilities for each phosphosite
set.seed(2020)
localisation_scores <- round(rnorm(nrow(ppe), 0.8, 0.05), 2)
table(localisation_scores >= 0.75)

# Filter
Localisation(ppe) <- localisation_scores
ppe_filtered <- selectLocalisedSites(ppe, prob=0.75)
ppe_mat_filtered <- selectLocalisedSites(ppe_mat, loc=localisation_scores,
  prob=0.75)

# After filtering
dim(ppe_filtered)
dim(ppe_mat_filtered)
```

---

selectOverallPercent *Select phosphosite by percentage of quantification*

---

**Description**

Select phosphosites that have been quantified in more than a given percentage of samples

**Usage**

```
selectOverallPercent(mat, percent, n, assay)
```

**Arguments**

mat	a matrix (or PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to samples in replicates for different treatments.
percent	a percent from 0 to 1, specifying the percentage of quantified values in across all samples for retaining a phosphosite for subsequent analysis.
n	an integer indicating n or more quantified values required for retaining a phosphosite for subsequent analysis.
assay	an assay to be selected if mat is a PhosphoExperiment object.

**Value**

a filtered matrix

**Examples**

```
data('phospho.cells.Ins.sample')

phospho.cells.Ins.filtered <- selectOverallPercent(phospho.cells.Ins, 0.5)

# Before filtering
dim(phospho.cells.Ins)
# After filtering
dim(phospho.cells.Ins.filtered)
```

---

selectTimes *selectTimes*

---

**Description**

selectTimes

**Usage**

```
selectTimes(mat, timepoint, order, percent, w, assay)
```

**Arguments**

mat	a matrix (or PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to samples in replicates for different treatments.
timepoint	a timepoint as factor with a length equal to the number of columns of mat.
order	a vector specifying the order of timepoints.
percent	a percent (decimal) from 0 to 1, to filter phosphosites with with missing value larger than percent per timepoint.
w	a timepoint window for selection of phosphosites to remove.
assay	an assay to be selected if mat is a PhosphoExperiment object.

**Value**

a filtered matrix. If param mat is a SummarizedExperiment object, a SummarizedExperiment object will be returned.

**Examples**

```
data("phospho_liverInsTC_RUV_sample")
timepoint = gsub("(.*)(\\d+[ms])(.*)", "\\2",
                colnames(phospho.liver.Ins.TC.ratio.RUV))
timepoint[which(timepoint == "0m")] = "0s"
timepoint = factor(timepoint)
timepointOrder = c("0s", "5s", "1m", "2m", "3m", "4m", "6m")

# For demonstration purpose, we introduce missing value at 0s
table(timepoint)

phospho.liver.Ins.TC.sim = phospho.liver.Ins.TC.ratio.RUV
rmId = which(timepoint == "0s")

# We replace the values to NA for the first 26 (~60%) of the '0s' samples
# for the first 100 phosphosite as NA
phospho.liver.Ins.TC.sim[seq(100),rmId[seq(26)]] = NA

phospho.liver.Ins.TC.sim = selectTimes(phospho.liver.Ins.TC.sim,
                                     timepoint, timepointOrder, 0.5,
                                     w = length(table(timepoint)))

# For PhosphoExperiment objects
# mat = PhosR::PhosphoExperiment(
#   assay = phospho.liver.Ins.TC.sim,
#   colData = S4Vectors::DataFrame(
#     timepoint = timepoint
#   )
# )
# phospho.liver.Ins.TC.sim = selectTimes(mat, mat$timepoint, timepointOrder,
#   0.5, w = length(table(mat$timepoint)))

# Before filtering
dim(phospho.liver.Ins.TC.ratio.RUV)
# After filtering
dim(phospho.liver.Ins.TC.sim)
```

Signalomes

*PhosR Signalomes***Description**

A function to generate signalomes

**Usage**

```
Signalomes(KSR, predMatrix, exprsMat, KOI, threskinaseNetwork=0.9,
  signalomeCutoff=0.5, module_res = NULL, filter = FALSE, verbose = TRUE)
```

**Arguments**

KSR	kinase-substrate relationship scoring results
predMatrix	output of kinaseSubstratePred function
exprsMat	a matrix with rows corresponding to phosphosites and columns corresponding to samples
KOI	a character vector that contains kinases of interest for which expanded signalomes will be generated
threskinaseNetwork	threshold used to select interconnected kinases for the expanded signalomes
signalomeCutoff	threshold used to filter kinase-substrate relationships
module_res	parameter to select number of final modules
filter	parameter to filter modules with only few proteins
verbose	Default to TRUE to show messages during the progress. All messages will be suppressed if set to FALSE

**Value**

A list of 3 elements. Signalomes, proteinModules and kinaseSubstrates

**Examples**

```
data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

grps = gsub('_.+', '', colnames(phospho.L6.ratio.pe))

# Construct a design matrix by condition
design = model.matrix(~ grps - 1)

# phosphoproteomics data normalisation using RUV

L6.sites = paste(sapply(GeneSymbol(phospho.L6.ratio.pe), function(x)paste(x)),
  ";",
  sapply(Residue(phospho.L6.ratio.pe), function(x)paste(x)),
  sapply(Site(phospho.L6.ratio.pe), function(x)paste(x)),
```

```

";", sep = "")
ctl = which(L6.sites %in% SPSs)
phospho.L6.ratio.RUV = RUVphospho(
  SummarizedExperiment::assay(phospho.L6.ratio.pe, "Quantification"),
  M = design, k = 3, ctl = ctl)

phosphoL6 = phospho.L6.ratio.RUV

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)
aov <- matANOVA(mat=phosphoL6, grps=grps)
phosphoL6.reg <- phosphoL6[(aov < 0.05) &
  (rowSums(phosphoL6.mean > 0.5) > 0)],, drop = FALSE]
L6.phos.std <- standardise(phosphoL6.reg)
idx <- match(rownames(L6.phos.std), rownames(phospho.L6.ratio.pe))
rownames(L6.phos.std) <- L6.sites[idx]

L6.phos.seq <- Sequence(phospho.L6.ratio.pe)[idx]

L6.matrices <- kinaseSubstrateScore(PhosphoSite.mouse, L6.phos.std,
  L6.phos.seq, numMotif = 5, numSub = 1)

set.seed(1)
L6.predMat <- kinaseSubstratePred(L6.matrices, top=30)

kinaseOI = c('PRKAA1', 'AKT1')

Signalomes_results <- Signalomes(KSR=L6.matrices,
  predMatrix=L6.predMat,
  exprsMat=L6.phos.std,
  KOI=kinaseOI)

```

---

siteAnnotate

*Phosphosite annotation*

---

## Description

This function plots the combined scores of each of all kinases for a given phosphosites

## Usage

```
siteAnnotate(site, phosScoringMatrices, predMatrix)
```

## Arguments

`site` site the ID of a phosphosite  
`phosScoringMatrices` output from function `kinaseSubstrateScore()`  
`predMatrix` a prediction matrix from `kinaseSubstratePred()`

## Value

A graphical plot

**Examples**

```

data('phospho_L6_ratio_pe')
data('SPSs')
data('PhosphoSitePlus')

ppe <- phospho.L6.ratio.pe
sites = paste(sapply(GeneSymbol(ppe), function(x)x),";",
  sapply(Residue(ppe), function(x)x),
  sapply(Site(ppe), function(x)x),
  ";", sep = "")
grps = gsub("_.", "", colnames(ppe))
design = model.matrix(~ grp - 1)
ctl = which(sites %in% SPSs)
ppe = RUVphospho(ppe, M = design, k = 3, ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(ppe, "normalised")

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grp = grp)
aov <- matANOVA(mat=phosphoL6, grp = grp)
idx <- (aov < 0.05) & (rowSums(phosphoL6.mean > 0.5) > 0)
phosphoL6.reg <- phosphoL6[idx, ,drop = FALSE]

L6.phos.std <- standardise(phosphoL6.reg)

rownames(L6.phos.std) <- paste0(GeneSymbol(ppe), ";", Residue(ppe),
  Site(ppe), ";")[idx]

L6.phos.seq <- Sequence(ppe)[idx]

L6.matrices <- kinaseSubstrateScore(PhosphoSite.mouse, L6.phos.std,
  L6.phos.seq, numMotif = 5, numSub = 1)

set.seed(1)
L6.predMat <- kinaseSubstratePred(L6.matrices, top=30)
dev.off()

# We will look at the phosphosite AAK1;S677 for demonstration purpose.
site = "AAK1;S677;"
siteAnnotate(site, L6.matrices, L6.predMat)

```

---

SPSs

*A list of Stably Phosphorylated Sites (SPSs)*


---

**Description**

A list of stably phosphorylated sites defined from a panel of phosphoproteomics datasets. For full list of the datasets used, please refer to our preprint for the full list.

**Usage**

```
data(SPSs)
```

**Format**

An object of class character of length 100.

---

standardise	<i>Standardisation</i>
-------------	------------------------

---

**Description**

Standardisation by z-score transformation.

**Usage**

```
standardise(mat)
```

**Arguments**

`mat` a matrix (or a PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to samples.

**Value**

A standardised matrix

**Examples**

```
data('phospho_L6_ratio_pe')
data('SPSS')

grps = gsub('_', '+', '', colnames(phospho.L6.ratio.pe))

# Construct a design matrix by condition
design = model.matrix(~ grps - 1)

# phosphoproteomics data normalisation using RUV
L6.sites = paste(sapply(GeneSymbol(phospho.L6.ratio.pe), function(x)paste(x)),
                ";",
                sapply(Residue(phospho.L6.ratio.pe), function(x)paste(x)),
                sapply(Site(phospho.L6.ratio.pe), function(x)paste(x)),
                ";", sep = "")
ctl = which(L6.sites %in% SPSS)
phospho.L6.ratio.pe = RUVphospho(phospho.L6.ratio.pe,
                                M = design, k = 3,ctl = ctl)

phosphoL6 = SummarizedExperiment::assay(phospho.L6.ratio.pe, "normalised")

# filter for up-regulated phosphosites
phosphoL6.mean <- meanAbundance(phosphoL6, grps = grps)
aov <- matANOVA(mat=phosphoL6, grps = grps)
phosphoL6.reg <- phosphoL6[(aov < 0.05) &
                          (rowSums(phosphoL6.mean > 0.5) > 0),,drop = FALSE]
L6.phos.std <- standardise(phosphoL6.reg)
```

---

tImpute	<i>Tail-based impute</i>
---------	--------------------------

---

### Description

Tail-based imputation approach as implemented in Perseus.

### Usage

```
tImpute(mat, m, s, assay)
```

### Arguments

mat	a matrix (or PhosphoExperiment object) with rows correspond to phosphosites and columns correspond to samples.
m	a numeric number for controlling mean downshifting.
s	a numeric number for controlling standard deviation of downshifted sampling values.
assay	an assay to be selected if mat is a PhosphoExperiment object.

### Value

An imputed matrix. If param mat is a SummarizedExperiment object, a SummarizedExperiment object will be returned.

### Examples

```
data('phospho.cells.Ins.sample')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins, grps, 0.5, n=1)

set.seed(123)
phospho.cells.Ins.impute <- tImpute(phospho.cells.Ins.filtered)

# For PhosphoExperiment Object
data('phospho.cells.Ins.pe')
grps = gsub('_[0-9]{1}', '', colnames(phospho.cells.Ins.pe))
phospho.cells.Ins.filtered <- selectGrps(phospho.cells.Ins.pe, grps,
  0.5, n=1)

set.seed(123)
phospho.cells.Ins.impute <- tImpute(phospho.cells.Ins.filtered)
```

# Index

## \* datasets

- hSEGs, [5](#)
- KinaseFamily, [6](#)
- motif.human.list, [16](#)
- motif.mouse.list, [17](#)
- motif.rat.list, [17](#)
- mSEGs, [17](#)
- phospho.cells.Ins, [23](#)
- phospho.L6.ratio, [24](#)
- phospho.L6.ratio.pe, [24](#)
- phospho.liver.Ins.TC.ratio.RUV, [25](#)
- phospho.liver.Ins.TC.ratio.RUV.pe, [25](#)
- PhosphoSite.human, [27](#)
- PhosphoSite.mouse, [27](#)
- PhosphoSite.rat, [28](#)
- SPSs, [45](#)
- [ (PPE-operate), [33](#)
- [,PhosphoExperiment,ANY,ANY,ANY-method (PPE-operate), [33](#)
- [<- (PPE-operate), [33](#)
- [<-,PhosphoExperiment,ANY,ANY,ANY-method (PPE-operate), [33](#)
  
- cbind, [34](#)
- cbind (PPE-operate), [33](#)
- cbind,PhosphoExperiment-method (PPE-operate), [33](#)
- coerce, (PhosphoExperiment-class), [26](#)
- createFrequencyMat, [3](#)
  
- frequencyScoring, [3](#)
  
- GeneSymbol (PPE-accessors), [31](#)
- GeneSymbol,PhosphoExperiment-method (PPE-accessors), [31](#)
- GeneSymbol<- (PPE-accessors), [31](#)
- GeneSymbol<- ,PhosphoExperiment-method (PPE-accessors), [31](#)
- getSPS, [4](#)
  
- hSEGs, [5](#)
  
- KinaseFamily, [6](#)
- kinaseSubstrateHeatmap, [6](#)
  
- kinaseSubstratePred, [7](#)
- kinaseSubstrateProfile, [9](#)
- kinaseSubstrateScore, [10](#)
  
- Localisation (PPE-accessors), [31](#)
- Localisation,PhosphoExperiment-method (PPE-accessors), [31](#)
- Localisation<- (PPE-accessors), [31](#)
- Localisation<- ,PhosphoExperiment-method (PPE-accessors), [31](#)
  
- matANOVA, [11](#)
- meanAbundance, [12](#)
- medianScaling, [13](#)
- minmax, [14](#)
- mIntersect, [15](#)
- motif.human.list, [16](#)
- motif.mouse.list, [17](#)
- motif.rat.list, [17](#)
- mSEGs, [17](#)
- mUnion (mIntersect), [15](#)
  
- pathwayOverrepresent, [18](#)
- pathwayRankBasedEnrichment, [20](#)
- phosCollapse, [21](#)
- phospho.cells.Ins, [23](#)
- phospho.L6.ratio, [24](#)
- phospho.L6.ratio.pe, [24](#)
- phospho.liver.Ins.TC.ratio.RUV, [25](#)
- phospho.liver.Ins.TC.ratio.RUV.pe, [25](#)
- PhosphoExperiment, [32](#)
- PhosphoExperiment (PhosphoExperiment-class), [26](#)
- PhosphoExperiment-class, [26](#)
- PhosphoExperiment-method (PhosphoExperiment-class), [26](#)
- PhosphoSite.human, [27](#)
- PhosphoSite.mouse, [27](#)
- PhosphoSite.rat, [28](#)
- plotKinaseNetwork, [28](#)
- plotQC, [29](#)
- plotSignalomeMap, [31](#)
- PPE-accessors, [31](#)
- PPE-operate, [33](#)

ptImpute, [35](#)

rbind (PPE-operate), [33](#)  
rbind, PhosphoExperiment-method  
(PPE-operate), [33](#)

Residue (PPE-accessors), [31](#)  
Residue, PhosphoExperiment-method  
(PPE-accessors), [31](#)

Residue<- (PPE-accessors), [31](#)  
Residue<-, PhosphoExperiment-method  
(PPE-accessors), [31](#)

RUVphospho, [36](#)  
RUVproteome (RUVphospho), [36](#)

scImpute, [38](#)  
selectGrps, [39](#)  
selectLocalisedSites, [40](#)  
selectOverallPercent, [41](#)  
selectTimes, [41](#)

Sequence (PPE-accessors), [31](#)  
Sequence, PhosphoExperiment-method  
(PPE-accessors), [31](#)

Sequence<- (PPE-accessors), [31](#)  
Sequence<-, PhosphoExperiment-method  
(PPE-accessors), [31](#)

Signalomes, [43](#)  
Site (PPE-accessors), [31](#)  
Site, PhosphoExperiment-method  
(PPE-accessors), [31](#)

Site<- (PPE-accessors), [31](#)  
Site<-, PhosphoExperiment-method  
(PPE-accessors), [31](#)

siteAnnotate, [44](#)  
SPSs, [45](#)  
standardise, [46](#)  
SummarizedExperiment, [26](#), [34](#)  
SummarizedExperiment,  
(PhosphoExperiment-class), [26](#)

tImpute, [47](#)

UniprotID (PPE-accessors), [31](#)  
UniprotID, PhosphoExperiment-method  
(PPE-accessors), [31](#)

UniprotID<- (PPE-accessors), [31](#)  
UniprotID<-, PhosphoExperiment-method  
(PPE-accessors), [31](#)