

# Package ‘SpaceMarkers’

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**Type** Package

**Title** Spatial Interaction Markers

**Version** 1.3.1

**BugReports** <https://github.com/DeshpandeLab/SpaceMarkers/issues>

**URL** <https://github.com/DeshpandeLab/SpaceMarkers>

**Description** Spatial transcriptomic technologies have helped to resolve the connection between gene expression and the 2D orientation of tissues relative to each other. However, the limited single-cell resolution makes it difficult to highlight the most important molecular interactions in these tissues. SpaceMarkers, R/Bioconductor software, can help to find molecular interactions, by identifying genes associated with latent space interactions in spatial transcriptomics.

**Depends** R (>= 4.4.0)

**biocViews** SingleCell, GeneExpression, Software, Spatial,  
Transcriptomics

**Imports** matrixStats, matrixTests, rstatix, spatstat.explore,  
spatstat.geom, ape, hdf5r, nanoparquet, jsonlite, Matrix,  
qvalue, stats, utils, methods

**Suggests** data.table, devtools, dplyr, ggplot2, hrbrthemes, knitr,  
RColorBrewer, cowplot, readbitmap, rjson, rmarkdown, BiocStyle,  
testthat (>= 3.0.0), viridis, CoGAPS

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**VignetteBuilder** knitr

**Config/testthat/edition** 3

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**License** MIT + file LICENSE

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**Author** Atul Deshpande [aut, cre] (ORCID:

<<https://orcid.org/0000-0001-5144-6924>>),

Ludmila Danilova [ctb],

Dmitrijs Lvovs [ctb] (ORCID: <<https://orcid.org/0009-0003-2152-6853>>)

**Maintainer** Atul Deshpande <[adeshpande@jhu.edu](mailto:adeshpande@jhu.edu)>

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.getBTMEfeatures	<i>.getBTMEfeatures Load features BayesTME object</i>
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## Description

.getBTMEfeatures Load features BayesTME object

## Usage

.getBTMEfeatures(hf)

---

.getCogapsFeatures     *.getCogapsFeatures Load features CoGAPS object*

---

**Description**

.getCogapsFeatures Load features CoGAPS object

**Usage**

.getCogapsFeatures(obj)

---

.getSeuratFeatures     *.getSeuratFeatures Load features Seurat object*

---

**Description**

.getSeuratFeatures Load features Seurat object

**Usage**

.getSeuratFeatures(obj)

---

.inferMethod     *inferMethod Infer the method used to obtain spatial features*

---

**Description**

inferMethod Infer the method used to obtain spatial features

**Usage**

.inferMethod(spObject, method)

---

.readFormat     *readFormat Reads a format into an R object*

---

**Description**

readFormat Reads a format into an R object

**Usage**

.readFormat(path)

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curated_genes	<i>Curated Genes for example purposes</i>
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**Description**

A vector with genes selected based on previous runs of SpaceMarkers on the Visium 10x breast ductal carcinoma spatial transcriptomics dataset

**Format**

A vector with 114 pre-selected genes

**Value**

a vector of genes

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find\_genes\_of\_interest

*find\_genes\_of\_interest Identify genes associated with pattern interaction. This function identifies genes exhibiting significantly higher values of testMat in the Interaction region of the two patterns compared to regions with exclusive influence from either pattern. It uses Kruskal-Wallis test followed by posthoc analysis using Dunn's Test to identify the genes.*

---

**Description**

find\_genes\_of\_interest Identify genes associated with pattern interaction. This function identifies genes exhibiting significantly higher values of testMat in the Interaction region of the two patterns compared to regions with exclusive influence from either pattern. It uses Kruskal-Wallis test followed by posthoc analysis using Dunn's Test to identify the genes.

**Usage**

```
find_genes_of_interest(testMat, goodGenes, region, fdr.level=0.05,
  analysis=c("enrichment", "overlap"), ...)
```

**Arguments**

testMat	A matrix of counts with cells as columns and genes as rows
goodGenes	A vector of user specified genes expected to interact a priori. The default for this is NULL as the function can find these genes itself
region	A data frame of the reference pattern regions that overlap with the other patterns
fdr.level	False Discovery Rate. The default value is 0.05.
analysis	a character string that specifies the type of analysis to carry out, whether overlap or enrichment.
...	Additional arguments to be passed to lower level functions

**Value**

a list of genes exhibiting significantly higher values of testMat in the Interaction region of the two #' patterns compared to regions with exclusive influence from either pattern.

---

getInteractingGenes	<i>getInteractingGenes Calculate Interaction Regions and Associated Genes This function calculates statistically significant genes using a non-parametric Kruskal-Wallis test for genes in any one region of influence and a post hoc Dunn's test is used for analysis of genes between regions.</i>
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---

**Description**

getInteractingGenes Calculate Interaction Regions and Associated Genes This function calculates statistically significant genes using a non-parametric Kruskal-Wallis test for genes in any one region of influence and a post hoc Dunn's test is used for analysis of genes between regions.

**Usage**

```
getInteractingGenes(
  data,
  spPatterns,
  refPattern = "Pattern_1",
  mode = c("DE", "residual"),
  optParams = NULL,
  reconstruction = NULL,
  hotspots = NULL,
  analysis = c("enrichment", "overlap"),
  minOverlap = 50,
  ...
)
```

**Arguments**

data	original spatial data matrix.
spPatterns	A data frame that contains the spatial coordinates for each cell type. The column names must include 'x' and 'y' as well as a set of numbered columns named 'Pattern_1.....N'.
refPattern	a character string that specifies the pattern whose "interaction" with every other pattern we want to study. The default value is "Pattern_1".
mode	SpaceMarkers mode of operation. Possible values are "DE" (the default) or "residual".
optParams	a matrix with dimensions 2 X N, where N is the number of patterns with optimal parameters for outlier detection calculated from function getSpatialParameters(). The first row contains the kernel width sigmaOpt for each pattern, and the second row is the threshOpt (outlier threshold) for each pattern. Users can also input their preferred param values. The default value is NULL.

reconstruction	reconstruction of the data matrix from latent spaces. Required for "residual" mode.
hotspots	a vector that specifies the patterns to compare to the 'refPattern'. The default is NULL which indicates that all patterns would be compared to the 'refPattern'.
analysis	a character string that specifies the type of downstream analysis to be performed. Possible values are "enrichment" (default) and "overlap". In enrichment mode, all genes are returned, ranked by the SpaceMarkers metric. In overlap mode, only the genes which are significantly overexpressed in the interaction region are returned.
minOverlap	a number that specifies the minimum overlap between genes in two patterns to be considered for the statistical tests. The default is 50.
...	Arguments passed to methods

**Value**

a list of data frames with information about the interacting genes of the refPattern and each latent feature pattern matrix (interacting\_genes object). There is also a data frame with all of the regions of influence for any two of patterns (the hotspots object).

**See Also**

Other getIntGenes: [getPairwiseInteractingGenes\(\)](#)

**Examples**

```
library(SpaceMarkers)
#Visium data links
urls <- read.csv(system.file("extdata","visium_data.txt",
package="SpaceMarkers",mustWork = TRUE))
counts_url <- urls[["visium_url"]][1]
sp_url <- urls[["visium_url"]][2]
#Remove present Directories if any
unlink(basename(sp_url))
unlink("spatial", recursive = TRUE)
files <- list.files(".")[grepl(basename(counts_url),list.files("."))]
unlink(files)
download.file(counts_url,basename(counts_url), mode = "wb")
counts_matrix<-load10XExpr(visiumDir=".",h5filename = basename(counts_url))
#Obtaining CoGAPS Patterns
cogaps_result <- readRDS(system.file("extdata","CoGAPS_result.rds",
package="SpaceMarkers",mustWork = TRUE))
features <- intersect(rownames(counts_matrix),rownames(
slot(cogaps_result,"featureLoadings")))
barcodes <- intersect(colnames(counts_matrix),rownames(
slot(cogaps_result,"sampleFactors")))
counts_matrix <- counts_matrix[features,barcodes]
cogaps_matrix <- slot(cogaps_result,"featureLoadings")[features,]%*%
t(slot(cogaps_result,"sampleFactors")[barcodes,])
#Obtaining Spatial Coordinates
download.file(sp_url, basename(sp_url), mode = "wb")
```

```

untar(basename(sp_url))
spCoords <- load10XCoords(visiumDir = ".", version = "1.0")
rownames(spCoords) <- spCoords$barcode
spCoords <- spCoords[barcodes,]
spPatterns <- cbind(spCoords,slot(cogaps_result,
"sampleFactors")[barcodes,])
data("curated_genes")
spPatterns<-spPatterns[c("barcode","y","x","Pattern_1","Pattern_5")]
counts_matrix <- counts_matrix[curated_genes,]
cogaps_matrix <- cogaps_matrix[curated_genes, ]
data("optParams")
SpaceMarkersMode <- "DE"
ref_Pattern <- "Pattern_1"
SpaceMarkers_test <- getInteractingGenes(
  data=counts_matrix,reconstruction=NULL,
  optParams = optParams,
  spPatterns = spPatterns,
  refPattern = "Pattern_1",
  mode="DE",analysis="overlap")
#Remove present Directories if any
unlink(basename(sp_url))
unlink("spatial", recursive = TRUE)
files <- list.files(".")[grepl(basename(counts_url),list.files("."))]
unlink(files)

```

---

```
getPairwiseInteractingGenes
```

```
getPairwiseInteractingGenes
```

---

## Description

Performs pairwise analysis to find genes associated with spatial interaction between pairs of spatially varying patterns.

## Usage

```

getPairwiseInteractingGenes(
  data,
  spPatterns,
  mode = c("DE", "residual"),
  optParams = NULL,
  reconstruction = NULL,
  hotspots = NULL,
  minOverlap = 50,
  analysis = c("enrichment", "overlap"),
  patternPairs = NULL,
  ...,
  workers = NULL
)

```

**Arguments**

<code>data</code>	original spatial data matrix.
<code>spPatterns</code>	A data frame that contains the spatial coordinates for each cell type. The column names must include 'x' and 'y' as well as a set of numbered columns named 'Pattern_1.....N'.
<code>mode</code>	SpaceMarkers mode of operation. Possible values are "DE" (the default) or "residual".
<code>optParams</code>	a matrix with dimensions 2 X N, where N is the number of patterns with optimal parameters for outlier detection calculated from function <code>getSpatialParameters()</code> . The first row contains the kernel width <code>sigmaOpt</code> for each pattern, and the second row is the <code>threshOpt</code> (outlier threshold) for each pattern. Users can also input their preferred param values. The default value is NULL.
<code>reconstruction</code>	reconstruction of the data matrix from latent spaces. Required for "residual" mode.
<code>hotspots</code>	a vector that specifies the patterns to compare to the 'refPattern'. The default is NULL which indicates that all patterns would be compared to the 'refPattern'.
<code>minOverlap</code>	a number that specifies the minimum overlap between genes in two patterns to be considered for the statistical tests. The default is 50.
<code>analysis</code>	a character string that specifies the type of downstream analysis to be performed. Possible values are "enrichment" (default) and "overlap". In enrichment mode, all genes are returned, ranked by the SpaceMarkers metric. In overlap mode, only the genes which are significantly overexpressed in the interaction region are returned.
<code>patternPairs</code>	A matrix of pattern pairs to be analyzed. Default is
<code>...</code>	Arguments passed to methods
<code>workers</code>	(optional) Number of workers to be used for parallel processing.

**Details**

=====

**Value**

a list of data frames for each pattern with 1) names of the patterns (patterns object) 2) data frame with the hotspots of influence for the two patterns (the hotspots object). 3) data frame with the genes associated with the interaction between the two patterns (interacting genes object, empty if insufficient interaction).

**See Also**

Other `getIntGenes`: [getInteractingGenes\(\)](#)



## Examples

```

library(SpaceMarkers)
#Visium data links
urls <- read.csv(system.file("extdata","visium_data.txt",
package="SpaceMarkers",mustWork = TRUE))
counts_url <- urls[["visium_url"]][1]
sp_url <- urls[["visium_url"]][2]
#Remove present Directories if any
unlink(basename(sp_url))
unlink("spatial", recursive = TRUE)
files <- list.files(".") [grepl(basename(counts_url),list.files("."))]
unlink(files)
download.file(counts_url,basename(counts_url), mode = "wb")
counts_matrix<-load10XExpr(visiumDir=".",
h5filename = basename(counts_url))
#Obtaining CoGAPS Patterns
cogaps_result <- readRDS(system.file("extdata","CoGAPS_result.rds",
package="SpaceMarkers",mustWork = TRUE))
features <- intersect(rownames(counts_matrix),rownames(
slot(cogaps_result,"featureLoadings")))
barcodes <- intersect(colnames(counts_matrix),rownames(
slot(cogaps_result,"sampleFactors")))
counts_matrix <- counts_matrix[features,barcodes]
cogaps_matrix <- slot(cogaps_result,"featureLoadings")[features,]%*%
t(slot(cogaps_result,"sampleFactors")[barcodes,])
#Obtaining Spatial Coordinates
download.file(sp_url, basename(sp_url), mode = "wb")
untar(basename(sp_url))
spCoords <- load10XCoords(visiumDir = ".", version = "1.0")
rownames(spCoords) <- spCoords$barcode
spCoords <- spCoords[barcodes,]
spPatterns <- cbind(spCoords,
slot(cogaps_result,"sampleFactors")[barcodes,])
data("curated_genes")
spPatterns<-spPatterns[c("barcode","y","x","Pattern_1",
"Pattern_3","Pattern_5")]
counts_matrix <- counts_matrix[curated_genes,]
cogaps_matrix <- cogaps_matrix[curated_genes, ]
optParams <- matrix(c(6, 2, 6, 2, 6, 2), nrow = 2)
rownames(optParams) <- c("sigmaOpt","threshOpt")
colnames(optParams) <- c("Pattern_1","Pattern_3","Pattern_5")
SpaceMarkersMode <- "DE"
patternPairs <- matrix(c("Pattern_1", "Pattern_1",
"Pattern_3", "Pattern_5"), nrow=2)
SpaceMarkers_test <- getPairwiseInteractingGenes(
data=counts_matrix,reconstruction=NULL,
optParams = optParams,
spPatterns = spPatterns,
mode="DE",analysis="enrichment", patternPairs=patternPairs)
#Remove present Directories if any
unlink(basename(sp_url))
unlink("spatial", recursive = TRUE)

```

```
files <- list.files(".")[grepl(basename(counts_url),list.files("."))]  
unlink(files)
```

---

getSpatialFeatures      *getSpatialFeatures Load spatial features*

---

## Description

This function loads spatial features from a file containing spatial features

## Usage

```
getSpatialFeatures(filePath, method = NULL, featureNames = ".")
```

## Arguments

filePath	A string path to the location of the file containing the spatial features.
method	A string specifying the type of object to obtain spatial feature from. Default NULL, where the method is inferred based on object type. Other methods are: "CoGAPS", "Seurat", or "BayesTME".
featureNames	An array of strings specifying the column names corresponding to the feature names or a regex string. In the case of Seurat, all metadata columns with "_Feature" suffix are selected.

## Value

a matrix of spatial features with barcodes associated with individual coordinates

## Examples

```
library(SpaceMarkers)  
#CoGAPS data filePath  
filePath <- system.file("extdata", "CoGAPS_result.rds",  
package = "SpaceMarkers", mustWork = TRUE)  
spFeatures <- getSpatialFeatures(filePath, method = "CoGAPS")  
head(spFeatures)
```

---

getSpatialParameters    *getSpatialParameters Calculate the Optimal Parameters for Interacting Cells*

---

### Description

This function calculates the optimal width of the gaussian distribution (sigmaOpt) as well as the outlier threshold around the set of spots (thresOpt) for each pattern from a latent feature space.

### Usage

```
getSpatialParameters(spatialPatterns, ...)
```

### Arguments

spatialPatterns	A data frame that contains the spatial coordinates for each cell type. The column names must include 'x' and 'y' as well as a set of numbered columns named 'Pattern_1.....N'.
...	Arguments passed to methods

### Value

a numeric matrix of sigmaOpts - the optimal width of the gaussian distribution, and the thresOpt - outlier threshold around the set of spots for each pattern

### Examples

```
library(SpaceMarkers)
# Create test data
cells <- c()
test_num <- 500
for(i in 1:test_num){
  cells[length(cells)+1] <- paste0("cell_",i)
}
spPatterns <- data.frame(barcode = cells,
y = runif(test_num, min=0, max=test_num),
x = runif(test_num, min=0, max=test_num),
Pattern_1 = runif(test_num, min=0, max=1),
Pattern_2 = runif(test_num, min=0, max=1) )
# Call the getSpatialParameters function with the test data
optParams <- getSpatialParameters(spPatterns)
```

---

```
getSpatialParametersExternal
```

*getSpatialParametersExternal Manually obtain Optimal Parameters for Interacting cells*

---

### Description

This function calculates obtains a specified width of a distribution (`sigmaOpt`) as well as the outlier threshold around the set of spots (`thresOpt`) for each pattern from a latent feature space.

### Usage

```
getSpatialParametersExternal(
  spatialPatterns,
  visiumDir = ".",
  spatialDir = "spatial",
  pattern = "scalefactors_json.json",
  spotDiameter = NULL,
  threshold = 3
)
```

### Arguments

<code>spatialPatterns</code>	A data frame that contains the spatial coordinates for each cell type. The column names must include 'x' and 'y' as well as a set of numbered columns named 'Pattern_1.....N'.
<code>visiumDir</code>	A string path specifying the location of the 10xVisium directory
<code>spatialDir</code>	A string path specifying the location of the spatial folder containing the .json file of the spot characteristics
<code>pattern</code>	A string specifying the name of the .json file
<code>spotDiameter</code>	A numeric value specifying your desired sigma
<code>threshold</code>	A numeric value specifying your hotspot threshold

### Value

a numeric matrix of `sigmaOpts` - the optimal width of the gaussian distribution, and the `thresOpt` - outlier threshold around the set of spots for each pattern

### Examples

```
library(SpaceMarkers)
# Create test data
cells <- c()
test_num <- 500
for(i in 1:test_num){
```

```

    cells[length(cells)+1] <- paste0("cell_",i)
  }
  spPatterns <- data.frame(barcode = cells,
  y = runif(test_num, min=0, max=test_num),
  x = runif(test_num, min=0, max=test_num),
  Pattern_1 = runif(test_num, min=0, max=1),
  Pattern_2 = runif(test_num, min=0, max=1) )
  # Call the getSpatialParameters function with the test data
  optParams <- getSpatialParametersExternal(spPatterns, spotDiameter = 10)

```

---

load10XCoords

*load10XCoords Load 10x Visium Spatial Coordinates*


---

### Description

This function loads spatial coordinates for each cell from a 10X Visium spatial folder.

### Usage

```
load10XCoords(visiumDir, resolution = "lowres", version = NULL)
```

### Arguments

visiumDir	A string path to the location of the folder containing the spatial coordinates. The folder in your visiumDir must be named 'spatial' and must contain files 'scalefactors_json.json' and 'tissue_positions_list.csv.'
resolution	A string specifying which values to look for in the .json object. Can be either lowres or highres.
version	A string specifying the version of the spaceranger data.

### Value

a data frame of the spatial coordinates ( x and y) for each spot/cell

### Examples

```

library(SpaceMarkers)
#Visium data links
urls <- read.csv(system.file("extdata","visium_data.txt",
package = "SpaceMarkers",mustWork = TRUE))
sp_url <- urls[["visium_url"]][2]
# Spatial Coordinates
download.file(sp_url, basename(sp_url), mode = "wb")
untar(basename(sp_url))
spCoords <- load10XCoords(visiumDir = ".", version = "1.0")
unlink("spatial", recursive = TRUE)
unlink("Visium_Human_Breast_Cancer_spatial.tar.gz")

```

---

load10XExpr	<i>load10XExpr load 10X Visium Expression Data</i>
-------------	--

---

### Description

This loads log-transformed 10X Visium expression data from standard 10X Visium folder.

### Usage

```
load10XExpr(visiumDir = NULL, h5filename = "filtered_feature_bc_matrix.h5")
```

### Arguments

visiumDir	A string path to the h5 file with expression information.
h5filename	A string of the name of the h5 file in the directory.

### Value

A matrix of class `dgeMatrix` or `Matrix` that contains the expression info for each sample (cells) across multiple features (genes)

### Examples

```
library(SpaceMarkers)
#Visium data links
urls <- read.csv(system.file("extdata","visium_data.txt",
package = "SpaceMarkers",mustWork = TRUE))
counts_url <- urls[["visium_url"]][1]
#Remove present Directories if any
files <- list.files(".")[grepl(basename(counts_url),list.files("."))]
unlink(files)
download.file(counts_url,basename(counts_url), mode = "wb")
counts_matrix<-load10XExpr(visiumDir=".",h5filename = basename(counts_url))
files <- list.files(".")[grepl(basename(counts_url),list.files("."))]
unlink(files)
```

---

optParams	<i>Optimal paramters of 5 patterns from CoGAPS.</i>
-----------	---

---

### Description

A dataset with the optimal width of the gaussian distribution (`sigmaOpt`) and the outlier threshold around the set of spots (`thresOpt`) for each pattern obtained from CoGAPS. CoGAPS was ran on spatial transcriptomic data from a breast cancer sample.

**Format**

A data frame with 2 rows and 5 columns:

**Pattern\_1** immune cell pattern parameters

**Pattern\_2** Disp.1 parameters

**Pattern\_3** intraductal carcinoma (DCIS) parameters

**Pattern\_4** Disp.2 parameters

**Pattern\_5** invasive carcinoma lesion pattern parameters

**Value**

A matrix of optimal parameters for patterns identified by CoGAPS

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