

# Package ‘SpNeigh’

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Analysis for Transcriptomics

**Version** 1.0.0

**Description** SpNeigh provides methods for neighborhood-aware analysis of spatial transcriptomics data. It supports boundary detection, spatial weighting (centroid- and boundary-based), spatially informed differential expression using spline-based models, and spatial enrichment analysis via the Spatial Enrichment Index (SEI). Designed for compatibility with Seurat objects, SpatialExperiment objects and spatial data frames, SpNeigh enables interpretable, publication-ready analysis of spatial gene expression patterns.

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SpNeigh-package	<i>SpNeigh: Spatial Neighborhood Modeling and Differential Expression Analysis for Transcriptomics</i>
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## Description

SpNeigh provides methods for neighborhood-aware analysis of spatial transcriptomics data. It supports boundary detection, spatial weighting (centroid- and boundary-based), spatially informed differential expression using spline-based models, and spatial enrichment analysis via the Spatial Enrichment Index (SEI). Designed for compatibility with Seurat objects, SpatialExperiment objects and spatial data frames, SpNeigh enables interpretable, publication-ready analysis of spatial gene expression patterns.

## Author(s)

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## See Also

Useful links:

- <https://github.com/jinming-cheng/SpNeigh>
- Report bugs at <https://github.com/jinming-cheng/SpNeigh/issues>

---

addBoundary	<i>Add boundary outlines to a spatial ggplot</i>
-------------	--

---

## Description

Overlays spatial boundaries (from points or polygons) onto a ggplot2 object. The input can be either a data frame of boundary points or an sf object of POLYGON geometries. This function is typically used as an additive layer (+ addBoundary(...)) in conjunction with a base plot created using plotBoundary().

## Usage

```
addBoundary(  
  boundary = NULL,  
  color_boundary = "black",  
  linewidth_boundary = 1.5  
)
```

**Arguments**

`boundary` A data frame with columns `x`, `y`, and `region_id` or an `sf` object of POLYGON or LINESTRING geometries.

`color_boundary` Color for boundary lines. Default is "black".

`linewidth_boundary` Numeric. Line width for boundary outlines. Default is 1.5.

**Value**

A `ggplot2::geom_path` layer that can be added to an existing plot.

**Examples**

```
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Automatically get boundary for a cluster
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  subregion_method = "dbscan",
  eps = 120, minPts = 10
)

# Plot with boundary overlay
plotBoundary(coords) + addBoundary(boundary_points)
```

---

addBoundaryPoly	<i>Add boundary polygons or linestrings to a spatial plot</i>
-----------------	---

---

**Description**

Overlays boundary polygons or linestrings on a spatial `ggplot2` plot. This function adds an `sf` geometry layer to display complete boundary shapes for visualizing spatial clusters, rings, or enriched zones.

**Usage**

```
addBoundaryPoly(
  boundary_poly,
  color_boundary = "black",
  linewidth_boundary = 1.5
)
```

**Arguments**

- `boundary_poly` An sf object containing POLYGON or LINESTRING geometries and a `region_id` column.
- `color_boundary` Color for boundary lines. Default is "black".
- `linewidth_boundary`  
Numeric. Line width for boundary outlines. Default is 1.5.

**Value**

A `ggplot2::geom_sf` layer that can be added to an existing plot.

**Examples**

```
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  subregion_method = "dbscan",
  eps = 120, minPts = 10
)
boundary_polys <- buildBoundaryPoly(boundary_points)

# Add boundary polygons to the plot
plotBoundary(coords) +
  addBoundaryPoly(boundary_polys, color_boundary = "blue")
```

---

`boundaryPolyToPoints` *Convert boundary polygons to boundary point coordinates*

---

**Description**

Extracts the vertex coordinates (x, y) of boundary geometries from an sf object containing POLYGON or LINESTRING features. This is useful for recovering the original boundary points from smoothed or labeled polygonal regions.

**Usage**

```
boundaryPolyToPoints(boundary_poly = NULL)
```

**Arguments**

- `boundary_poly` An sf object containing only POLYGON or LINESTRING geometries. Must include a `region_id` column for labeling subregions.

**Value**

A data frame with columns `x`, `y`, and `region_id`, containing the vertex coordinates of the boundary geometries.

**Examples**

```
# Load coordinates and generate boundary
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
boundary_points <- getBoundary(data = coords, one_cluster = 2)
boundary_polys <- buildBoundaryPoly(boundary_points)

# Convert back to boundary points
boundary_pts <- boundaryPolyToPoints(boundary_polys)
head(boundary_pts)
```

---

<code>buildBoundaryPoly</code>	<i>Convert boundary points into valid polygon geometries</i>
--------------------------------	--

---

**Description**

Constructs spatial polygon objects from boundary points generated by the `getBoundary()` function. Each set of boundary points (grouped by `region_id`) is converted into a closed polygon. This function ensures that each polygon is valid and ready for downstream spatial analysis.

**Usage**

```
buildBoundaryPoly(boundary = NULL)
```

**Arguments**

<code>boundary</code>	A data frame of boundary points, typically returned by <code>getBoundary()</code> . Must contain columns <code>x</code> , <code>y</code> , and <code>region_id</code> .
-----------------------	---

**Value**

An `sf` object containing one or more valid POLYGON geometries with a `region_id` column.

**Examples**

```
# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Get boundary points for cluster 2
boundary_points <- getBoundary(data = coords, one_cluster = 2)
```

```
# Convert to polygon
boundary_polys <- buildBoundaryPoly(boundary_points)

# Plot the resulting polygons
plot(boundary_polys)
```

---

colors15_cheng	<i>Custom Color Palette</i>
----------------	-----------------------------

---

### Description

A character vector containing 15 colors.

### Usage

```
colors15_cheng
```

### Format

A character vector of length 15.

### Examples

```
plot(1:15, 1:15, pch = 16, col = colors15_cheng)
barplot(rep(1, 15), col = colors15_cheng)
```

---

computeBoundaryWeights	<i>Compute spatial weights based on distance to nearest boundary</i>
------------------------	--

---

### Description

Computes spatial weights for a subset of cells based on their Euclidean distance to the nearest boundary segment. This method supports both closed boundary polygons and open boundary edges (e.g., LINESTRINGs), and is useful for modeling proximity-based enrichment near anatomical or user-defined regions.

**Usage**

```
computeBoundaryWeights(
  data = NULL,
  cell_ids = NULL,
  boundary = NULL,
  scale = TRUE,
  method = c("inverse", "gaussian", "linear", "quadratic"),
  sigma = 0.5
)
```

**Arguments**

<code>data</code>	A data frame, Seurat object or SpatialExperiment object containing spatial coordinates. Must include columns: cell, x, and y.
<code>cell_ids</code>	A character vector of cell IDs to use for weight computation.
<code>boundary</code>	Either an sf object containing boundary geometries (POLYGON or LINESTRING), or a data frame of boundary points returned from <code>getBoundary()</code> .
<code>scale</code>	Logical. Whether to scale distances to the range [0, 1] before applying decay functions. Default is TRUE.
<code>method</code>	Decay function to convert distances to weights. One of: "inverse", "gaussian", "linear", or "quadratic".
<code>sigma</code>	Standard deviation for the Gaussian decay (used only if <code>method = "gaussian"</code> ). Default is 0.5 (recommended for scaled distances).

**Details**

Supports multiple decay methods for converting distance into weights. Optionally scales distances to the [0, 1] range before computing weights.

**Value**

A named numeric vector of weights, with names corresponding to `cell_ids`.

**Examples**

```
# Load spatial coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Get and build boundary polygons from cluster 2
boundary_points <- getBoundary(data = coords, one_cluster = 2)
boundary_polys <- buildBoundaryPoly(boundary_points)

# Compute weights to polygon boundary
cells_c2 <- subset(coords, cluster == 2)$cell
weights <- computeBoundaryWeights(
  data = coords, cell_ids = cells_c2,
```

```

    boundary = boundary_polys[1, ]
  )

# Compute weights to a specific boundary edge
boundary_edges <- splitBoundaryPolyByAnchor(boundary_polys[1, ])
weights_edge <- computeBoundaryWeights(
  data = coords, cell_ids = cells_c2,
  boundary = boundary_edges[2, ]
)

```

---

```
computeCentroidWeights
```

*Compute spatial weights based on distance to the centroid*

---

## Description

Computes spatial weights for a set of cells based on their Euclidean distance to the centroid of the selected group of cells. This is useful for modeling gradient-like spatial expression centered around a cluster or region. Supports multiple decay methods and optional distance scaling.

## Usage

```

computeCentroidWeights(
  data = NULL,
  cell_ids = NULL,
  scale = TRUE,
  method = c("inverse", "gaussian", "linear", "quadratic"),
  sigma = 0.5
)

```

## Arguments

<code>data</code>	A data frame, Seurat object or SpatialExperiment object containing spatial coordinates. Must include columns: <code>cell</code> , <code>x</code> , and <code>y</code> .
<code>cell_ids</code>	A character vector of cell IDs to use for weight computation.
<code>scale</code>	Logical. Whether to scale distances to the range [0, 1] before applying decay functions. Default is TRUE.
<code>method</code>	Decay function to convert distances to weights. One of: "inverse", "gaussian", "linear", or "quadratic".
<code>sigma</code>	Standard deviation for the Gaussian decay (used only if <code>method = "gaussian"</code> ). Default is 0.5 (recommended for scaled distances).

## Value

A named numeric vector of weights (length = number of cells in `cell_ids`). Higher weights correspond to cells closer to the centroid.

## Examples

```
# Load spatial coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Select cells from cluster 2
cells_c2 <- subset(coords, cluster == 2)$cell

# Compute centroid-based weights using default settings
weights <- computeCentroidWeights(data = coords, cell_ids = cells_c2)
head(weights)
```

---

computeSEI

*Compute Spatial Enrichment Index (SEI)*

---

## Description

Alias for [computeSpatialEnrichmentIndex](#).

## Usage

```
computeSEI(exp_mat = NULL, weights = NULL)
```

## Arguments

exp_mat	A normalized gene expression matrix with genes as rows and cells as columns. Should be of class <code>matrix</code> or <code>dgCMatrix</code> .
weights	A numeric vector of spatial weights (e.g., from <code>computeBoundaryWeights</code> or <code>computeCentroidWeights</code> ). Must be the same length as the number of columns (cells) in <code>exp_mat</code> .

## Value

A data frame containing the spatial enrichment index (SEI) results.

## Examples

```
# Load spatial coordinates and log-normalized expression
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
logNorm_expr <- readRDS(system.file("extdata", "LogNormExpr.rds",
  package = "SpNeigh"
))

# Compute spatial weights and SEI
bon_c0 <- getBoundary(data = coords, one_cluster = 0)
```

```

cells_c0 <- subset(coords, cluster == 0)$cell
weights <- computeBoundaryWeights(
  data = coords,
  cell_ids = cells_c0,
  boundary = bon_c0
)
sei_df <- computeSEI(logNorm_expr[, cells_c0], weights)
head(sei_df)

```

---

computeSpatialEnrichmentIndex

*Compute Spatial Enrichment Index (SEI) for Each Gene*

---

### Description

Calculates the spatial enrichment index (SEI) for each gene based on a user-supplied set of spatial weights. The SEI reflects the extent to which gene expression is enriched in spatially weighted regions of the tissue (e.g., near boundaries or centroids).

### Usage

```
computeSpatialEnrichmentIndex(exp_mat = NULL, weights = NULL)
```

### Arguments

exp_mat	A normalized gene expression matrix with genes as rows and cells as columns. Should be of class <code>matrix</code> or <code>dgCMatrix</code> .
weights	A numeric vector of spatial weights (e.g., from <code>computeBoundaryWeights</code> or <code>computeCentroidWeights</code> ). Must be the same length as the number of columns (cells) in <code>exp_mat</code> .

### Details

This method supports both dense (`matrix`) and sparse (`dgCMatrix`) gene expression formats, and can be applied using any distance-based weighting scheme.

### Value

A data frame with the following columns:

gene	Gene name
SEI	Spatial enrichment index: weighted mean expression across cells
mean_expr	Mean expression across all cells (unweighted)
normalized_SEI	Ratio of SEI to mean expression; used to compare genes independent of baseline expression

The result is sorted in descending order by `normalized_SEI`.

**Examples**

```

# Load spatial coordinates and log-normalized expression
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
logNorm_expr <- readRDS(system.file("extdata", "LogNormExpr.rds",
  package = "SpNeigh"
))

# Compute spatial weights and SEI
bon_c0 <- getBoundary(data = coords, one_cluster = 0)
cells_c0 <- subset(coords, cluster == 0)$cell
weights <- computeBoundaryWeights(
  data = coords,
  cell_ids = cells_c0,
  boundary = bon_c0
)
sei_df <- computeSpatialEnrichmentIndex(logNorm_expr[, cells_c0], weights)
head(sei_df)

```

---

```
computeSpatialInteractionMatrix
```

*Compute a spatial neighborhood interaction matrix using K-nearest neighbors (KNN)*

---

**Description**

Computes a spatial interaction matrix where each entry quantifies the number of neighboring cells from a given cluster (columns) that are among the k-nearest neighbors of cells in another cluster (rows). This provides a summary of spatial proximity and enrichment of neighboring clusters around each focal cluster.

**Usage**

```
computeSpatialInteractionMatrix(data = NULL, cluster_col = NULL, k = 10)
```

**Arguments**

data	A Seurat object, a SpatialExperiment object, or a data frame containing spatial coordinates.
cluster_col	Character scalar specifying the metadata column name containing cluster assignments. If NULL, a default is used depending on the input object type: <ul style="list-style-type: none"> <li>• "seurat_clusters" for Seurat objects</li> <li>• "cluster" for SpatialExperiment objects</li> <li>• "cluster" for data.frame objects</li> </ul>
k	Integer. Number of nearest neighbors to use for each cell. Default is 10.

**Details**

The matrix is built by identifying the  $k$  nearest neighbors for each cell based on spatial coordinates, and then tabulating the cluster identities of those neighbors with respect to the cluster identity of the focal cell.

**Value**

A numeric matrix where rows represent focal clusters and columns represent neighboring clusters. Each cell in the matrix indicates how frequently a neighbor cluster appears among the  $k$ -nearest neighbors of cells from the focal cluster.

**Examples**

```
# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Compute interaction matrix using all cells
interaction_matrix <- computeSpatialInteractionMatrix(coords)
head(interaction_matrix)

# Compute interaction matrix for cells inside boundaries
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
boundary_points <- subset(boundary_points, region_id == 2) # (Optional)
cells_inside <- getCellsInside(data = coords, boundary = boundary_points)
coords_sub <- subset(coords, cell %in% cells_inside$cell)
computeSpatialInteractionMatrix(coords_sub)

# Compute interaction matrix for cells inside ring region 2
ring_regions <- getRingRegion(boundary = boundary_points, dist = 100)
cells_ring <- getCellsInside(data = coords, boundary = ring_regions)
coords_sub <- subset(coords, cell %in% cells_ring$cell)
computeSpatialInteractionMatrix(coords_sub)
```

---

 extractCoords

*Extract spatial coordinates and cluster information*


---

**Description**

Extract spatial coordinates and (optionally) cluster assignments from a Seurat object, a SpatialExperiment object, or a user-supplied data frame.

**Usage**

```
extractCoords(data, cluster_col = NULL, extract_cluster = TRUE, ...)
```

**Arguments**

<code>data</code>	A Seurat object, a SpatialExperiment object, or a data frame containing spatial coordinates.
<code>cluster_col</code>	Character scalar specifying the metadata column name containing cluster assignments. If NULL, a default is used depending on the input object type: <ul style="list-style-type: none"> <li>• "seurat_clusters" for Seurat objects</li> <li>• "cluster" for SpatialExperiment objects</li> <li>• "cluster" for data.frame objects</li> </ul>
<code>extract_cluster</code>	Logical indicating whether to extract cluster information. If FALSE, only spatial coordinates and cell IDs are returned. Default is TRUE.
<code>...</code>	Additional arguments (unused).

**Details**

This is an S3 generic with methods implemented for Seurat, SpatialExperiment, and data.frame.

**Value**

A data frame containing columns `x`, `y`, and `cell`, and optionally `cluster`. For Seurat and SpatialExperiment inputs, only these standardized columns are returned. For data.frame input, additional columns present in the input may also be retained.

**Examples**

```
coords <- readRDS(system.file(
  "extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

head(extractCoords(coords))

head(extractCoords(coords, extract_cluster = FALSE))
```

---

factorNaturalOrder      *Create a factor with natural (human-friendly) ordering*

---

**Description**

Converts a character or numeric vector into a factor where the levels are ordered naturally (e.g., a1, a2, ..., a10 instead of lexicographically as a1, a10, a2, ...). This is useful for plotting or labeling grouped data where numeric substrings should follow numeric order.

**Usage**

```
factorNaturalOrder(x)
```

**Arguments**

x                    A character or numeric vector to convert to a factor with natural order.

**Value**

A factor with levels sorted in natural (human-readable) order.

**Examples**

```
# Numeric vector
factorNaturalOrder(10:1)

# Character vector with embedded numbers
factorNaturalOrder(c("a11", "a12", "a1", "a2", "a"))
```

---

getBoundary

*Extract spatial boundary points for a cluster or cell population*

---

**Description**

Identifies and returns smoothed spatial boundary points for a specified cell cluster or population using a concave hull algorithm. The function supports both single-region and multi-region boundaries. In multi-region mode, subregions can be detected automatically via DBSCAN or manually using k-means clustering. Outlier cells are first removed using a k-nearest neighbor distance filter to ensure boundary smoothness.

**Usage**

```
getBoundary(
  data = NULL,
  cluster_col = NULL,
  one_cluster = NULL,
  k = 5,
  distance_cutoff = 30,
  multi_region = TRUE,
  subregion_method = c("dbscan", "kmeans"),
  eps = 80,
  minPts = 10,
  n_subregions = 3
)
```

**Arguments**

data                A Seurat object, a SpatialExperiment object, or a data frame containing spatial coordinates.

cluster\_col        Character scalar specifying the metadata column name containing cluster assignments. If NULL, a default is used depending on the input object type:

	<ul style="list-style-type: none"> <li>• "seurat_clusters" for Seurat objects</li> <li>• "cluster" for SpatialExperiment objects</li> <li>• "cluster" for data.frame objects</li> </ul>
one_cluster	The cluster ID (numeric or character) to extract the boundary for.
k	The number of nearest neighbors to use for computing local distances. Default is 5.
distance_cutoff	A numeric threshold on the average distance to neighbors. Cells with a higher mean distance will be removed. Default is 30.
multi_region	Logical. If TRUE, identifies multiple spatial subregions within the cluster. Default is TRUE.
subregion_method	Subregion detection method when multi_region = TRUE. Choose from "dbscan" (automatic) or "kmeans" (manual). Default is "dbscan".
eps	Neighborhood radius for DBSCAN subregion detection. Only used if subregion_method = "dbscan". Default is 80.
minPts	Minimum number of points for DBSCAN core point. Only used if subregion_method = "dbscan". Default is 10.
n_subregions	Number of subregions to use if subregion_method = "kmeans". Default is 3.

### Value

A data frame containing boundary points with columns x, y, and region\_id. If multi\_region = TRUE, multiple boundaries are returned and labeled by region\_id. Otherwise, a single boundary is returned with region\_id = 1.

### Examples

```
# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
head(coords)

# Get boundary points of cluster 1
boundary_points <- getBoundary(data = coords, one_cluster = 1)
head(boundary_points)

# Number of subregions
table(boundary_points$region_id)

# Get boundary points of cluster 1 using kmeans method
# and manually specify subregion number
boundary_points <- getBoundary(
  data = coords,
  one_cluster = 1,
  subregion_method = "kmeans",
  n_subregions = 2
```

```

)
table(boundary_points$region_id)

# Get boundary points of cluster 1 without multiple regions
boundary_points <- getBoundary(
  data = coords,
  one_cluster = 1,
  multi_region = FALSE
)
table(boundary_points$region_id)

```

---

getCellsInside	<i>Identify cells located within spatial boundaries or ring regions</i>
----------------	---

---

### Description

Returns the subset of cells from the input data that fall spatially within a given boundary or ring. The boundary can be provided either as raw boundary points (from `getBoundary()`), as polygons (from `buildBoundaryPoly()`), or as ring regions (from `getRingRegion()`). The function uses spatial point-in-polygon matching via `sf::st_within`.

### Usage

```
getCellsInside(data = NULL, cluster_col = NULL, boundary = NULL)
```

### Arguments

data	A Seurat object, a SpatialExperiment object, or a data frame containing spatial coordinates.
cluster_col	Character scalar specifying the metadata column name containing cluster assignments. If NULL, a default is used depending on the input object type: <ul style="list-style-type: none"> <li>• "seurat_clusters" for Seurat objects</li> <li>• "cluster" for SpatialExperiment objects</li> <li>• "cluster" for data.frame objects</li> </ul>
boundary	An sf object (polygon or ring) or a data frame of boundary points returned by <code>getBoundary()</code> , <code>buildBoundaryPoly()</code> , or <code>getRingRegion()</code> .

### Value

A data frame (tibble) of cells located inside the given spatial region(s), with region assignment in a `region_id` column.

**Examples**

```

# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
                             package = "SpNeigh"
))
head(coords)

# Get cells inside boundaries
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)

# Select regions of interests if needed (Optional)
boundary_points <- subset(boundary_points, region_id == 2)

cells_inside <- getCellsInside(data = coords, boundary = boundary_points)
cells_inside

# Get cells inside rings
ring_regions <- getRingRegion(boundary = boundary_points, dist = 100)
cells_ring <- getCellsInside(data = coords, boundary = ring_regions)
cells_ring

```

---

getInnerBoundary	<i>Generate an inner boundary polygon by shrinking an existing boundary inward</i>
------------------	--

---

**Description**

Computes an inward-shifted (contracted) boundary by applying a negative spatial buffer to an existing boundary polygon. This function is a wrapper around `getOuterBoundary()` and is useful for defining an inner region around a spatial cluster or structure.

**Usage**

```
getInnerBoundary(boundary = NULL, dist = 50)
```

**Arguments**

boundary	A data frame of boundary points (with columns x, y, region_id) or an sf object of POLYGON geometries.
dist	A positive numeric value specifying how far inward to shrink the boundary. This is automatically converted to a negative buffer distance. Default is 50.

**Details**

Be careful: if the shrinkage distance is too large, the resulting geometry may become invalid or disappear entirely, especially for narrow or irregular shapes.

**Value**

An sf object containing the inward-shrunk polygons, one per region\_id.

**See Also**

[getOuterBoundary\(\)](#) for the outward (positive) buffer version.

**Examples**

```
# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Get boundary polygons of cluster 2
boundary_points <- getBoundary(data = coords, one_cluster = 2)
boundary_polys <- buildBoundaryPoly(boundary_points)
plot(boundary_polys)

# Generate inner boundary with 50-unit buffer for boundary region 1
inner_boundary <- getInnerBoundary(boundary_polys)
plot(inner_boundary)
```

---

getOuterBoundary	<i>Generate an outer or inner boundary polygon by buffering an existing boundary</i>
------------------	--

---

**Description**

Computes an expanded or shrunken boundary by applying a spatial buffer to an existing polygon. The input can be either boundary points (as returned by `getBoundary()`) or polygon geometries (as returned by `buildBoundaryPoly()`). This is useful for defining outer spatial neighborhoods or for shrinking boundaries inward to define inner regions.

**Usage**

```
getOuterBoundary(boundary = NULL, dist = 100)
```

**Arguments**

boundary	A data frame of boundary points (with columns x, y, region_id) or an sf object.
dist	A numeric value specifying the buffer distance in spatial units. Use positive values to expand (outer boundary), and negative values to shrink (inner boundary). Default is 100.

### Details

Be careful: when using a negative buffer distance (for inner boundaries), polygons may collapse, become invalid, or disappear entirely if the buffer width exceeds the shape's interior size.

### Value

An sf object of expanded outer boundary polygons with the same `region_id` values as the original input.

### See Also

[getInnerBoundary\(\)](#) for a simplified wrapper for inward shrinking.

### Examples

```
# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Get boundary points of cluster 2
boundary_points <- getBoundary(data = coords, one_cluster = 2)

# Build polygons from boundary points
boundary_polys <- buildBoundaryPoly(boundary_points)

# Generate outer boundaries with 100-unit buffer
outer1 <- getOuterBoundary(boundary_points, dist = 100)
outer2 <- getOuterBoundary(boundary_polys, dist = 100)

# Plot original and expanded boundaries
plot(boundary_polys)
plot(outer2, add = TRUE, border = "red")
```

---

getRingRegion

*Generate ring regions between a boundary and its outer buffer*

---

### Description

Computes spatial ring-shaped regions by subtracting the original boundary polygons from their corresponding outer buffered polygons. If the `outer_boundary` is not supplied, it will be automatically computed using `getOuterBoundary()`. This is useful for analyzing periphery-enriched cell types or gradient-based features near a boundary.

### Usage

```
getRingRegion(boundary = NULL, outer_boundary = NULL, ...)
```

**Arguments**

boundary	A data frame of boundary points (with columns x, y, region_id) or an sf object.
outer_boundary	Optional sf object containing buffered (outer) boundary polygons. If not provided, it will be automatically computed using getOuterBoundary().
...	Additional arguments passed to getOuterBoundary() if outer_boundary is not provided.

**Value**

An sf object containing the ring-shaped spatial regions generated by subtracting each inner boundary polygon from its corresponding outer boundary polygon.

**Examples**

```
# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
head(coords)

# Get boundary points of cluster 2
boundary_points <- getBoundary(data = coords, one_cluster = 2)

# Automatically compute outer boundary and get rings
ring_regions <- getRingRegion(boundary = boundary_points, dist = 100)
plot(ring_regions)

# Or provide both inner and outer boundaries explicitly
outer <- getOuterBoundary(boundary_points, dist = 100)
rings <- getRingRegion(boundary = boundary_points, outer_boundary = outer)
plot(rings)
```

---

plotBoundary

*Plot spatial cell coordinates with cluster boundaries*

---

**Description**

Plots spatial cell locations and overlays cluster or population boundaries if available. If boundary is not provided and one\_cluster is specified, the boundary will be automatically generated using the getBoundary() function. This function supports plotting either all clusters or a specific cluster using sub\_plot = TRUE. Boundaries can be overlaid as polygons to visualize spatial subregions.

**Usage**

```

plotBoundary(
  data = NULL,
  cluster_col = NULL,
  one_cluster = NULL,
  boundary = NULL,
  colors = colors15_cheng,
  point_size = 0.5,
  color_boundary = "black",
  linewidth_boundary = 1.5,
  sub_plot = FALSE,
  split_by = NULL,
  ncol = NULL,
  angle_x_label = 0,
  theme_ggplot = theme_spneigh(),
  legend_size = 2,
  ...
)

```

**Arguments**

<code>data</code>	A Seurat object, a SpatialExperiment object, or a data frame containing spatial coordinates.
<code>cluster_col</code>	Character scalar specifying the metadata column name containing cluster assignments. If NULL, a default is used depending on the input object type: <ul style="list-style-type: none"> <li>• "seurat_clusters" for Seurat objects</li> <li>• "cluster" for SpatialExperiment objects</li> <li>• "cluster" for data.frame objects</li> </ul>
<code>one_cluster</code>	The cluster ID to plot and optionally compute its boundary. Required if <code>sub_plot = TRUE</code> and <code>boundary</code> is not provided.
<code>boundary</code>	A data frame with columns <code>x</code> , <code>y</code> , and <code>region_id</code> or an <code>sf</code> object of POLYGON or LINESTRING geometries.
<code>colors</code>	A vector of cluster colors. Default uses <code>colors15_cheng</code> .
<code>point_size</code>	Numeric. Size of the points representing cells. Default is 0.5.
<code>color_boundary</code>	Color for boundary lines. Default is "black".
<code>linewidth_boundary</code>	Numeric. Line width for boundary outlines. Default is 1.5.
<code>sub_plot</code>	Logical. If TRUE, only cells from the specified <code>one_cluster</code> are plotted. If FALSE (default), all clusters are plotted.
<code>split_by</code>	Optional column name in <code>data</code> to facet the plot by (e.g., sample, condition).
<code>ncol</code>	Number of columns in the faceted plot when <code>split_by</code> is used. Passed to <code>ggplot2::facet_wrap()</code> . Default is NULL, which lets ggplot2 determine layout automatically.
<code>angle_x_label</code>	Numeric angle (in degrees) to rotate the x-axis labels. Useful for improving label readability in faceted or dense plots. Default is 0 (no rotation).

**theme\_ggplot** A ggplot2 theme object. Default is theme\_spneigh().  
**legend\_size** Numeric. Size of legend keys. Default is 2.  
**...** Additional arguments passed to [getBoundary](#) when auto-generating boundaries.

### Value

A ggplot object displaying the spatial layout of cells, with optional boundary overlays.

### Examples

```

# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
head(coords)

# Plot all cells without boundaries
plotBoundary(coords)

# Plot one cluster and its boundary
plotBoundary(coords, one_cluster = 2)

# Manually compute boundary and plot
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
plotBoundary(data = coords, boundary = boundary_points)

# plotBoundary for a SpatialExperiment object
logNorm_expr <- readRDS(system.file("extdata", "LogNormExpr.rds",
  package = "SpNeigh"
))
coords_sub <- subset(coords, cluster %in% c("0", "2"))
coords_sub <- as.matrix(coords_sub[, c("x", "y")])
metadata_sub <- subset(
  coords[, c("cell", "cluster")],
  cluster %in% c("0", "2")
)

spe <- SpatialExperiment::SpatialExperiment(
  assay = list("logcounts" = logNorm_expr),
  colData = metadata_sub,
  spatialCoords = coords_sub
)

plotBoundary(data = spe, one_cluster = 2)

# plotBoundary for a Seurat object
seu_sp <- Seurat::CreateSeuratObject(
  assay = "Spatial",
  counts = logNorm_expr,

```

```

    meta.data = metadata_sub
  )
  SeuratObject::LayerData(seu_sp,
    assay = "Spatial",
    layer = "data"
  ) <- logNorm_expr

  cents <- SeuratObject::CreateCentroids(coords_sub[, c("x", "y")])
  fov <- SeuratObject::CreateFOV(
    coords = list("centroids" = cents),
    type = c("centroids"),
    assay = "Spatial"
  )
  seu_sp[["fov"]] <- fov

  seu_sp$seurat_clusters <- seu_sp$cluster

  plotBoundary(data = seu_sp, one_cluster = 2, eps = 120)

```

---

plotCellsInside

*Plot cells located within spatial boundaries or ring regions*


---

## Description

Visualizes cells that fall within defined spatial regions (boundaries or rings), typically obtained using the `getCellsInside()` function. The cells are colored by cluster, and the function offers two plotting modes: using `geom_sf()` (with fixed 1:1 aspect ratio) or `geom_point()` (with more flexible layout).

## Usage

```

plotCellsInside(
  cells_inside = NULL,
  point_size = 0.5,
  colors = colors15_cheng,
  theme_ggplot = theme_spneigh(),
  legend_size = 2,
  fixed_aspect_ratio = TRUE
)

```

## Arguments

<code>cells_inside</code>	An <code>sf</code> object of cells returned by <code>getCellsInside()</code> . Must contain cluster and <code>region_id</code> columns.
<code>point_size</code>	Numeric. Size of the points representing cells. Default is 0.5.
<code>colors</code>	A vector of cluster colors. Default uses <code>colors15_cheng</code> .
<code>theme_ggplot</code>	A <code>ggplot2</code> theme object. Default is <code>theme_spneigh()</code> .

**legend\_size**      Numeric. Size of legend keys. Default is 2.  
**fixed\_aspect\_ratio**      Logical. If TRUE, uses `geom_sf()` to preserve spatial scale. If FALSE, uses `geom_point()` with extracted coordinates. Default is TRUE.

### Value

A ggplot object showing the cells colored by cluster within spatial regions.

### Examples

```

coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Obtain boundaries
boundary_points <- getBoundary(data = coords, one_cluster = 2)

# Select regions of interests if needed (Optional)
boundary_points <- subset(boundary_points, region_id == 2)

# Plot cells inside boundaries
cells_inside <- getCellsInside(data = coords, boundary = boundary_points)
plotCellsInside(cells_inside)

# Plot cells inside rings
ring_regions <- getRingRegion(boundary = boundary_points, dist = 100)
cells_ring <- getCellsInside(data = coords, boundary = ring_regions)
plotCellsInside(cells_ring, fixed_aspect_ratio = FALSE)

```

---

plotEdge

*Plot boundary edges or segmented boundary lines*

---

### Description

Plots boundary edges as colored LINESTRING or POLYGON outlines using ggplot2. This function is especially useful for visualizing specific edges extracted from a polygon using `splitBoundaryPolyByAnchor()`.

### Usage

```

plotEdge(
  boundary_poly = NULL,
  linewidth_boundary = 1,
  theme_ggplot = theme_spneigh(),
  ...
)

```

**Arguments**

`boundary_poly` An `sf` object containing POLYGON or LINESTRING geometries and a `region_id` column.

`linewidth_boundary` Numeric value specifying the line width of the edge. Default is 1.

`theme_ggplot` A `ggplot2` theme object. Default is `theme_spneigh()`.

... Additional arguments passed to `ggplot2::geom_sf()`.

**Value**

A `ggplot` object displaying the edge outlines colored by `region_id`.

**Examples**

```
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Build boundary polygon and plot its outline
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
boundary_polys <- buildBoundaryPoly(boundary_points)
plotEdge(boundary_poly = boundary_polys)

# Split a polygon into edge segments and plot
boundary_edges <- splitBoundaryPolyByAnchor(boundary_polys[1, ])
plotEdge(boundary_poly = boundary_edges)
```

---

plotExpression

*Plot gene expression across spatial coordinates*

---

**Description**

Visualizes expression of selected genes on a spatial plot using cell coordinates and expression matrix. Can display expression for all cells or a subset (e.g., by cluster or manually specified cells). Also supports splitting the plot using metadata columns (e.g., `cluster`) and returning either a combined plot or a list of individual `ggplot` objects.

**Usage**

```
plotExpression(
  data = NULL,
  exp_mat = NULL,
  genes = NULL,
```

```

sub_plot = FALSE,
cluster_col = NULL,
one_cluster = NULL,
sub_cells = NULL,
split_by = NULL,
ncol = NULL,
return_list = FALSE,
point_size = 0.2,
angle_x_label = 0,
shuffle = FALSE,
theme_ggplot = theme_spneigh()
)

```

### Arguments

data	A Seurat object, a SpatialExperiment object, or a data frame containing spatial coordinates.
exp_mat	A numeric gene expression matrix with genes as rows and cells as columns. Must be of class matrix or dgCMatix. If data is a Seurat object, exp_mat can be omitted and will be automatically extracted using <code>Seurat::GetAssayData()</code> from the active assay. If data is a SpatialExperiment object, exp_mat can be omitted and will be automatically extracted from <code>SingleCellExperiment::logcounts()</code> . The column names of exp_mat must match the cell identifiers used in downstream analyses.
genes	Character vector specifying gene names to be plotted. Must match row names in exp_mat.
sub_plot	Logical. If TRUE, only a subset of cells is plotted (based on one_cluster or sub_cells). Default is FALSE.
cluster_col	Character scalar specifying the metadata column name containing cluster assignments. If NULL, a default is used depending on the input object type: <ul style="list-style-type: none"> <li>• "seurat_clusters" for Seurat objects</li> <li>• "cluster" for SpatialExperiment objects</li> <li>• "cluster" for data.frame objects</li> </ul>
one_cluster	Optional. Cluster ID to subset cells if sub_plot = TRUE.
sub_cells	Optional. Vector of cell IDs to include in the plot if sub_plot = TRUE. If both one_cluster and sub_cells are provided, the intersection is used.
split_by	Optional. Column name in the metadata (from data) to facet the plots (e.g., by cluster).
ncol	Number of columns in the faceted plot when split_by is used. Passed to <code>ggplot2::facet_wrap()</code> . Default is NULL, which lets ggplot2 determine layout automatically.
return_list	Logical. If TRUE, returns a named list of individual ggplot objects per gene. If FALSE (default), plots are wrapped into a single patchwork layout.
point_size	Numeric. Size of plotted points. Default is 0.2.

angle_x_label	Numeric angle (in degrees) to rotate the x-axis labels. Useful for improving label readability in faceted or dense plots. Default is 0 (no rotation).
shuffle	Logical. If TRUE, shuffles cell order before plotting. Otherwise, cells with higher expression are plotted on top. Default is FALSE.
theme_ggplot	A ggplot2 theme object. Default is theme_spneigh().

**Value**

A patchwork object or a list of ggplot objects if return\_list = TRUE.

**Examples**

```
df <- data.frame(
  x = c(rnorm(100, 1), rnorm(100, 5)),
  y = c(rnorm(100, 1), rnorm(100, 5)),
  cell = 1:200,
  cluster = rep(1:2, each = 100)
)
exp_mat <- data.frame(
  gene1 = c(runif(100, 4, 6), runif(100, 0, 2)),
  gene2 = c(runif(100, 0, 1), runif(100, 5, 8))
)

exp_mat <- t(exp_mat)
colnames(exp_mat) <- df$cell

# set a random seed when shuffle is TRUE to reproduce the plot
set.seed(123)
plotExpression(
  data = df, exp_mat = exp_mat, shuffle = TRUE,
  genes = c("gene1", "gene2"), point_size = 2
)

plotExpression(
  data = df, exp_mat = exp_mat,
  genes = "gene1", sub_plot = TRUE,
  one_cluster = 1, point_size = 2
)
```

---

plotInteractionMatrix *Plot a heatmap of a row-scaled spatial interaction matrix*

---

**Description**

Visualizes a spatial interaction matrix using a heatmap, where rows represent focal clusters and columns represent neighbor clusters. Each row is scaled using z-scores to highlight relative enrichment patterns across neighbor types. This is useful for detecting spatial proximity patterns between cell populations.

**Usage**

```
plotInteractionMatrix(
  interaction_matrix = NULL,
  low_color = "blue",
  mid_color = "white",
  high_color = "red",
  angle_x_label = 45,
  title = "Row-Scaled Interaction Matrix (Z-scores)"
)
```

**Arguments**

<code>interaction_matrix</code>	A numeric matrix with focal clusters as rows and neighbor clusters as columns. Typically the output from <code>computeSpatialInteractionMatrix()</code> .
<code>low_color</code>	Color representing low z-score values. Default is "blue".
<code>mid_color</code>	Color representing the midpoint (z-score = 0). Default is "white".
<code>high_color</code>	Color representing high z-score values. Default is "red".
<code>angle_x_label</code>	Angle (in degrees) to rotate x-axis labels. Default is 45.
<code>title</code>	Title for the heatmap.

**Value**

A ggplot object representing the row-scaled heatmap of the interaction matrix.

**Examples**

```
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Obtain boundaries
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
# Select regions of interests if needed (Optional)
boundary_points <- subset(boundary_points, region_id == 2)

ring_regions <- getRingRegion(boundary = boundary_points, dist = 100)
cells_ring <- getCellsInside(data = coords, boundary = ring_regions)
coords_sub <- subset(coords, cell %in% cells_ring$cell)
interaction_matrix <- computeSpatialInteractionMatrix(coords_sub)

plotInteractionMatrix(interaction_matrix)
```

---

plotRegion	<i>Plot filled spatial regions inside boundaries or rings</i>
------------	---

---

### Description

Creates a ggplot of spatial regions (e.g., subregions or ring areas) using filled polygons. Each region is automatically assigned a fill color based on its `region_id`. This function is commonly used to visualize the area inside spatial boundaries or surrounding rings, such as those created by `buildBoundaryPoly()` or `getRingRegion()`.

### Usage

```
plotRegion(
  boundary_poly = NULL,
  alpha = 0.5,
  color_boundary = "black",
  linewidth_boundary = 1,
  theme_ggplot = theme_spneigh(),
  ...
)
```

### Arguments

<code>boundary_poly</code>	An sf object of POLYGON geometries containing a <code>region_id</code> column. Typically created by <code>buildBoundaryPoly()</code> or <code>getRingRegion()</code> .
<code>alpha</code>	Numeric value controlling the transparency of the filled regions. Default is 0.5.
<code>color_boundary</code>	Color of the region outlines. Default is "black".
<code>linewidth_boundary</code>	Numeric line width of the region borders. Default is 1.
<code>theme_ggplot</code>	A ggplot2 theme object. Default is <code>theme_spneigh()</code> .
<code>...</code>	Additional arguments passed to <code>ggplot2::geom_sf()</code> .

### Value

A ggplot object displaying filled spatial regions by `region_id`.

### Examples

```
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Plot filled boundary regions
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
```

```

boundary_polys <- buildBoundaryPoly(boundary_points)
plotRegion(boundary_poly = boundary_polys)

# Plot filled ring regions
ring_regions <- getRingRegion(boundary = boundary_points, dist = 100)
plotRegion(boundary_poly = ring_regions)

```

---

plotSpatialExpression *Plot average gene expression along spatial distance*

---

### Description

Visualizes how the average expression of specified genes varies along a spatial distance gradient. The spatial distance is binned, and the average expression within each bin is plotted as a heatmap.

### Usage

```

plotSpatialExpression(
  exp_mat = NULL,
  spatial_distance = NULL,
  genes = NULL,
  n_bins = 50,
  scale_method = c("none", "zscore", "minmax"),
  n_labels = 6,
  row_gap = 0.1,
  column_gap = 0,
  label_x = "Spatial distance",
  label_y = "Gene",
  theme_ggplot = theme_spneigh()
)

```

### Arguments

exp_mat	A normalized gene expression matrix (genes x cells), either a matrix or dgCMatix. Typically log-normalized counts, e.g., from a Seurat object.
spatial_distance	A named numeric vector containing the spatial distance (or weights) for each cell.
genes	Character vector specifying gene names to be plotted. Must match row names in exp_mat.
n_bins	Integer. Number of bins to divide the spatial distance into. Default is 50.
scale_method	A string indicating how to scale the average expression values across bins for each gene. Options are: "none" No scaling (default). The average expression is plotted as-is. "zscore" Standardize expression (mean 0, SD 1) per gene using scale().

	"minmax" Normalize expression to [0, 1] range per gene using scales::rescale().
n_labels	Integer. Number of axis labels to show along the distance axis. Default is 6.
row_gap	Numeric between 0 (inclusive) and 1 (exclusive). Gap between rows (genes) in the plot. Default is 0.1.
column_gap	Numeric between 0 (inclusive) and 1 (exclusive). Gap between columns (distance bins) in the plot. Default is 0.
label_x	Character. Label for the x-axis. Default is "Spatial distance".
label_y	Character. Label for the y-axis. Default is "Gene".
theme_ggplot	A ggplot2 theme object. Default is theme_spneigh().

**Value**

A ggplot2 object displaying a heatmap of binned average gene expression across spatial distances.

**Examples**

```
# Example spatial expression heatmap
set.seed(1)
exp_mat <- matrix(runif(1000), nrow = 10)
rownames(exp_mat) <- paste0("Gene", 1:10)
spatial_distance <- runif(100)
plotSpatialExpression(
  exp_mat = exp_mat,
  spatial_distance = spatial_distance,
  genes = rownames(exp_mat)[1:5]
)
```

---

plotStatsBar

*Bar plot of cluster statistics for cells inside boundaries or ring regions*

---

**Description**

Creates a bar plot to visualize the distribution of cells inside spatial regions (e.g., boundaries or rings), either as raw counts or proportions per cluster. The plot is faceted by region\_id to show statistics across multiple spatial subregions.

**Usage**

```
plotStatsBar(
  cell_stats = NULL,
  stat_column = c("proportion", "count"),
  colors = colors15_cheng,
  angle_x_label = 0,
  theme_ggplot = theme_spneigh()
)
```

**Arguments**

cell_stats	A data frame containing summarized cell statistics, typically the output from statsCellsInside(). Must include columns region_id, cluster, and the specified stat_column.
stat_column	Character. Column name in cell_stats to use for the y-axis. Options are "count" (number of cells) or "proportion" (relative fraction per region).
colors	A vector of cluster colors. Default uses colors15_cheng.
angle_x_label	Numeric angle (in degrees) to rotate the x-axis labels. Useful for improving label readability in faceted or dense plots. Default is 0 (no rotation).
theme_ggplot	A ggplot2 theme object. Default is theme_spneigh().

**Value**

A ggplot2 object showing a faceted bar plot of cell statistics per region.

**Examples**

```
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
boundary_points <- subset(boundary_points, region_id == 2) # (Optional)
cells_inside <- getCellsInside(data = coords, boundary = boundary_points)
stats_cells <- statsCellsInside(cells_inside)

plotStatsBar(stats_cells, stat_column = "proportion")
plotStatsBar(stats_cells, stat_column = "count")
```

---

plotStatsPie

*Pie chart or donut chart of cluster proportions inside spatial regions*

---

**Description**

Generates pie or donut charts to visualize the proportion of cells from different clusters within each spatial region (e.g., boundary or ring). The plot is faceted by region\_id to show the composition of each spatial subregion. Optionally, percentage labels can be added with filtering based on a minimum proportion threshold.

**Usage**

```
plotStatsPie(
  cell_stats = NULL,
  plot_donut = FALSE,
  add_labels = TRUE,
  label_cutoff = 0.01,
  label_color = "white",
  label_size = 4,
  label_nudge_x = 0.1,
  colors = colors15_cheng
)
```

**Arguments**

<code>cell_stats</code>	A data frame containing cluster statistics per region, typically the output from <code>statsCellsInside()</code> . Must include columns <code>region_id</code> , <code>cluster</code> , and <code>proportion</code> .
<code>plot_donut</code>	Logical. If TRUE, a donut chart is generated; otherwise, a pie chart. Default is FALSE.
<code>add_labels</code>	Logical. If TRUE, percentage labels are displayed inside each slice. Default is TRUE.
<code>label_cutoff</code>	Numeric. Proportional threshold below which labels are hidden (e.g., 0.01 = 1%). Default is 0.01.
<code>label_color</code>	Character. Color of the percentage labels. Default is "white".
<code>label_size</code>	Numeric. Text size for percentage labels. Default is 4.
<code>label_nudge_x</code>	Numeric. Horizontal adjustment for label positioning. Default is 0.1.
<code>colors</code>	A vector of cluster colors. Default uses <code>colors15_cheng</code> .

**Value**

A `ggplot2` object representing a faceted pie or donut chart per spatial region.

**Examples**

```
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
boundary_points <- subset(boundary_points, region_id == 2) # (Optional)
cells_inside <- getCellsInside(data = coords, boundary = boundary_points)
stats_cells <- statsCellsInside(cells_inside)

plotStatsPie(stats_cells, add_labels = FALSE)
plotStatsPie(stats_cells, label_cutoff = 0)
plotStatsPie(stats_cells, label_cutoff = 0.01)
```

```
plotStatsPie(stats_cells, plot_donut = TRUE)
```

---

plotWeights	<i>Plot spatial weights for cells on a spatial plot</i>
-------------	---

---

## Description

Visualizes spatial weights by plotting cell coordinates colored by a numeric weight value. Only cells in data that match the names in weights will be included. This is useful for visualizing spatial trends such as proximity to boundaries or centroids.

## Usage

```
plotWeights(
  data = NULL,
  weights = NULL,
  point_size = 0.2,
  theme_ggplot = theme_spneigh()
)
```

## Arguments

<code>data</code>	A data frame, Seurat object or SpatialExperiment object containing spatial coordinates. Must include columns: cell, x, and y.
<code>weights</code>	A named numeric vector of spatial weights, with cell IDs as names.
<code>point_size</code>	Numeric. Point size of the cells in the plot. Default is 0.2.
<code>theme_ggplot</code>	A ggplot2 theme object. Default is theme_spneigh().

## Value

A ggplot2 object displaying a scatter plot of cells colored by weights.

## Examples

```
# Load coordinate data
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Cells in cluster 2
cells_c2 <- subset(coords, cluster == 2)[, "cell"]

# Compute centroid weights and plot
weights_cen <- computeCentroidWeights(data = coords, cell_ids = cells_c2)
plotWeights(data = coords, weights = weights_cen)

# Compute boundary weights and plot
```

```

boundary_points <- getBoundary(data = coords, one_cluster = 2)
weights_bon <- computeBoundaryWeights(
  data = coords, cell_ids = cells_c2,
  boundary = boundary_points
)
plotWeights(data = coords, weights = weights_bon)

```

---

removeOutliers	<i>Removes spatial outlier cells based on local k-nearest neighbor distances</i>
----------------	--

---

### Description

Identifies and removes spatial outliers based on local density. For each cell, the average distance to its k nearest neighbors is computed. Cells with a mean k-NN distance greater than a specified cutoff are considered outliers and removed. This helps retain densely connected cells while filtering isolated ones.

### Usage

```
removeOutliers(coords, k = 5, distance_cutoff = 30)
```

### Arguments

coords	A data frame or matrix of cell coordinates.
k	The number of nearest neighbors to use for computing local distances. Default is 5.
distance_cutoff	A numeric threshold on the average distance to neighbors. Cells with a higher mean distance will be removed. Default is 30.

### Value

A data frame containing the filtered coordinates with an additional column:

- mean\_knn\_dist: The average distance to the k nearest neighbors for each point.

Only points with a mean\_knn\_dist less than the specified distance\_cutoff are retained.

### Examples

```

# Set seed for reproducibility
set.seed(123)

# Generate 20 clustered points
n1 <- 20
x1 <- rnorm(n1, mean = 5, sd = 0.5)
y1 <- rnorm(n1, mean = 5, sd = 0.5)

```

```
# Generate 5 outliers
n2 <- 5
x2 <- runif(n2, min = 10, max = 15)
y2 <- runif(n2, min = 10, max = 15)

# Combine clustered points and outliers
coords <- data.frame(x = c(x1, x2), y = c(y1, y2))
dim(coords)

# Plot clustered points and outlier points
plot(coords$x, coords$y,
      pch = 16,
      col = rep(c("red", "green"), times = c(20, 5))
)

# Remove outlier points with a specified knn distance cutoff
new_coords <- removeOutliers(coords, k = 5, distance_cutoff = 2)
dim(new_coords)

# Returns TRUE meaning outliers have been removed in new_coords
all((new_coords$x == x1) & (new_coords$y == y1))
```

---

runLimmaDE

*Differential expression analysis between two groups of cells using limma*

---

## Description

Performs differential expression analysis between two groups of cells using the limma linear modeling framework. Supports optional observation-level weights (e.g., spatial weights) and filters genes by minimum expression threshold across groups.

## Usage

```
runLimmaDE(
  exp_mat = NULL,
  cells_reference = NULL,
  cells_target = NULL,
  weights = NULL,
  adj_p.value = 0.05,
  min.pct = 0
)
```

## Arguments

**exp\_mat** A normalized gene expression matrix (genes x cells), either a matrix or dgCMatrix. Typically log-normalized counts, e.g., from a Seurat object.

<code>cells_reference</code>	A character vector of cell IDs to use as the reference (baseline) group.
<code>cells_target</code>	A character vector of cell IDs to use as the target (comparison) group.
<code>weights</code>	Optional numeric vector of observation-level weights. Must be named with cell IDs and match the length of <code>cells_reference</code> + <code>cells_target</code> .
<code>adj.p.value</code>	Adjusted p-value threshold for reporting differentially expressed genes. Default is 0.05.
<code>min.pct</code>	Minimum proportion of cells expressing the gene in either group (values between 0 and 1). Genes not meeting this threshold are excluded before testing. Default is 0.

### Value

A data frame with differentially expressed genes, sorted by absolute log fold change. Includes columns:

**logFC** Log2 fold change of expression (target vs. reference)

**AveExpr** Average expression across both groups

**t, P.Value, adj.P.Val, B** Statistical results from limma

**pct.reference** Proportion of reference cells expressing the gene

**pct.target** Proportion of target cells expressing the gene

**gene** Gene name (rownames from `exp_mat`)

### Examples

```
# Load coordinates and log-normalized expression data
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
logNorm_expr <- readRDS(system.file("extdata", "LogNormExpr.rds",
  package = "SpNeigh"
))

# Subset cells from cluster 0 and 2
cells_ref <- subset(coords, cluster == 0)$cell
cells_tar <- subset(coords, cluster == 2)$cell

# Run differential expression with minimum expression threshold
tab <- runLimmaDE(
  exp_mat = logNorm_expr,
  cells_reference = cells_ref,
  cells_target = cells_tar,
  min.pct = 0.25
)

head(tab[, c("gene", "logFC", "adj.P.Val", "pct.reference", "pct.target")])
```

runSpatialDE

*Differential expression along spatial distance gradients using splines***Description**

Performs spatially-aware differential expression (DE) analysis by modeling gene expression as a smooth function of a continuous spatial covariate (e.g., distance to a boundary or centroid). Natural spline basis functions are used to capture non-linear trends in expression relative to spatial distance. This method is suitable for identifying genes whose expression varies continuously across spatial structures.

**Usage**

```
runSpatialDE(
  exp_mat = NULL,
  cell_ids = NULL,
  spatial_distance = NULL,
  adj_p.value = 0.05,
  df = 3
)
```

**Arguments**

<code>exp_mat</code>	A normalized gene expression matrix (genes x cells), either a matrix or <code>dgCMatrix</code> . Typically log-normalized counts, e.g., from a Seurat object.
<code>cell_ids</code>	A character vector of cell IDs (column names of <code>exp_mat</code> ) used for DE analysis.
<code>spatial_distance</code>	A named numeric vector containing the spatial distance (or weights) for each cell. Must be the same length as <code>cell_ids</code> . Scaled distances are recommended.
<code>adj_p.value</code>	Adjusted p-value threshold for reporting differentially expressed genes. Default is 0.05.
<code>df</code>	Integer. Degrees of freedom for the spline basis. Default is 3.

**Value**

A data frame of differentially expressed genes, including:

**AveExpr**, **F**, **P.Value**, **adj.P.Val** limma differential expression outputs

**Z1**, **Z2**, **Z3** Spline coefficients (Z1 typically corresponds to linear trend)

**gene** Gene name (from `exp_mat`)

**trend** "Positive" or "Negative" trend based on the sign of Z1

The first spline coefficient (Z1) captures the main expression trend along the spatial distance.

## Examples

```
# Load example data
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
logNorm_expr <- readRDS(system.file("extdata", "LogNormExpr.rds",
  package = "SpNeigh"
))

# Identify cluster-specific cells and compute spatial weights
cells_c0 <- subset(coords, cluster == 0)$cell
bon_c0 <- getBoundary(data = coords, one_cluster = 0)
weights <- computeBoundaryWeights(
  data = coords, cell_ids = cells_c0,
  boundary = bon_c0
)

# Run spatial DE
result <- runSpatialDE(
  exp_mat = logNorm_expr, cell_ids = cells_c0,
  spatial_distance = weights
)
head(result)
```

---

safeColorPalette

*Generate a safe color palette for discrete clusters*

---

## Description

Returns a vector of visually distinct colors for plotting discrete clusters. Uses colors15\_cheng as the base palette. If the number of clusters exceeds the base palette, additional colors are generated using scales::hue\_pal().

## Usage

```
safeColorPalette(
  n_clusters = NULL,
  base_colors = colors15_cheng,
  verbose = TRUE
)
```

## Arguments

n_clusters	Number of unique clusters.
base_colors	A character vector of base colors. Default is colors15_cheng.
verbose	Logical. If TRUE, displays a message when extended colors are used. Default is TRUE.

**Value**

A character vector of colors of length `n_clusters`.

**Examples**

```
safeColorPalette(5)
safeColorPalette(20)
```

---

`splineDesign`*Generate an orthonormal spline-based design matrix*

---

**Description**

Constructs an orthonormal design matrix from a numeric covariate (e.g., spatial distance) using a natural cubic spline basis. The output matrix can be used in linear modeling to capture smooth, non-linear trends along continuous variables.

**Usage**

```
splineDesign(x, df = 3)
```

**Arguments**

<code>x</code>	A numeric vector representing a continuous covariate (e.g., distance or pseudo-time).
<code>df</code>	Integer. Degrees of freedom for the spline basis. Default is 3.

**Details**

The first column of the resulting matrix is aligned to show a positive correlation with the input vector and typically captures the main linear or monotonic trend.

**Value**

A numeric matrix with orthonormal columns (same number of rows as `x`). The columns represent smoothed trends extracted from the spline basis. The first column is directionally aligned with the input vector (`x`).

**Examples**

```
x <- seq(0, 1, length.out = 100)
Z <- splineDesign(x)
cor(Z[, 1], x) # Should be > 0

# Use Z in modeling
y <- sin(2 * pi * x) + rnorm(100, sd = 0.2)
fit <- lm(y ~ Z)
summary(fit)
```

---

`splitBoundaryPolyByAnchor`*Split a polygon boundary into two parts using anchor points*

---

### Description

This function takes an sf POLYGON object and two anchor points (or infers them) to split the polygon boundary into two LINESTRING edge segments.

### Usage

```
splitBoundaryPolyByAnchor(boundary_poly = NULL, pt1 = NULL, pt2 = NULL)
```

### Arguments

<code>boundary_poly</code>	An sf POLYGON object.
<code>pt1</code>	A numeric vector of length 2 (x, y) or NULL. If NULL, the leftmost boundary point is used.
<code>pt2</code>	A numeric vector of length 2 (x, y) or NULL. If NULL, the rightmost boundary point is used.

### Value

An sf object with two LINESTRING features and a 'region\_id' column indicating edge1 and edge2.

### Examples

```
# Load coordinates
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))
head(coords)

# Build boundary polygons from the boundary points
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  subregion_method = "dbscan",
  eps = 120, minPts = 10
)
boundary_polys <- buildBoundaryPoly(boundary_points)

# Split boundary polygon 1 into two edges using leftmost
# and rightmost anchor points
boundary_edges <- splitBoundaryPolyByAnchor(boundary_polys[1, ])
plot(boundary_edges, lwd = 2)

# Split boundary polygon 1 into two edges using two anchor points
pt1 <- c(4000, 1500)
```

```
pt2 <- c(2000, 3000)
boundary_edges <- splitBoundaryPolyByAnchor(boundary_polys[1, ],
  pt1 = pt1,
  pt2 = pt2
)
plot(boundary_edges, lwd = 2)
```

---

statsCellsInside	<i>Summarize cell counts and proportions inside spatial regions</i>
------------------	---

---

### Description

Computes the number and proportion of cells from each cluster inside boundaries or ring regions. This function is useful for downstream visualizations such as bar plots or pie charts showing the spatial composition of cell types per region.

### Usage

```
statsCellsInside(cells_inside = NULL)
```

### Arguments

`cells_inside` An sf object of cells returned by `getCellsInside()`. Must contain `cluster` and `region_id` columns.

### Value

A data frame with one row per cluster per region, containing the following columns:

- `region_id`: Identifier for each spatial region.
- `cluster`: Cluster label of the cells.
- `count`: Number of cells from the given cluster in the region.
- `proportion`: Proportion of cells from the given cluster relative to the total number of cells in the region.

### Examples

```
# Load coordinates data
coords <- readRDS(system.file("extdata", "MouseBrainCoords.rds",
  package = "SpNeigh"
))

# Get boundary and cells inside
boundary_points <- getBoundary(
  data = coords, one_cluster = 2,
  eps = 120, minPts = 10
)
```

```
# Select regions of interests if needed (Optional)
boundary_points <- subset(boundary_points, region_id == 2)

cells_inside <- getCellsInside(data = coords, boundary = boundary_points)

# Summarize cluster statistics per region
stats_cells <- statsCellsInside(cells_inside)
head(stats_cells)
```

---

theme\_spneigh

*Custom ggplot2 theme*

---

### Description

Provides a consistent and clean visual style for plots generated within this package. This theme builds on theme\_classic() and adjusts text sizes and margins for better readability in figures.

### Usage

```
theme_spneigh()
```

### Value

A ggplot2 theme object that can be added to ggplot visualizations.

### Examples

```
library(ggplot2)
ggplot(mtcars, aes(mpg, wt)) +
  geom_point() +
  theme_spneigh()
```

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