

# Package ‘BiocNeighbors’

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**Description** Implements exact and approximate methods for nearest neighbor detection, in a framework that allows them to be easily switched within Bioconductor packages or workflows. Exact searches can be performed using the k-means for k-nearest neighbors algorithm or with vantage point trees. Approximate searches can be performed using the Annoy or HNSW libraries. Searching on either Euclidean or Manhattan distances is supported. Parallelization is achieved for all methods by using BiocParallel. Functions are also provided to search for all neighbors within a given distance.

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BiocNeighbors-package *BiocNeighbors: Nearest Neighbor Detection for Bioconductor Packages*

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### Description

Implements exact and approximate methods for nearest neighbor detection, in a framework that allows them to be easily switched within Bioconductor packages or workflows. Exact searches can be performed using the k-means for k-nearest neighbors algorithm or with vantage point trees. Approximate searches can be performed using the Annoy or HNSW libraries. Searching on either Euclidean or Manhattan distances is supported. Parallelization is achieved for all methods by using BiocParallel. Functions are also provided to search for all neighbors within a given distance.

### Author(s)

**Maintainer:** Aaron Lun <infinite.monkeys.with.keyboards@gmail.com> [copyright holder]

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AnnoyParam	<i>The AnnoyParam class</i>
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### Description

A class to hold parameters for the Annoy algorithm for approximate nearest neighbor identification.

### Usage

```
AnnoyParam(
  ntrees = 50,
  search.mult = ntrees,
  distance = c("Euclidean", "Manhattan", "Cosine")
)

## S4 method for signature 'AnnoyParam'
defineBuilder(BNPARAM)
```

**Arguments**

<code>ntrees</code>	Integer scalar, number of trees to use for index generation.
<code>search.mult</code>	Numeric scalar, multiplier for the number of points to search.
<code>distance</code>	String specifying the distance metric to use. Cosine distances are implemented as Euclidean distances on L2-normalized coordinates.
<code>BNPARAM</code>	An AnnoyParam instance.

**Details**

The Approximate nearest neighbors Oh Yeah (Annoy) algorithm is based on recursive hyperplane partitions. Briefly, a tree is constructed where a random hyperplane splits the points into two subsets at each internal node. Leaf nodes are defined when the number of points in a subset falls below a threshold (close to twice the number of dimensions for the settings used here). Multiple trees are constructed in this manner, each of which is different due to the random choice of hyperplanes. For a given query point, each tree is searched to identify the subset of all points in the same leaf node as the query point. The union of these subsets across all trees is exhaustively searched to identify the actual nearest neighbors to the query.

The `ntrees` parameter controls the trade-off between accuracy and computational work. More trees provide greater accuracy at the cost of more computational work (both in terms of the indexing time and search speed in downstream functions).

The `search.mult` controls the parameter known as `search_k` in the original Annoy documentation. Specifically, `search_k` is defined as  $k * \text{search.mult}$  where  $k$  is the number of nearest neighbors to identify in downstream functions. This represents the number of points to search exhaustively and determines the run-time balance between speed and accuracy. The default `search.mult=ntrees` is based on the Annoy library defaults. Note that this parameter is not actually used in the index construction itself, and is only included here so that the output index fully parametrizes the search.

Technically, the index construction algorithm is stochastic but, for various logistical reasons, the seed is hard-coded into the C++ code. This means that the results of the Annoy neighbor searches will be fully deterministic for the same inputs, even though the theory provides no such guarantees.

**Value**

The AnnoyParam constructor returns an instance of the AnnoyParam class.

The `defineBuilder` method returns a list that can be used in `buildIndex` to construct an Annoy index.

**Author(s)**

Aaron Lun

**See Also**

[BiocNeighborParam](#), for the parent class and its available methods.

<https://github.com/spotify/annoy>, for details on the underlying algorithm.

**Examples**

```
(out <- AnnoyParam())
out[['ntrees']]

out[['ntrees']] <- 20L
```

out

---

BiocNeighborIndex	<i>The BiocNeighborIndex class</i>
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## Description

A virtual class for indexing structures of different nearest-neighbor search algorithms. Developers should define subclasses for their own [buildIndex](#) and/or [defineBuilder](#) methods.

## Details

In general, the internal structure of a BiocNeighborIndex class is arbitrary and left to the discretion of the developer. If an arbitrary structure is used, the associated methods should be written for all downstream generics like [findKNN](#), etc.

Alternatively, developers may choose to derive from the BiocNeighborGenericIndex class. This expects:

- A ptr slot containing an external pointer that refers to a BiocNeighbors::Prebuilt object (see definition in `system.file("include", "BiocNeighbors.h", package="BiocNeighbors")`).
- A names slot containing a character vector with the names of the observations, or NULL if no names are available. This is used by `subset=` in the various `find*` generics.

In this case, no additional methods are required for the downstream generics.

## Author(s)

Aaron Lun

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BiocNeighborParam	<i>The BiocNeighborParam class</i>
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## Description

A virtual class for specifying the type of nearest-neighbor search algorithm and associated parameters.

## Details

The BiocNeighborParam class is a virtual base class on which other parameter objects are built. There are currently 5 concrete subclasses in **BiocNeighbors**:

[KmknnParam](#): Exact nearest-neighbor search with the KMKNN algorithm.

[VptreeParam](#): Exact nearest-neighbor search with the tree algorithm.

[ExhaustiveParam](#): Exact nearest-neighbor search via brute-force.

[AnnoyParam](#): Approximate nearest-neighbor search with the Annoy algorithm.

[HnswParam](#): Approximate nearest-neighbor search with the HNSW algorithm.

These objects hold parameters specifying how each algorithm should be run on an arbitrary data set. See the associated documentation pages for more details.

## Methods

In the following code snippets, `x` and `object` are `BiocNeighborParam` objects.

`show(object)`: Display the class and arguments of `object`.

`bndistance(object)`: Return a string specifying the distance metric to be used for searching. This should be one of "Euclidean", "Manhattan" or "Cosine".

`x[[i]]`: Return the value of slot `i`, as used in the constructor for `x`.

`x[[i]] <- value`: Set slot `i` to the specified value.

## Author(s)

Aaron Lun

## See Also

[KmknnParam](#), [VptreeParam](#), [AnnoyParam](#), and [HnswParam](#) for constructors.

[buildIndex](#), [findKNN](#) and [queryKNN](#) for dispatch.

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buildIndex	<i>Build a nearest-neighbor index</i>
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## Description

Build indices for nearest-neighbor searching with different algorithms.

## Usage

```
buildIndex(X, transposed = FALSE, ..., BNPARAM = NULL)
```

## Arguments

<code>X</code>	A numeric matrix where rows correspond to data points and columns correspond to variables (i.e., dimensions).
<code>transposed</code>	Logical scalar indicating whether <code>X</code> is transposed, i.e., rows are variables and columns are data points.
<code>...</code>	Further arguments to be passed to individual methods.
<code>BNPARAM</code>	A <a href="#">BiocNeighborParam</a> object specifying the type of index to be constructed. If <code>NULL</code> , this defaults to a <a href="#">KmknnParam</a> object. Alternatively, this may be a list returned by <a href="#">defineBuilder</a> .

## Details

Each `buildIndex` method is expected to return an instance of a [BiocNeighborIndex](#) subclass. The structure of this subclass is arbitrary and left to the discretion of the method developer. Developers are also responsible for defining methods for their subclass in each of the relevant functions (e.g., [findKNN](#), [queryKNN](#)). The exception is if the method returns an instance of a [BiocNeighborGenericIndex](#) subclass, which can be used with the existing methods for [findKNN](#), etc. without further effort.

**Value**

A [BiocNeighborIndex](#) object can be used in [findKNN](#) and related functions as the `X=` argument. Users should assume that the index is not serializable, i.e., cannot be saved or transferred between processes.

**Author(s)**

Aaron Lun

**Examples**

```
Y <- matrix(rnorm(100000), ncol=20)
(k.out <- buildIndex(Y))
(a.out <- buildIndex(Y, BNPARAM=AnnoyParam()))
```

---

defineBuilder	<i>Define an index builder</i>
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**Description**

Define a builder object that can construct C++ indices for neighbor searches.

**Usage**

```
defineBuilder(BNPARAM)
```

**Arguments**

BNPARAM	A <a href="#">BiocNeighborParam</a> object specifying the type of index to be constructed. If NULL, this defaults to a <a href="#">KmknnParam</a> object.
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**Details**

The external pointer returned in `builder` should refer to a `BiocNeighbors::Builder` object, see the definition in `system.file("include", "BiocNeighbors.h", package="BiocNeighbors")` for details. If a developer defines a `defineBuilder` method for a search algorithm, they do not have to define a new `buildIndex` method. The existing `buildIndex` methods will automatically create an instance of the appropriate [BiocNeighborGenericIndex](#) subclass based on `class`, which can be immediately used in all generics (e.g., [findKNN](#), [queryNeighbors](#)) without further effort.

Note that the pointer returned by `defineBuilder` should *not* be used as the `ptr` in the [BiocNeighborIndex](#) subclasses. The `ptr` slot is expected to contain a pointer referring to a `BiocNeighbors::Prebuilt` object, as returned by the default [buildIndex](#). Using the pointer from `builder` will probably crash the R session.

Needless to say, users should not attempt to serialize the external pointer returned by this generic. Attempting to use a deserialized pointer in [buildIndex](#) will cause the R session to crash.

**Value**

List containing:

- `builder`, a pointer to a builder instance that can be used to construct a prebuilt index in [buildIndex](#).
- `class`, the constructor for a [BiocNeighborGenericIndex](#) subclass that accepts `ptr` and `names` arguments.

**Author(s)**

Aaron Lun

**See Also**

[defineBuilder](#), [KmknnParam-method](#), [defineBuilder](#), [VptreeParam-method](#), [defineBuilder](#), [AnnoyParam-method](#) and [defineBuilder](#), [HnswParam-method](#) for specific methods.

**Examples**

```
(out <- defineBuilder())
(out2 <- defineBuilder(AnnoyParam()))
```

---

ExhaustiveParam	<i>The ExhaustiveParam class</i>
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**Description**

A class to hold parameters for the exhaustive algorithm for exact nearest neighbor identification.

**Usage**

```
ExhaustiveParam(distance = c("Euclidean", "Manhattan", "Cosine"))

## S4 method for signature 'ExhaustiveParam'
defineBuilder(BNPARAM)
```

**Arguments**

<code>distance</code>	String specifying the distance metric to use. Cosine distances are implemented as Euclidean distances on L2-normalized coordinates.
<code>BNPARAM</code>	An ExhaustiveParam instance.

**Details**

The exhaustive search computes all pairwise distances between data and query points to identify nearest neighbors of the latter. It has quadratic complexity and is theoretically the worst-performing method; however, it has effectively no overhead from constructing or querying indexing structures, making it faster for in situations where indexing provides little benefit. This includes queries against datasets with few data points or very high dimensionality.

All that said, this algorithm is largely provided as a baseline for comparing against the other algorithms.

**Value**

The ExhaustiveParam constructor returns an instance of the ExhaustiveParam class.

The [defineBuilder](#) method returns an external pointer that can be used in [buildIndex](#) to construct an exhaustive index.

**Author(s)**

Allison Vuong

**See Also**

[BiocNeighborParam](#), for the parent class and its available methods.

**Examples**

```
(out <- ExhaustiveParam())
```

---

findDistance	<i>Distance to the k-th nearest neighbor</i>
--------------	--

---

**Description**

Find the distance to the k-th nearest neighbor for each point in a dataset.

**Usage**

```
findDistance(X, k, num.threads = 1, subset = NULL, ..., BNPARAM = NULL)
```

**Arguments**

X	A numeric matrix where rows correspond to data points and columns correspond to variables (i.e., dimensions). Alternatively, a prebuilt <a href="#">BiocNeighborIndex</a> object from <a href="#">buildIndex</a> .
k	A positive integer scalar specifying the number of nearest neighbors to retrieve. Alternatively, an integer vector of length equal to the number of points in X, specifying the number of neighbors to identify for each point. If subset is provided, this should have length equal to the length of subset. Users should wrap this vector in an <a href="#">AsIs</a> class to distinguish length-1 vectors from integer scalars. All k should be less than or equal to the number of points in X minus 1, otherwise the former will be capped at the latter with a warning.
num.threads	Integer scalar specifying the number of threads to use for the search.
subset	An integer, logical or character vector specifying the indices of points in X for which the nearest neighbors should be identified. This yields the same result as (but is more efficient than) subsetting the output matrices after computing neighbors for all points.
...	Further arguments to pass to <a href="#">buildIndex</a> when X is not an external pointer.
BNPARAM	A <a href="#">BiocNeighborParam</a> object specifying how the index should be constructed. If NULL, this defaults to a <a href="#">KmknnParam</a> . Ignored if x contains a prebuilt index.



**Details**

If multiple queries are to be performed to the same  $X$ , it may be beneficial to build the index from  $X$  with [buildIndex](#). The resulting pointer object can be supplied as  $X$  to multiple `findDistance` calls, avoiding the need to repeat index construction in each call.

**Value**

Numeric vector of length equal to the number of points in  $X$  (or subset, if provided), containing the distance from each point to its  $k$ -th nearest neighbor. This is equivalent to but more memory efficient than using [findKNN](#) and subsetting to the last distance.

**Author(s)**

Aaron Lun

**See Also**

[buildIndex](#), to build an index ahead of time.

**Examples**

```
Y <- matrix(rnorm(100000), ncol=20)
out <- findDistance(Y, k=8)
summary(out)
```

---

findKNN

*Find k-nearest neighbors*


---

**Description**

Find the  $k$ -nearest neighbors of each point in a dataset.

**Usage**

```
findKNN(
  X,
  k,
  get.index = TRUE,
  get.distance = TRUE,
  num.threads = 1,
  subset = NULL,
  ...,
  BNPARAM = NULL
)
```

## Arguments

<code>X</code>	A numeric matrix where rows correspond to data points and columns correspond to variables (i.e., dimensions). Alternatively, a prebuilt <a href="#">BiocNeighborIndex</a> object from <a href="#">buildIndex</a> .
<code>k</code>	A positive integer scalar specifying the number of nearest neighbors to retrieve. Alternatively, an integer vector of length equal to the number of points in <code>X</code> , specifying the number of neighbors to identify for each point. If <code>subset</code> is provided, this should have length equal to the length of <code>subset</code> . Users should wrap this vector in an <a href="#">AsIs</a> class to distinguish length-1 vectors from integer scalars.  All <code>k</code> should be less than or equal to the number of points in <code>X</code> minus 1, otherwise the former will be capped at the latter with a warning.
<code>get.index</code>	A logical scalar indicating whether the indices of the nearest neighbors should be recorded. Setting this to <code>FALSE</code> improves efficiency if the indices are not of interest.  Alternatively, if <code>k</code> is an integer scalar, this may be a string containing "normal" or "transposed". The former is the same as <code>TRUE</code> , while the latter returns the index matrix in transposed format.
<code>get.distance</code>	A logical scalar indicating whether distances to the nearest neighbors should be recorded. Setting this to <code>FALSE</code> improves efficiency if the distances are not of interest.  Alternatively, if <code>k</code> is an integer scalar, this may be a string containing "normal" or "transposed". The former is the same as <code>TRUE</code> , while the latter returns the distance matrix in transposed format.
<code>num.threads</code>	Integer scalar specifying the number of threads to use for the search.
<code>subset</code>	An integer, logical or character vector specifying the indices of points in <code>X</code> for which the nearest neighbors should be identified. This yields the same result as (but is more efficient than) subsetting the output matrices after computing neighbors for all points.
<code>...</code>	Further arguments to pass to <a href="#">buildIndex</a> when <code>X</code> is not an external pointer.
<code>BNPARAM</code>	A <a href="#">BiocNeighborParam</a> object specifying how the index should be constructed. If <code>NULL</code> , this defaults to a <a href="#">KmknnParam</a> . Ignored if <code>x</code> contains a prebuilt index.

## Details

If multiple queries are to be performed to the same `X`, it may be beneficial to build the index from `X` with [buildIndex](#). The resulting pointer object can be supplied as `X` to multiple `findKNN` calls, avoiding the need to repeat index construction in each call.

## Value

List containing index (if `get.index` is not `FALSE`) and distance (if `get.distance` is not `FALSE`).

- If `get.index=TRUE` or "normal" and `k` is an integer scalar, index is an integer matrix with `k` columns where each row corresponds to a point (denoted here as  $i$ ) in `X`. The  $i$ -th row contains the indices of points in `X` that are the nearest neighbors to point  $i$ , sorted by increasing distance from  $i$ .  $i$  will *not* be included in its own set of nearest neighbors.

If `get.index=FALSE` or "transposed" and `k` is an integer scalar, index is as described above but transposed, i.e., the  $i$ -th column contains the indices of neighboring points in `X`.

- If `get.distance=TRUE` or "normal" and `k` is an integer scalar, `distance` is a numeric matrix of the same dimensions as `index`. The  $i$ -th row contains the distances of neighboring points in `X` to the point  $i$ , sorted in increasing order.

If `get.distance=FALSE` or "transposed" and `k` is an integer scalar, `distance` is as described above but transposed, i.e., the  $i$ -th column contains the distances to neighboring points in `X`.

- If `get.index` is not `FALSE` and `k` is an integer vector, `index` is a list of integer vectors where each vector corresponds to a point (denoted here as  $i$ ) in `X`. The  $i$ -th vector has length `k[i]` and contains the indices of points in `X` that are the nearest neighbors to point  $i$ , sorted by increasing distance from  $i$ .
- If `get.distance` is not `FALSE` and `k` is an integer vector, `distance` is a list of numeric vectors of the same lengths as those in `index`. The  $i$ -th vector contains the distances of neighboring points in `X` to the point  $i$ , sorted in increasing order.

### Author(s)

Aaron Lun

### See Also

[buildIndex](#), to build an index ahead of time.

[findDistance](#), to efficiently obtain the distance to the  $k$ -th nearest neighbor.

### Examples

```
Y <- matrix(rnorm(100000), ncol=20)
out <- findKNN(Y, k=8)
head(out$index)
head(out$distance)
```

---

findMutualNN	<i>Find mutual nearest neighbors</i>
--------------	--------------------------------------

---

### Description

Find mutual nearest neighbors (MNN) across two data sets.

### Usage

```
findMutualNN(data1, data2, k1, k2 = k1, BNINDEX1 = NULL, BNINDEX2 = NULL, ...)
```

### Arguments

<code>data1</code>	A numeric matrix containing points in the rows and variables/dimensions in the columns.
<code>data2</code>	A numeric matrix like <code>data1</code> for another dataset with the same variables/dimensions.
<code>k1</code>	Integer scalar specifying the number of neighbors to search for in <code>data1</code> .
<code>k2</code>	Integer scalar specifying the number of neighbors to search for in <code>data2</code> .
<code>BNINDEX1</code>	A pre-built index for <code>data1</code> . If <code>NULL</code> , this is constructed from <code>data1</code> within the internal <a href="#">queryKNN</a> call.

BNINDEX2	A pre-built index for data2. If NULL, this is constructed from data2 within the internal <a href="#">queryKNN</a> call.
...	Other arguments to be passed to the underlying <a href="#">queryKNN</a> calls, e.g., BNPARAM, .

### Details

For each point in dataset 1, the set of  $k_2$  nearest points in dataset 2 is identified. For each point in dataset 2, the set of  $k_1$  nearest points in dataset 1 is similarly identified. Two points in different datasets are considered to be part of an MNN pair if each point lies in the other's set of neighbors. This concept allows us to identify matching points across datasets, which is useful for, e.g., batch correction.

Any values for the BNINDEX1 and BNINDEX2 arguments should be equal to the output of [buildIndex](#) for the respective matrices, using the algorithm specified with BNPARAM. These arguments are only provided to improve efficiency during repeated searches on the same datasets (e.g., for comparisons between all pairs). The specification of these arguments should not, generally speaking, alter the output of the function.

### Value

A list containing the integer vectors `first` and `second`, containing row indices from data1 and data2 respectively. Corresponding entries in `first` and `second` specify a MNN pair consisting of the specified rows from each matrix.

### Author(s)

Aaron Lun

### See Also

[queryKNN](#) for the underlying neighbor search code.

`fastMNN` and related functions from the **batchelor** package, from which this code was originally derived.

### Examples

```
B1 <- matrix(rnorm(10000), ncol=50) # Batch 1
B2 <- matrix(rnorm(10000), ncol=50) # Batch 2
out <- findMutualNN(B1, B2, k1=20)
head(out$first)
head(out$second)
```

---

findNeighbors

*Find neighbors within a threshold distance*

---

### Description

Find all neighbors within a threshold distance of each point of a dataset.

**Usage**

```
findNeighbors(
  X,
  threshold,
  get.index = TRUE,
  get.distance = TRUE,
  num.threads = 1,
  subset = NULL,
  ...,
  BNPARAM = NULL
)
```

**Arguments**

X	A numeric matrix where rows correspond to data points and columns correspond to variables (i.e., dimensions). Alternatively, a prebuilt <a href="#">BiocNeighborIndex</a> object from <a href="#">buildIndex</a> .
threshold	A positive numeric scalar specifying the maximum distance at which a point is considered a neighbor. Alternatively, a vector containing a different distance threshold for each point.
get.index	A logical scalar indicating whether the indices of the neighbors should be recorded.
get.distance	A logical scalar indicating whether distances to the neighbors should be recorded.
num.threads	Integer scalar specifying the number of threads to use for the search.
subset	An integer, logical or character vector specifying the indices of points in X for which the nearest neighbors should be identified. This yields the same result as (but is more efficient than) subsetting the output matrices after computing neighbors for all points.
...	Further arguments to pass to <a href="#">buildIndex</a> when X is not an external pointer.
BNPARAM	A <a href="#">BiocNeighborParam</a> object specifying how the index should be constructed. If NULL, this defaults to a <a href="#">KmknnParam</a> . Ignored if x contains a prebuilt index.

**Details**

This function identifies all points in X that within threshold of each point in X. For Euclidean distances, this is equivalent to identifying all points in a hypersphere centered around the point of interest. Not all implementations support this search mode, but we can use [KmknnParam](#) and [VptreeParam](#).

If threshold is a vector, each entry is assumed to specify a (possibly different) threshold for each point in X. If subset is also specified, each entry is assumed to specify a threshold for each point in subset. An error will be raised if threshold is a vector of incorrect length.

If multiple queries are to be performed to the same X, it may be beneficial to build the index from X with [buildIndex](#). The resulting pointer object can be supplied as X to multiple findNeighbors calls, avoiding the need to repeat index construction in each call.

**Value**

A list is returned containing:

- index, if get.index=TRUE. This is a list of integer vectors where each entry corresponds to a point (denoted here as  $i$ ) in X. The vector for  $i$  contains the set of row indices of all points in X that lie within threshold of point  $i$ . Neighbors for  $i$  are sorted by increasing distance.

- `distance`, if `get.distance=TRUE`. This is a list of numeric vectors where each entry corresponds to a point (as above) and contains the distances of the neighbors from  $i$ . Elements of each vector in `distance` match to elements of the corresponding vector in `index`.

If both `get.index=FALSE` and `get.distance=FALSE`, an integer vector is returned of length equal to the number of observations. The  $i$ -th entry contains the number of neighbors of  $i$  within threshold.

If `subset` is not `NULL`, each entry of the above vector/lists corresponds to a point in the subset, in the same order as supplied in `subset`.

### Author(s)

Aaron Lun

### See Also

[buildIndex](#), to build an index ahead of time.

### Examples

```
Y <- matrix(runif(100000), ncol=20)
out <- findNeighbors(Y, threshold=1)
summary(lengths(out$index))
```

---

HnswParam

*The HnswParam class*


---

### Description

A class to hold parameters for the HNSW algorithm for approximate nearest neighbor identification.

### Usage

```
HnswParam(
  nlinks = 16,
  ef.construction = 200,
  ef.search = 10,
  distance = c("Euclidean", "Manhattan", "Cosine")
)
```

```
## S4 method for signature 'HnswParam'
defineBuilder(BNPARAM)
```

### Arguments

<code>nlinks</code>	Integer scalar, number of bi-directional links per element for index generation.
<code>ef.construction</code>	Integer scalar, size of the dynamic list for index generation.
<code>ef.search</code>	Integer scalar, size of the dynamic list for neighbor searching.
<code>distance</code>	String specifying the distance metric to use. Cosine distances are implemented as Euclidean distances on L2-normalized coordinates.
<code>BNPARAM</code>	A HsnwParam instance.

## Details

In the HNSW algorithm (Malkov and Yashunin, 2016), each point is a node in a “navigable small world” graph. The nearest neighbor search proceeds by starting at a node and walking through the graph to obtain closer neighbors to a given query point. Navigable small world graphs are used to maintain connectivity across the data set by creating links between distant points. This speeds up the search by ensuring that the algorithm does not need to take many small steps to move from one cluster to another. The HNSW algorithm extends this idea by using a hierarchy of such graphs containing links of different lengths, which avoids wasting time on small steps in the early stages of the search where the current node position is far from the query.

Larger values of `nlinks` improve accuracy at the expense of speed and memory usage. Larger values of `ef.construction` improve index quality at the expense of indexing time. The value of `ef.search` controls the accuracy of the neighbor search at run time, where larger values improve accuracy at the expense of a slower search.

Technically, the index construction algorithm is stochastic but, for various logistical reasons, the seed is hard-coded into the C++ code. This means that the results of the HNSW neighbor searches will be fully deterministic for the same inputs, even though the theory provides no such guarantees.

## Value

The `HnswParam` constructor returns an instance of the `HnswParam` class.

The `defineBuilder` method returns an external pointer that can be used in `buildIndex` to construct a HNSW index.

## Author(s)

Aaron Lun

## See Also

[BiocNeighborParam](#), for the parent class and its available methods.

<https://github.com/nmslib/hnswlib>, for details on the underlying algorithm.

## Examples

```
(out <- HnswParam())
out[['nlinks']]

out[['nlinks']] <- 20L
out
```

---

KmknnParam

*The KmknnParam class*


---

## Description

A class to hold parameters for the k-means k-nearest-neighbors (KMKN) algorithm for exact nearest neighbor identification.

## Usage

```
KmknnParam(..., distance = c("Euclidean", "Manhattan", "Cosine"))

## S4 method for signature 'KmknnParam'
defineBuilder(BNPARAM)
```

## Arguments

...	Further arguments, ignored.
distance	String specifying the distance metric to use. Cosine distances are implemented as Euclidean distances on L2-normalized coordinates.
BNPARAM	A KmknnParam instance.

## Details

In the KMKNN algorithm (Wang, 2012), k-means clustering is first applied to the data points using the square root of the number of points as the number of cluster centers. The cluster assignment and distance to the assigned cluster center for each point represent the KMKNN indexing information. This speeds up the nearest neighbor search by exploiting the triangle inequality between cluster centers, the query point and each point in the cluster to narrow the search space. The advantage of the KMKNN approach is its simplicity and minimal overhead, resulting in performance improvements over conventional tree-based methods for high-dimensional data where most points need to be searched anyway. It is also trivially extended to find all neighbors within a threshold distance from a query point.

Note that KMKNN operates much more naturally with Euclidean distances. Computational efficiency may not be optimal when using it with other choices of distance, though the results will still be exact.

## Value

The KmknnParam constructor returns an instance of the KmknnParam class.

The `defineBuilder` method returns a list that can be used in `buildIndex` to construct a KMKNN index.

## Author(s)

Aaron Lun, using code from the **cydar** package.

## References

Wang X (2012). A fast exact k-nearest neighbors algorithm for high dimensional search using k-means clustering and triangle inequality. *Proc Int Jt Conf Neural Netw*, 43, 6:2351-2358.

## See Also

[BiocNeighborParam](#), for the parent class and its available methods.

## Examples

```
(out <- KmknnParam(iter.max=100))
```



---

queryDistance	<i>Distance to the k-th nearest neighbor to query points</i>
---------------	--

---

## Description

Query a reference dataset to determine the distance to the k-th nearest neighbor of each point in a query dataset.

## Usage

```
queryDistance(
  X,
  query,
  k,
  num.threads = 1,
  subset = NULL,
  transposed = FALSE,
  ...,
  BNPARAM = NULL
)
```

## Arguments

X	The reference dataset to be queried. This should be a numeric matrix where rows correspond to reference points and columns correspond to variables (i.e., dimensions). Alternatively, a prebuilt <a href="#">BiocNeighborIndex</a> object from <a href="#">buildIndex</a> .
query	A numeric matrix of query points, containing the same number of columns as X.
k	A positive integer scalar specifying the number of nearest neighbors to retrieve. Alternatively, an integer vector of length equal to the number of points in query, specifying the number of neighbors to identify for each point. If subset is provided, this should have length equal to the length of subset. Users should wrap this vector in an <a href="#">AsIs</a> class to distinguish length-1 vectors from integer scalars.  All k should be less than or equal to the number of points in X, otherwise the former will be capped at the latter with a warning.
num.threads	Integer scalar specifying the number of threads to use for the search.
subset	An integer, logical or character vector indicating the rows of query (or columns, if transposed=TRUE) for which the nearest neighbors should be identified.
transposed	A logical scalar indicating whether X and query are transposed, in which case both matrices are assumed to contain dimensions in the rows and data points in the columns.
...	Further arguments to pass to <a href="#">buildIndex</a> when X is not an external pointer.
BNPARAM	A <a href="#">BiocNeighborParam</a> object specifying how the index should be constructed. If NULL, this defaults to a <a href="#">KmknnParam</a> . Ignored if x contains a prebuilt index.

## Details

If multiple queries are to be performed to the same X, it may be beneficial to build the index from X with [buildIndex](#). The resulting pointer object can be supplied as X to multiple queryKNN calls, avoiding the need to repeat index construction in each call.

**Value**

Numeric vector of length equal to the number of points in query (or subset, if provided), containing the distance from each point to its k-th nearest neighbor. This is equivalent to but more memory efficient than using [queryKNN](#) and subsetting to the last distance.

**Author(s)**

Aaron Lun

**See Also**

[buildIndex](#), to build an index ahead of time.

**Examples**

```
Y <- matrix(rnorm(100000), ncol=20)
Z <- matrix(rnorm(20000), ncol=20)
out <- queryDistance(Y, query=Z, k=5)
head(out)
```

---

queryKNN

---

*Query k-nearest neighbors*


---

**Description**

Query a reference dataset for the k-nearest neighbors of each point in a query dataset.

**Usage**

```
queryKNN(
  X,
  query,
  k,
  get.index = TRUE,
  get.distance = TRUE,
  num.threads = 1,
  subset = NULL,
  transposed = FALSE,
  ...,
  BNPARAM = NULL
)
```

**Arguments**

X	The reference dataset to be queried. This should be a numeric matrix where rows correspond to reference points and columns correspond to variables (i.e., dimensions). Alternatively, a prebuilt <a href="#">BiocNeighborIndex</a> object from <a href="#">buildIndex</a> .
query	A numeric matrix of query points, containing the same number of columns as X.

k	<p>A positive integer scalar specifying the number of nearest neighbors to retrieve. Alternatively, an integer vector of length equal to the number of points in query, specifying the number of neighbors to identify for each point. If subset is provided, this should have length equal to the length of subset. Users should wrap this vector in an <a href="#">AsIs</a> class to distinguish length-1 vectors from integer scalars.</p> <p>All k should be less than or equal to the number of points in X, otherwise the former will be capped at the latter with a warning.</p>
get.index	<p>A logical scalar indicating whether the indices of the nearest neighbors should be recorded. Setting this to FALSE improves efficiency if the indices are not of interest.</p> <p>Alternatively, if k is an integer scalar, this may be a string containing "normal" or "transposed". The former is the same as TRUE, while the latter returns the index matrix in transposed format.</p>
get.distance	<p>A logical scalar indicating whether distances to the nearest neighbors should be recorded. Setting this to FALSE improves efficiency if the distances are not of interest.</p> <p>Alternatively, if k is an integer scalar, this may be a string containing "normal" or "transposed". The former is the same as TRUE, while the latter returns the distance matrix in transposed format.</p>
num.threads	Integer scalar specifying the number of threads to use for the search.
subset	An integer, logical or character vector indicating the rows of query (or columns, if transposed=TRUE) for which the nearest neighbors should be identified.
transposed	A logical scalar indicating whether X and query are transposed, in which case both matrices are assumed to contain dimensions in the rows and data points in the columns.
...	Further arguments to pass to <a href="#">buildIndex</a> when X is not an external pointer.
BNPARAM	A <a href="#">BiocNeighborParam</a> object specifying how the index should be constructed. If NULL, this defaults to a <a href="#">KmknnParam</a> . Ignored if x contains a prebuilt index.

## Details

If multiple queries are to be performed to the same X, it may be beneficial to build the index from X with [buildIndex](#). The resulting pointer object can be supplied as X to multiple queryKNN calls, avoiding the need to repeat index construction in each call.

## Value

List containing index (if get.index is not FALSE) and distance (if get.distance is not FALSE).

- If get.index=TRUE or "normal" and k is an integer scalar, index is an integer matrix with k columns where each row corresponds to a point (denoted here as  $i$ ) in query. The  $i$ -th row contains the indices of points in X that are the nearest neighbors to point  $i$ , sorted by increasing distance from  $i$ .  
If get.index=FALSE or "transposed" and k is an integer scalar, index is as described above but transposed, i.e., the  $i$ -th column contains the indices of neighboring points in X.
- If get.distance=TRUE or "normal" and k is an integer scalar, distance is a numeric matrix of the same dimensions as index. The  $i$ -th row contains the distances of neighboring points in X to the point  $i$ , sorted in increasing order.  
If get.distance=FALSE or "transposed" and k is an integer scalar, distance is as described above but transposed, i.e., the  $i$ -th column contains the distances to neighboring points in X.

- If `get.index` is not `FALSE` and `k` is an integer vector, `index` is a list of integer vectors where each vector corresponds to a point (denoted here as  $i$ ) in  $X$ . The  $i$ -th vector has length `k[i]` and contains the indices of points in  $X$  that are the nearest neighbors to point  $i$ , sorted by increasing distance from  $i$ .
- If `get.distance` is not `FALSE` and `k` is an integer vector, `distance` is a list of numeric vectors of the same lengths as those in `index`. The  $i$ -th vector contains the distances of neighboring points in  $X$  to the point  $i$ , sorted in increasing order.

### Author(s)

Aaron Lun

### See Also

[buildIndex](#), to build an index ahead of time.

[queryDistance](#), to obtain the distance from each query point to its  $k$ -th nearest neighbor.

### Examples

```
Y <- matrix(rnorm(100000), ncol=20)
Z <- matrix(rnorm(20000), ncol=20)
out <- queryKNN(Y, query=Z, k=5)
head(out$index)
head(out$distance)
```

---

queryNeighbors

*Query neighbors within a threshold distance*

---

### Description

Find all points in a reference dataset that lie within a threshold distance of each point in a query dataset.

### Usage

```
queryNeighbors(
  X,
  query,
  threshold,
  get.index = TRUE,
  get.distance = TRUE,
  num.threads = 1,
  subset = NULL,
  transposed = FALSE,
  ...,
  BNPARAM = NULL
)
```

**Arguments**

<code>X</code>	The reference dataset to be queried. This should be a numeric matrix where rows correspond to reference points and columns correspond to variables (i.e., dimensions). Alternatively, a prebuilt <a href="#">BiocNeighborIndex</a> object from <a href="#">buildIndex</a> .
<code>query</code>	A numeric matrix of query points, containing the same number of columns as <code>X</code> .
<code>threshold</code>	A positive numeric scalar specifying the maximum distance at which a point is considered a neighbor. Alternatively, a vector containing a different distance threshold for each query point.
<code>get.index</code>	A logical scalar indicating whether the indices of the neighbors should be recorded.
<code>get.distance</code>	A logical scalar indicating whether distances to the neighbors should be recorded.
<code>num.threads</code>	Integer scalar specifying the number of threads to use for the search.
<code>subset</code>	An integer, logical or character vector indicating the rows of query (or columns, if <code>transposed=TRUE</code> ) for which the nearest neighbors should be identified.
<code>transposed</code>	A logical scalar indicating whether <code>X</code> and <code>query</code> are transposed, in which case both matrices are assumed to contain dimensions in the rows and data points in the columns.
<code>...</code>	Further arguments to pass to <a href="#">buildIndex</a> when <code>X</code> is not an external pointer.
<code>BNPARAM</code>	A <a href="#">BiocNeighborParam</a> object specifying how the index should be constructed. If <code>NULL</code> , this defaults to a <a href="#">KmknnParam</a> . Ignored if <code>x</code> contains a prebuilt index.

**Details**

This function identifies all points in `X` that within `threshold` of each point in `query`. For Euclidean distances, this is equivalent to identifying all points in a hypersphere centered around the point of interest. Not all implementations support this search mode, but we can use [KmknnParam](#) and [VptreeParam](#).

If `threshold` is a vector, each entry is assumed to specify a (possibly different) threshold for each point in `query`. If `subset` is also specified, each entry is assumed to specify a threshold for each point in `subset`. An error will be raised if `threshold` is a vector of incorrect length.

If multiple queries are to be performed to the same `X`, it may be beneficial to build the index from `X` with [buildIndex](#). The resulting pointer object can be supplied as `X` to multiple `queryKNN` calls, avoiding the need to repeat index construction in each call.

**Value**

A list is returned containing:

- `index`, if `get.index=TRUE`. This is a list of integer vectors where each entry corresponds to a point (denoted here as  $i$ ) in `query`. The vector for  $i$  contains the set of row indices of all points in `X` that lie within `threshold` of point  $i$ . Neighbors for  $i$  are sorted by increasing distance from  $i$ .
- `distance`, if `get.distance=TRUE`. This is a list of numeric vectors where each entry corresponds to a point (as above) and contains the distances of the neighbors from  $i$ . Elements of each vector in `distance` match to elements of the corresponding vector in `index`.

If both `get.index=FALSE` and `get.distance=FALSE`, an integer vector is returned of length equal to the number of observations. The  $i$ -th entry contains the number of neighbors of  $i$  within `threshold`.

If `subset` is not `NULL`, each entry of the above vector/lists refers to a point in the `subset`, in the same order as supplied in `subset`.

**Author(s)**

Aaron Lun

**See Also**[buildIndex](#), to build an index ahead of time.**Examples**

```
Y <- matrix(rnorm(100000), ncol=20)
Z <- matrix(rnorm(20000), ncol=20)
out <- queryNeighbors(Y, query=Z, threshold=3)
summary(lengths(out$index))
```

VptreeParam

*The VptreeParam class***Description**

A class to hold parameters for the vantage point (VP) tree algorithm for exact nearest neighbor identification.

**Usage**

```
VptreeParam(distance = c("Euclidean", "Manhattan", "Cosine"))

## S4 method for signature 'VptreeParam'
defineBuilder(BNPARAM)
```

**Arguments**

distance	String specifying the distance metric to use. Cosine distances are implemented as Euclidean distances on L2-normalized coordinates.
BNPARAM	A VptreeParam instance.

**Details**

In a VP tree (Yianilos, 1993), each node contains a subset of points that is split into two further partitions. The split is determined by picking an arbitrary point inside that subset as the node center, computing the distance to all other points from the center, and taking the median as the “radius”. The left child of this node contains all points within the median distance from the radius, while the right child contains the remaining points. This is applied recursively until all points resolve to individual nodes. The nearest neighbor search traverses the tree and exploits the triangle inequality between query points, node centers and thresholds to narrow the search space.

VP trees are often faster than more conventional KD-trees or ball trees as the former uses the points themselves as the nodes of the tree, avoiding the need to create many intermediate nodes and reducing the total number of distance calculations. Like KMKNN, it is also trivially extended to find all neighbors within a threshold distance from a query point.

**Value**

The VptreeParam constructor returns an instance of the VptreeParam class.

The `defineBuilder` method returns an external pointer that can be used in `buildIndex` to construct a VP tree index.

**Author(s)**

Aaron Lun

**References**

Yianilos PN (1993). Data structures and algorithms for nearest neighbor search in general metric spaces. *Proceedings of the Fourth Annual ACM-SIAM Symposium on Discrete Algorithms*, 311-321.

**See Also**

[BiocNeighborParam](#), for the parent class and its available methods.

<https://stevehanov.ca/blog/index.php?id=130>, for a description of the algorithm.

**Examples**

```
(out <- VptreeParam())
```

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