

Package ‘MsExperiment’

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Title Infrastructure for Mass Spectrometry Experiments

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Description Infrastructure to store and manage all aspects related to a complete proteomics or metabolomics mass spectrometry (MS) experiment. The MsExperiment package provides light-weight and flexible containers for MS experiments building on the new MS infrastructure provided by the Spectra, QFeatures and related packages. Along with raw data representations, links to original data files and sample annotations, additional metadata or annotations can also be stored within the MsExperiment container. To guarantee maximum flexibility only minimal constraints are put on the type and content of the data within the containers.

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dbWriteSampleData	<i>Write sample annotations to a MsBackendSql SQL database</i>
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Description

For MsExperiment objects with their MS data represented by a Spectra object that use a MsBackendSql backend, its sample annotations can be written to the backend's SQL database with the dbWriteSampleData() function. The content of the object's [sampleData()] (as well as eventually present *linking* between samples and spectra) will be stored in two separate database tables *sample_data* and *sample_to_msms_spectrum* in the same database.

This requires that the MS data of the experiment is *represented* by a MsBackendSql backend (see help on the createMsBackendSqlDatabase or the *MsBackendSql* package vignette for more information on how to create or use such SQL databases).

Usage

```
dbWriteSampleData(x)
```

Arguments

x MsExperiment from which sample annotations should be written to the database.

Author(s)

Johannes Rainer, Laurent Gatto

Examples

```

library(MsExperiment)

## Create a MsBackendSql database from two mzML files.
## Connect first to an empty SQLite database (for the example we create
## a database in a temporary file).
library(RSQLite)
sqlite_db <- tempfile()
con <- dbConnect(SQLite(), sqlite_db)

## Define the files from which we import the data
fls <- dir(system.file("sciex", package = "msdata"), pattern = "mzML",
  full.names = TRUE)

## Create a MsBackendSql database containing the full MS data
library(MsBackendSql)
createMsBackendSqlDatabase(con, fls)

## Note: alternatively it would be possible to first import the MS data
## to a `Spectra` object and then change the backend to a `MsBackendSql`
## using the `setBackend` function.

## Load this data as a `Spectra` object (using a `MsBackendOfflineSql`
## backend)
library(Spectra)
sps <- Spectra(sqlite_db, source = MsBackendOfflineSql(),
  drv = SQLite())
sps

## Define sample annotations for the two data files. Adding one column
## `file` that contains the file name of the data files.
df <- data.frame(sample = c("QC1", "QC2"), file = basename(fls))

## Add a spectra variable `file` to the `Spectra` object with
## the raw data files' file names to simplify the linking between
## samples and spectra performed later.
sps$file <- basename(dataOrigin(sps))

## Create a MsExperiment with the spectra and sample data.
mse <- MsExperiment(spectra = sps, sampleData = df)

## Establish the link (mapping) between samples and spectra
## using the column `file` in the `sampleData` and the spectra
## variable `file`.
mse <- linkSampleData(mse, with = "sampleData.file = spectra.file")
mse

## Write sample data (and the sample to spectra mapping) to the
## *MsBackendSql* database.
dbWriteSampleData(mse)

## List the tables in the database
dbListTables(con)

## Sample data was thus stored to the database.
dbGetQuery(con, "select * from sample_data;")

```

Description

The MsExperiment class allows the storage and management of all aspects related to a complete proteomics or metabolomics mass spectrometry experiment. This includes experimental design (i.e. a table with samples), raw mass spectrometry data as spectra and chromatograms, quantitative features, and identification data or any other relevant data files.

For details, see <https://rformassspectrometry.github.io/MsExperiment>

This package is part of the RforMassSpectrometry initiative: <https://www.rformassspectrometry.org/>

Usage

```
experimentFiles(object)

experimentFiles(object) <- value

sampleData(object)

sampleData(object) <- value

qdata(object)

qdata(object) <- value

spectraSampleIndex(x, duplicates = c("first", "keep"))

MsExperiment(
  experimentFiles = MsExperimentFiles(),
  otherData = List(),
  qdata = NULL,
  sampleData = DataFrame(),
  spectra = NULL
)

## S4 method for signature 'MsExperiment'
show(object)

## S4 method for signature 'MsExperiment'
length(x)

## S4 method for signature 'MsExperiment'
spectra(object)

## S4 replacement method for signature 'MsExperiment'
spectra(object) <- value

otherData(object)
```

```

otherData(object) <- value

linkSampleData(
  object,
  with = character(),
  sampleIndex = seq_len(nrow(sampleData(object))),
  withIndex = integer(),
  subsetBy = 1L
)

## S4 method for signature 'MsExperiment,ANY,ANY,ANY'
x[i, j, ..., drop = FALSE]

## S4 method for signature 'MsExperiment,function'
filterSpectra(object, filter, ...)

```

Arguments

object	An instance of class MsExperiment.
value	An object of the appropriate class for the slot to be populated.
x	an MsExperiment.
duplicates	for spectraSampleIndex(): character(1) defining the type of result returned by spectraSampleIndex(). With duplicates = "first" an integer vector is returned with the first match while duplicates = "keep" returns a list of integer with the index of all matches.
experimentFiles	MsExperimentFiles() defining (external) files to data or annotation.
otherData	List with arbitrary additional (<i>other</i>) information or data.
qdata	QFeatures or SummarizedExperiment with the quantification data.
sampleData	DataFrame (or data.frame) with information on individual samples of the experiment.
spectra	Spectra::Spectra() object with the MS spectra data of the experiment.
with	for linkSampleData(): character(1) defining the data to which samples should be linked. See section <i>Linking sample data to other experimental data</i> for details.
sampleIndex	for linkSampleData(): integer with the indices of the samples in sampleData(object) that should be linked.
withIndex	for linkSampleData(): integer with the indices of the elements in with to which the samples (specified by sampleIndex) should be linked to.
subsetBy	for linkSampleData(): optional integer(1) defining the dimension on which the subsetting will occur on the linked data. Defaults to subsetBy = 1L thus subsetting will happen on the first dimension (rows or elements).
i	for [: an integer, character or logical referring to the indices or names (rowname of sampleData) of the samples to subset.
j	for [: not supported.
...	optional additional parameters. For filterSpectra(): parameters to be passed to the filter function (parameter filter).
drop	for [: ignored.

`filter` for `filterSpectra()`: any filter function supported by `Spectra::Spectra()` to filter the spectra object (such as `filterRt` or `filterMsLevel`). Parameters for the filter function can be passed through . . .

Value

See help of the individual functions.

Slots

`experimentFiles` An instance of class `MsExperimentFiles` or `NULL`.

`spectra` An instance of class `Spectra` or `NULL`.

`qdata` An instance of class `QFeatures`, `SummarizedExperiment` or `NULL`.

`otherData` A `List` to store any additional data objects.

`sampleData` A `DataFrame` documenting the experimental design.

`sampleDataLinks` A `List` with link definitions between samples and data elements. Should not be directly accessed or modified by the user.

`metadata` A `list` to store additional metadata.

General information

An experiment is typically composed of several items

- Description and information (covariates etc) of each sample from the experiment. These are stored in the `sampleData` slot as a `DataFrame`, each row describing a sample with columns containing all relevant information on that sample.
- Files to data or annotations. These are stored in the `@experimentFiles` slot as an instance of class `MsExperimentFiles`.
- General metadata about the experiment, stored as a `list` in the `@metadata` slot.
- Mass spectrometry data. Spectra and their metadata are stored as an `[Spectra::Spectra()]` object in the `spectra` slot. Chromatographic data is not yet supported but will be stored as a `Chromatograms()` object in the `@chromatograms` slot.
- Quantification data is stored as `QFeatures` or `SummarizedExperiment` objects in the `@qdata` slot and can be accessed or replaced with the `qdata()` or `qdata<-` functions, respectively.
- Any additional data, be it other spectra data, or proteomics identification data (i.e peptide-spectrum matches defined as `PSM` objects) can be added as elements to the `list` stored in the `otherData` slot.

The *length* of a `MsExperiment` is defined by the number of samples (i.e. the number of rows of the object's `sampleData`). A `MsExperiment` with two samples will thus have a length of two, independently of the number of files or length of raw data in the object. This also defines the subsetting of the object using the `[]` function which will always subset by samples. See the section for filtering and subsetting below for more information.

`MsExperiment` objects can be created using the `MsExperiment()` function providing the data with the parameters listed below. If the `Spectra::Spectra()` object provided with the `spectra` param uses a `MsBackendSql` backend, sample data could be retrieved from the associated `SQL` database (see section *Using MsExperiment with MsBackendSql* in the vignette for details). Alternatively, it is also possible to subsequently add data and information to an existing `MsExperiment`. Finally, with the `readMsExperiment()` function it is possible to create a `MsExperiment` by importing `MS` spectra data directly from provided data files. See examples below or the package vignette for more information.

Accessing data

Data from an MsExperiment object can be accessed with the dedicated accessor functions:

- `experimentFiles()`, `experimentFiles<-`: gets or sets experiment files.
- `length()`: get the *length* of the object which represents the number of samples available in the object's `sampleData`.
- `metadata()`, `metadata<-`: gets or sets the object's metadata.
- `sampleData()`, `sampleData<-`: gets or sets the object's sample data (i.e. a `DataFrame` containing sample descriptions).
- `spectra()`, `spectra<-`: gets or sets spectra data. `spectra()` returns a `Spectra::Spectra()` object, `spectra<-` takes a `Spectra` data as input and returns the updated `MsExperiment`.
- `spectraSampleIndex()`: depending on parameter `duplicates` it returns either an integer (`duplicates = "first"`, the default) or a list (`duplicates = "keep"`) of length equal to the number of spectra within the object with the indices of the sample(s) (in `sampleData()`) a spectrum is assigned to. With `duplicates = "first"`, an integer with the index is returned for each spectrum. If a spectrum was assigned to more than one sample a warning is shown and only the first sample index is returned for that spectrum. For `duplicates = "keep"`, assignments are returned as a list of integer vectors, each element being the index(es) of the sample(s) a spectrum is assigned to. For spectra that are not linked to any sample an `NA_integer_` is returned as index for `duplicates = "first"` and an empty integer (`integer()`) for `duplicates = "keep"`. Note that the default `duplicates = "first"` will work in almost all use cases, as generally, a spectrum will be assigned to a single sample.
- `qdata()`, `qdata<-`: gets or sets the quantification data, which can be a `QFeatures` or `SummarizedExperiment`.
- `otherData()` , `otherData<-`: gets or sets the addition data types, stored as a `List` in the object's `otherData` slot.

Linking sample data to other experimental data

To start with, an `MsExperiment` is just a loose collection of files and data related to an experiment, no explicit links or associations are present between the samples and related data. Such links can however be created with the `linkSampleData()` function. This function can establish links between individual (or all) samples within the object's `sampleData` to individual, or multiple, data elements or files, such as `Spectra` or raw data files.

The presence of such links enables a (consistent) subsetting of an `MsExperiment` by samples. Thus, once the link is defined, any subsetting by sample will also correctly subset the linked data. All other, not linked, data elements are always retained as in the original `MsExperiment`.

To be able to link different elements within an `MsExperiment` it is also required to *identify* them with a consistent naming scheme. The naming scheme of slots and data elements within follows an SQL-like scheme, in which the variable (element) is identified by the name of the database table, followed by a "." and the name of the database table column. For `MsExperiment`, the naming scheme is defined as "<slot name>.<element name>". A column called "sample_name" within the `sampleData` data frame can thus be addressed with "`sampleData.sample_name`", while `spectra.msLevel` would represent the spectra variable called `msLevel` within the `Spectra` stored in the spectra slot.

Links between sample data rows and any other data element are stored as integer matrices within the `@sampleDataLinks` slot of the object (see also the vignette for examples and illustrations). The first column of a matrix is always the index of the sample, and the second column the index of the element that is linked to that sample, with one row per element. Links can be defined/added with the `linkSampleData()` function which adds a relationship between rows in `sampleData`

to elements in any other data within the MsExperiment that are specified with parameter with. linkSampleData() supports two different ways to define the link:

- Parameter with defines the data to which the link should be established. To link samples to raw data files that would for example be available as a character in an element called "raw_files" within the object's experimentFiles, with = experimentFiles.raw_files would have to be used. Next it is required to specify which samples should be linked with which elements in with. This needs to be defined with the parameters sampleIndex and withIndex, both are expected to be integer vectors specifying which sample in sampleData should be linked to which element in with (see examples below or vignette for examples and details).
- As an alternative way, a link could be defined with an SQL-like syntax that relates a column in sampleData to a column/element in the data to which the link should be established. To link for example individual spectra to the corresponding samples with = "sampleData.raw_file = spectra.dataOrigin" could be used assuming that sampleData contains a column named "raw_file" with the (full path) of the raw data file for each sample from which the spectra were imported. In this case both sampleIndex and withIndex can be omitted, but it is expected/required that the columns/elements from sampleData and the data element to which the link should be established contain matching values.

Note that linkSampleData will **replace** a previously existing link to the same data element.

- spectraSampleIndex() is a convenience function that extracts for each spectrum in the object's spectra() the index of the sample it is associated with (see function's help above for more information).

Subsetting and filtering

- [: MsExperiment objects can be subset **by samples** with [i] where i is the index or a logical defining to which samples the data should be subset. Subsetting by sample will (correctly) subset all linked data to the respective samples. If multiple samples are linked to the same data element, subsetting might duplicate that data element. This duplication of *n:m* relationships between samples to elements does however not affect data consistency (see examples below for more information). Not linked data (slots) will be returned as they are. Subsetting in arbitrary order is supported. See the vignette for details and examples.
- filterSpectra(): subsets the Spectra within an MsExperiment using a provided filter function (parameter filter). Parameters for the filter function can be passed with parameter Any of the filter functions of a Spectra:Spectra() object can be passed with parameter filter. Possibly present relationships between samples and spectra (*links*, see also linkSampleData()) are updated. Filtering affects only the spectra data of the object, none of the other slots and data (e.g. sampleData) are modified. The function returns an MsExperiment with the filtered Spectra object.

Author(s)

Laurent Gatto, Johannes Rainer

Examples

```
## An empty MsExperiment object
msexp <- MsExperiment()
msexp

example(MsExperimentFiles)
```

```
experimentFiles(msexp) <- fls
msexp

## Linking samples to data elements

## Create a small experiment
library(S4Vectors)
mse <- MsExperiment()
sd <- DataFrame(sample_id = c("QC1", "QC2"),
                sample_name = c("QC Pool", "QC Pool"),
                injection_idx = c(1, 3))
sampleData(mse) <- sd

## define file names containing spectra data for the samples and
## add them, along with other arbitrary files to the experiment
fls <- dir(system.file("sciex", package = "msdata"), full.names = TRUE)
experimentFiles(mse) <- MsExperimentFiles(
  mzML_files = fls,
  annotations = "internal_standards.txt")

## Link samples to data files: first sample to first file in "mzML_files",
## second sample to second file in "mzML_files"
mse <- linkSampleData(mse, with = "experimentFiles.mzML_files",
  sampleIndex = c(1, 2), withIndex = c(1, 2))

## Link all samples to the one file in "annotations"
mse <- linkSampleData(mse, with = "experimentFiles.annotations",
  sampleIndex = c(1, 2), withIndex = c(1, 1))
mse

## Import the spectra data and add it to the experiment
library(Spectra)
spectra(mse) <- Spectra(fls, backend = MsBackendMzR())

## Link each spectrum to the respective sample. We use the alternative
## link definition that does not require sampleIndex and withIndex but
## links elements based on matching values in the specified data elements.
## We need to add the full file name as an additional column to sampleData
## in order to allow matching this file names with the value in
## spectra(mse)$dataOrigin which contains the original file names from which
## the spectra were imported.
sampleData(mse)$raw_file <- normalizePath(fls)

## The links can be added using the short notation below
mse <- linkSampleData(mse, with = "sampleData.raw_file = spectra.dataOrigin")
mse

## With sampleData links present, any subsetting of the experiment by sample
## will ensure that all linked elements are subset accordingly
b <- mse[2]
b
sampleData(b)
experimentFiles(b)$mzML_files

## The `spectraSampleIndex()` function returns, for each spectrum, the
## index in the object's `sampleData` to which it is linked/assigned
spectraSampleIndex(mse)
```

```

## Subsetting with duplication of n:m sample to data relationships
##
## Both samples were assigned above to one "annotation" file in
## `experimentFiles`:
experimentFiles(mse[1])[["annotations"]]
experimentFiles(mse[2])[["annotations"]]

## Subsetting will always keep the relationship between samples and linked
## data elements. Subsetting will however possibly duplicate data elements
## that are shared among samples. Thus, while in the original object the
## element "annotations" has a single entry, subsetting with [1:2] will
## result in an MsExperiment with duplicated entries in "annotations"
experimentFiles(mse)[["annotations"]]
experimentFiles(mse[1:2])[["annotations"]]

## Spectra within an MsExperiment can be filtered/subset with the
## `filterSpectra` function and any of the filter functions supported
## by `Spectra` objects. Below we restrict the spectra data to spectra
## with a retention time between 200 and 210 seconds.
res <- filterSpectra(mse, filterRt, rt = c(200, 210))
res

## The object contains now much less spectra. The retention times for these
rttime(spectra(res))

## Relationship between samples and spectra was preserved by the filtering
a <- res[1L]
spectra(a)

```

MsExperimentFiles *A class to store experiment files*

Description

The MsExperimentFiles class stores files that are part of a mass spectrometry experiment. The objects are created with the MsExperimentFiles() function.

The files encoded in a MsExperimentFiles instance don't need to exist on the current filesystem - sometimes, these might be created in anticipation of their creation. The existMsExperimentFiles() function can be used to verify which ones currently exist: it returns a list of logicals (formally an instance of `IRanges::LogicalList()`) of lengths equal to the MsExperimentFiles used as input.

Usage

```

MsExperimentFiles(..., metadata = list())

## S4 method for signature 'MsExperimentFiles'
show(object)

existMsExperimentFiles(object)

```

Arguments

...	Either a named list or a set of named vectors. All elements are coerced to characters.
metadata	list() holding arbitrary R objects as annotations.
object	The existMsExperimentFiles() function works with either an instance of MsExperimentFiles or MsExperiment.

Value

MsExperimentFiles returns an instance of MsExperimentFiles.

Author(s)

Laurent Gatto

Examples

```
f1s <- MsExperimentFiles(mzmls = c("/path/to/f1.mzML", "/path/to/f2.mzML"),
                        mzids = "/another/path/to/id1.mzid",
                        fasta = "file.fas")

f1s

## A new MsExperimentFiles containing mzML or mzid files
f1s[1]
f1s["mzids"]

## The actual file names
f1s[[1]]
f1s[[2]]
f1s[["fasta"]]

## None of the files used in this example actually exist
existMsExperimentFiles(f1s)
```

readMsExperiment *Import MS spectra data of an experiment*

Description

Read/import MS spectra data of an experiment from the respective (raw) data files into an `MsExperiment()` object. Files provided with the `spectraFiles` parameter are imported as a `Spectra` object and each file is automatically *linked* to rows (samples) of a `sampleData` data frame (if provided).

Usage

```
readMsExperiment(spectraFiles = character(), sampleData = data.frame(), ...)
```

Arguments

spectraFiles	character with the (absolute) file names of the MS data files that should be imported as a <code>Spectra::Spectra()</code> object.
sampleData	data.frame or DataFrame with the sample annotations. Each row is expected to contain annotations for one file (sample). The order of the data frame's rows is expected to match the order of the provided files (with parameter <code>spectraFiles</code>).
...	additional parameters for the <code>Spectra::Spectra()</code> call to import the data.

Value

MsExperiment.

Author(s)

Johannes Rainer

Examples

```
## Define the files of the experiment to import
fls <- c(system.file("microtofq/MM14.mzML", package = "msdata"),
         system.file("microtofq/MM8.mzML", package = "msdata"))

## Define a data frame with some sample annotations
ann <- data.frame(
  injection_index = 1:2,
  sample_id = c("MM14", "MM8"))

## Import the data
library(MsExperiment)
mse <- readMsExperiment(spectraFiles = fls, ann)
mse

## Access the spectra data
spectra(mse)

## Access the sample annotations
sampleData(mse)

## Import the data reading all MS spectra directly into memory
mse <- readMsExperiment(spectraFiles = fls, ann,
                       backend = Spectra::MsBackendMemory())
mse
```

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