Package: DelayedArray (via r-universe)

November 1, 2026

Title A unified framework for working transparently with on-disk and in-memory array-like datasets

Description Wrapping an array-like object (typically an on-disk object) in a DelayedArray object allows one to perform common array operations on it without loading the object in memory. In order to reduce memory usage and optimize performance, operations on the object are either delayed or executed using a block processing mechanism. Note that this also works on in-memory array-like objects like DataFrame objects (typically with Rle columns), Matrix objects, ordinary arrays and, data frames.

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DelayedUnaryIsoOpStack-class.R
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AutoBlock-global-settings
Control the geometry of automatic blocks

Description

A family of utilities to control the automatic block size (or length) and shape.

Usage

```
getAutoBlockSize()
setAutoBlockSize(size=1e8)

getAutoBlockLength(type)

getAutoBlockShape()
setAutoBlockShape(shape=c("hypercube",
                          "scale",
                          "first-dim-grows-first",
                          "last-dim-grows-first"))
```

Arguments

size	The *auto block size* (automatic block size) in bytes. Note that, except when the type of the array data is "character" or "list", the size of a block is its length multiplied by the size of an array element. For example, a block of 500 x 1000 x 500 doubles has a length of 250 million elements and a size of 2 Gb (each double occupies 8 bytes of memory). The *auto block size* is set to 100 Mb at package startup and can be reset anytime to this value by calling setAutoBlockSize() with no argument.
type	A string specifying the type of the array data.
shape	A string specifying the *auto block shape* (automatic block shape). See makeCappedVolumeBox for a description of the supported shapes. The *auto block shape* is set to "hypercube" at package startup and can be reset anytime to this value by calling setAutoBlockShape() with no argument.

Details

block size != *block length*

block length = number of array elements in a block (i.e. prod(dim(block))).

block size = *block length* * size of the individual elements in memory.

For example, for an integer array, *block size* (in bytes) is going to be 4 x *block length*. For a numeric array x (i.e. type(x) == "double"), it's going to be 8 x *block length*.

In its current form, block processing in the **DelayedArray** package must decide the geometry of the blocks before starting the walk on the blocks. It does this based on several criteria. Two of them are:

- The *auto block size*: maximum size (in bytes) of a block once loaded in memory.
- The `type()` of the array (e.g. `integer`, `double`, `complex`, etc...)

The *auto block size* setting and `type(x)` control the maximum length of the blocks. Other criteria control their shape. So for example if you set the *auto block size* to 8GB, this will cap the length of the blocks to 2e9 if your DelayedArray object `x` is of type `integer`, and to 1e9 if it's of type `double`.

Note that this simple relationship between *block size* and *block length* assumes that blocks are loaded in memory as ordinary (a.k.a. dense) matrices or arrays. With sparse blocks, all bets are off. But the max block length is always taken to be the *auto block size* divided by `get_type_size(type())` whether the blocks are going to be loaded as dense or sparse arrays. If they are going to be loaded as sparse arrays, their memory footprint is very likely to be smaller than if they were loaded as dense arrays so this is safe (although probably not optimal).

It's important to keep in mind that the *auto block size* setting is a simple way for the user to put a cap on the memory footprint of the blocks. Nothing more. In particular it doesn't control the maximum amount of memory used by the block processing algorithm. Other variables can impact dramatically memory usage like parallelization (where more than one block is loaded in memory at any given time), what the algorithm is doing with the blocks (e.g. something like `blockApply(x, identity)` will actually load the entire array data in memory), what delayed operations are on `x`, etc... It would be awesome to have a way to control the maximum amount of memory used by a block processing algorithm as a whole but we don't know how to do that.

Value

`getAutoBlockSize`: The current *auto block size* in bytes as a single numeric value.

`setAutoBlockSize`: The new *auto block size* in bytes as an invisible single numeric value.

`getAutoBlockLength`: The *auto block length* as a single integer value.

`getAutoBlockShape`: The current *auto block shape* as a single string.

`setAutoBlockShape`: The new *auto block shape* as an invisible single string.

See Also

- `defaultAutoGrid` and family to create automatic grids to use for block processing of array-like objects.
- `blockApply` and family for convenient block processing of an array-like object.
- The `makeCappedVolumeBox` utility to make *capped volume boxes*.

Examples

```
getAutoBlockSize()

getAutoBlockLength("double")
getAutoBlockLength("integer")
getAutoBlockLength("logical")
getAutoBlockLength("raw")

m <- matrix(runif(600), ncol=12)
```

```
setAutoBlockSize(140)
getAutoBlockLength(type(m))
defaultAutoGrid(m)
lengths(defaultAutoGrid(m))
dims(defaultAutoGrid(m))

getAutoBlockShape()
setAutoBlockShape("scale")
defaultAutoGrid(m)
lengths(defaultAutoGrid(m))
dims(defaultAutoGrid(m))

## Reset the auto block size and shape to factory settings:
setAutoBlockSize()
setAutoBlockShape()
```

AutoGrid *Create automatic grids to use for block processing of array-like objects*

Description

We provide various utility functions to create grids that can be used for block processing of array-like objects:

- `defaultAutoGrid()` is the default *automatic grid maker*. It creates a grid that is suitable for block processing of the array-like object passed to it.
- `rowAutoGrid()` and `colAutoGrid()` are more specialized *automatic grid makers*, for the 2-dimensional case. They can be used to create a grid where the blocks are made of full rows or full columns, respectively.
- `defaultSinkAutoGrid()` is a specialized version of `defaultAutoGrid()` for creating a grid that is suitable for writing to a RealizationSink derivative while walking on it.

Usage

```
defaultAutoGrid(x, block.length=NULL, chunk.grid=NULL, block.shape=NULL)

## Two specialized "automatic grid makers" for the 2-dimensional case:
rowAutoGrid(x, nrow=NULL, block.length=NULL)
colAutoGrid(x, ncol=NULL, block.length=NULL)

## Replace default automatic grid maker with user-defined one:
getAutoGridMaker()
setAutoGridMaker(GRIDMAKER="defaultAutoGrid")

## A specialized version of defaultAutoGrid() to create an automatic
## grid on a RealizationSink derivative:
defaultSinkAutoGrid(sink, block.length=NULL, chunk.grid=NULL)
```

Arguments

x	An array-like or matrix-like object for defaultAutoGrid. A matrix-like object for rowAutoGrid and colAutoGrid.
block.length	The length of the blocks i.e. the number of array elements per block. By default the automatic block length (returned by getAutoBlockLength(type(x)), or getAutoBlockLength(type(sink)) in the case of defaultSinkAutoGrid()) is used. Depending on how much memory is available on your machine, you might want to increase (or decrease) the automatic block length by adjusting the automatic block size with setAutoBlockSize().
chunk.grid	The grid of physical chunks. By default chunkGrid(x) (or chunkGrid(sink) in the case of defaultSinkAutoGrid()) is used.
block.shape	A string specifying the shape of the blocks. See makeCappedVolumeBox for a description of the supported shapes. By default getAutoBlockShape() is used.
nrow	The number of rows of the blocks. The bottommost blocks might have less. See examples below.
ncol	The number of columns of the blocks. The rightmost blocks might have less. See examples below.
GRIDMAKER	The function to use as *automatic grid maker*, that is, the function that will be used by blockApply() and blockReduce() to make a grid when no grid is supplied via their grid argument. The function will be called on array-like object x and must return an ArrayGrid object, say grid, that is compatible with x i.e. such that refdim(grid) is identical to dim(x). GRIDMAKER can be specified as a function or as a single string naming a function. It can be a user-defined function or a pre-defined grid maker like defaultAutoGrid, rowAutoGrid, or colAutoGrid. The *automatic grid maker* is set to defaultAutoGrid at package startup and can be reset anytime to this value by calling setAutoGridMaker() with no argument.
sink	A RealizationSink derivative.

Details

By default, primary block processing functions blockApply() and blockReduce() use the grid returned by defaultAutoGrid(x) to walk on the blocks of array-like object x. This can be changed with setAutoGridMaker().

By default sinkApply() uses the grid returned by defaultSinkAutoGrid(sink) to walk on the viewports of RealizationSink derivative sink and write to them.

Value

defaultAutoGrid: An ArrayGrid object on reference array x. The grid elements define the blocks that will be used to process x by block. The grid is *optimal* in the sense that:

1. It's *compatible* with the grid of physical chunks a.k.a. *chunk grid*. This means that, when the chunk grid is known (i.e. when chunkGrid(x) is not NULL or chunk.grid is supplied), every block in the grid contains one or more *full* chunks. In other words, chunks never cross block boundaries.

2. Its *resolution* is such that the blocks have a length that is as close as possibe to (but does not exceed) `block.length`. An exception is made when some chunks already have a length that is >= `block.length`, in which case the returned grid is the same as the chunk grid.

Note that the returned grid is regular (i.e. is a RegularArrayGrid object) unless the chunk grid is not regular (i.e. is an ArbitraryArrayGrid object).

`rowAutoGrid`: A RegularArrayGrid object on reference array `x` where the grid elements define blocks made of full rows of `x`.

`colAutoGrid`: A RegularArrayGrid object on reference array `x` where the grid elements define blocks made of full columns of `x`.

`defaultSinkAutoGrid`: Like `defaultAutoGrid` except that `defaultSinkAutoGrid` always returns a grid with a "first-dim-grows-first" shape (note that, unlike the former, the latter has no `block.shape` argument). The advantage of using a grid with a "first-dim-grows-first" shape in the context of writing to the viewports of a RealizationSink derivative is that such a grid is guaranteed to work with "linear write only" realization backends. See important notes about "Cross realization backend compatibility" in ?`write_block` in the **S4Arrays** package for more information.

See Also

- `setAutoBlockSize` and `setAutoBlockShape` to control the geometry of automatic blocks.
- `blockApply` and family for convenient block processing of an array-like object.
- ArrayGrid in the **S4Arrays** package for the formal representation of grids and viewports.
- The `makeCappedVolumeBox` utility to make *capped volume boxes*.
- `chunkGrid`.
- `read_block` and `write_block` in the **S4Arrays** package.

Examples

```
## ---------------------------------------------------------------------
## A VERSION OF sum() THAT USES BLOCK PROCESSING
## ---------------------------------------------------------------------

block_sum <- function(a, grid) {
  sums <- lapply(grid, function(viewport) sum(read_block(a, viewport)))
  sum(unlist(sums))
}

## On an ordinary matrix:
m <- matrix(runif(600), ncol=12)
m_grid <- defaultAutoGrid(m, block.length=120)
sum1 <- block_sum(m, m_grid)
sum1

## On a DelayedArray object:
library(HDF5Array)
M <- as(m, "HDF5Array")
sum2 <- block_sum(M, m_grid)
sum2
```

```
sum3 <- block_sum(M, colAutoGrid(M, block.length=120))
sum3

sum4 <- block_sum(M, rowAutoGrid(M, block.length=80))
sum4

## Sanity checks:
sum0 <- sum(m)
stopifnot(identical(sum1, sum0))
stopifnot(identical(sum2, sum0))
stopifnot(identical(sum3, sum0))
stopifnot(identical(sum4, sum0))

## ---------------------------------------------------------------------
## defaultAutoGrid()
## ---------------------------------------------------------------------
grid <- defaultAutoGrid(m, block.length=120)
grid
as.list(grid)  # turn the grid into a list of ArrayViewport objects
table(lengths(grid))
stopifnot(maxlength(grid) <= 120)

grid <- defaultAutoGrid(m, block.length=120,
                           block.shape="first-dim-grows-first")
grid
table(lengths(grid))
stopifnot(maxlength(grid) <= 120)

grid <- defaultAutoGrid(m, block.length=120,
                           block.shape="last-dim-grows-first")
grid
table(lengths(grid))
stopifnot(maxlength(grid) <= 120)

defaultAutoGrid(m, block.length=100)
defaultAutoGrid(m, block.length=75)
defaultAutoGrid(m, block.length=25)
defaultAutoGrid(m, block.length=20)
defaultAutoGrid(m, block.length=10)

## ---------------------------------------------------------------------
## rowAutoGrid() AND colAutoGrid()
## ---------------------------------------------------------------------
rowAutoGrid(m, nrow=10)  # 5 blocks of 10 rows each
rowAutoGrid(m, nrow=15)  # 3 blocks of 15 rows each plus 1 block of 5 rows
colAutoGrid(m, ncol=5)   # 2 blocks of 5 cols each plus 1 block of 2 cols

## See '?RealizationSink' for advanced examples of user-implemented
## block processing using colAutoGrid() and a realization sink.

## ---------------------------------------------------------------------
## REPLACE DEFAULT AUTOMATIC GRID MAKER WITH USER-DEFINED ONE
## ---------------------------------------------------------------------
```

```
getAutoGridMaker()
setAutoGridMaker(function(x) colAutoGrid(x, ncol=5))
getAutoGridMaker()

blockApply(m, function(block) currentViewport())

## Reset automatic grid maker to factory settings:
setAutoGridMaker()
```

---

blockApply *blockApply() and family*

Description

A family of convenience functions to walk on the blocks of an array-like object and process them.

Usage

```
## Main looping functions:

blockApply(x, FUN, ..., grid=NULL, as.sparse=FALSE,
           BPPARAM=getAutoBPPARAM(), verbose=NA)

blockReduce(FUN, x, init, ..., BREAKIF=NULL, grid=NULL, as.sparse=FALSE,
            verbose=NA)

## Lower-level looping functions:
gridApply(grid, FUN, ..., BPPARAM=getAutoBPPARAM(), verbose=NA)
gridReduce(FUN, grid, init, ..., BREAKIF=NULL, verbose=NA)

## Retrieve grid context for the current block/viewport:
effectiveGrid(envir=parent.frame(2))
currentBlockId(envir=parent.frame(2))
currentViewport(envir=parent.frame(2))

## Get/set automatic parallel back-end:
getAutoBPPARAM()
setAutoBPPARAM(BPPARAM=NULL)

## For testing/debugging callback functions:
set_grid_context(effective_grid, current_block_id, current_viewport=NULL,
                 envir=parent.frame(1))
```

Arguments

x	An array-like object, typically a DelayedArray object or derivative.

FUN — For blockApply and blockReduce, FUN is the callback function to apply to each block of data in x. More precisely, FUN will be called on each block of data in x defined by the grid used to walk on x.

IMPORTANT: If as.sparse is set to FALSE, all blocks will be passed to FUN as ordinary arrays. If it's set to TRUE, they will be passed as SparseArray objects. If it's set to NA, then is_sparse(x) determines how they will be passed to FUN.

For gridApply() and gridReduce(), FUN is the callback function to apply to each **viewport** in grid.

Beware that FUN must take at least **two** arguments for blockReduce() and gridReduce(). More precisely:

- blockReduce() will perform init <- FUN(block, init, ...) on each block, so FUN must take at least arguments block and init.
- gridReduce() will perform init <- FUN(viewport, init, ...) on each viewport, so FUN must take at least arguments viewport and init.

In both cases, the exact names of the two arguments doesn't really matter. Also FUN is expected to return a value of the same type as its 2nd argument (init).

... — Additional arguments passed to FUN.

grid — The grid used for the walk, that is, an ArrayGrid object that defines the blocks (or viewports) to walk on.

For blockApply() and blockReduce() the supplied grid must be compatible with the geometry of x. If not specified, an automatic grid is used. By default defaultAutoGrid(x) is called to create an automatic grid. The *automatic grid maker* can be changed with setAutoGridMaker(). See ?setAutoGridMaker for more information.

as.sparse — Passed to the internal calls to read_block. See ?read_block in the **S4Arrays** package for more information.

BPPARAM — A NULL, in which case blocks are processed sequentially, or a BiocParallelParam instance (from the **BiocParallel** package), in which case they are processed in parallel. The specific BiocParallelParam instance determines the parallel back-end to use. See ?BiocParallelParam in the **BiocParallel** package for more information about parallel back-ends.

verbose — Whether block processing progress should be displayed or not. If set to NA (the default), verbosity is controlled by DelayedArray:::get_verbose_block_processing(). Setting verbose to TRUE or FALSE overrides this.

init — The value to pass to the first call to FUN(block, init) (or FUN(viewport, init)) when blockReduce() (or gridReduce()) starts the walk. Note that blockReduce() and gridReduce() always operate sequentially.

BREAKIF — An optional callback function that detects a break condition. Must return TRUE or FALSE. At each iteration blockReduce() (and gridReduce()) will call it on the result of init <- FUN(block, init) (on the result of init <- FUN(viewport, init) for gridReduce()) and exit the walk if BREAKIF(init) returned TRUE.

envir — Do not use (unless you know what you are doing).

effective_grid, current_block_id, current_viewport
See Details below.

Details

`effectiveGrid()`, `currentBlockId()`, and `currentViewport()` return the "grid context" for the block/viewport being currently processed. By "grid context" we mean:

- The *effective grid*, that is, the user-supplied grid or `defaultAutoGrid(x)` if the user didn't supply any grid.
- The *current block id* (a.k.a. block rank).
- The *current viewport*, that is, the ArrayViewport object describing the position of the current block w.r.t. the effective grid.

Note that `effectiveGrid()`, `currentBlockId()`, and `currentViewport()` can only be called (with no arguments) from **within** the callback functions `FUN` and/or `BREAKIF` passed to `blockApply()` and family.

If you need to be able to test/debug your callback function as a standalone function, set an arbitrary *effective grid*, *current block id*, and *current_viewport*, by calling

```
set_grid_context(effective_grid, current_block_id, current_viewport)
```

right before calling the callback function.

Value

For `blockApply()` and `gridApply()`, a list with one list element per block/viewport visited.

For `blockReduce()` and `gridReduce()`, the result of the last call to `FUN`.

For `effectiveGrid()`, the grid (ArrayGrid object) being effectively used.

For `currentBlockId()`, the id (a.k.a. rank) of the current block.

For `currentViewport()`, the viewport (ArrayViewport object) of the current block.

See Also

- `defaultAutoGrid` and family to create automatic grids to use for block processing of array-like objects.
- ArrayGrid in the **S4Arrays** package for the formal representation of grids and viewports.
- `read_block` and `write_block` in the **S4Arrays** package.
- SparseArray objects implemented in the **SparseArray** package.
- `MulticoreParam`, `SnowParam`, and `bpparam`, from the **BiocParallel** package.
- DelayedArray objects.

Examples

```
m <- matrix(1:60, nrow=10)
m_grid <- defaultAutoGrid(m, block.length=16, block.shape="hypercube")

## ---------------------------------------------------------------------
## blockApply()
## ---------------------------------------------------------------------
```

```
blockApply(m, identity, grid=m_grid)
blockApply(m, sum, grid=m_grid)

blockApply(m, function(block) {block + currentBlockId()*1e3}, grid=m_grid)
blockApply(m, function(block) currentViewport(), grid=m_grid)
blockApply(m, dim, grid=m_grid)

## The grid does not need to be regularly spaced:
a <- array(runif(8000), dim=c(25, 40, 8))
a_tickmarks <- list(c(7L, 15L, 25L), c(14L, 22L, 40L), c(2L, 8L))
a_grid <- ArbitraryArrayGrid(a_tickmarks)
a_grid
blockApply(a, function(block) sum(log(block + 0.5)), grid=a_grid)

## See block processing in action:
blockApply(m, function(block) sum(log(block + 0.5)), grid=m_grid,
           verbose=TRUE)

## Use parallel evaluation:
library(BiocParallel)
if (.Platform$OS.type != "windows") {
    BPPARAM <- MulticoreParam(workers=4)
} else {
    ## MulticoreParam() is not supported on Windows so we use
    ## SnowParam() on this platform.
    BPPARAM <- SnowParam(4)
}
blockApply(m, function(block) sum(log(block + 0.5)), grid=m_grid,
           BPPARAM=BPPARAM, verbose=TRUE)
## Note that blocks can be visited in any order!

## ---------------------------------------------------------------------
## blockReduce()
## ---------------------------------------------------------------------
FUN <- function(block, init) anyNA(block) || init
blockReduce(FUN, m, init=FALSE, grid=m_grid, verbose=TRUE)

m[10, 1] <- NA
blockReduce(FUN, m, init=FALSE, grid=m_grid, verbose=TRUE)

## With early bailout:
blockReduce(FUN, m, init=FALSE, BREAKIF=identity, grid=m_grid,
            verbose=TRUE)

## Note that this is how the anyNA() method for DelayedArray objects is
## implemented.
```

ConstantArray *A DelayedArray subclass that contains a constant value*

Description

A DelayedArray subclass to efficiently mimic an array containing a constant value, without actually creating said array in memory.

Usage

```
## Constructor function:
ConstantArray(dim, value=NA)
```

Arguments

dim	The dimensions (specified as an integer vector) of the ConstantArray object to create.
value	Vector (atomic or list) of length 1, containing the value to fill the matrix.

Details

This class allows us to efficiently create arrays containing a single value. For example, we can create matrices full of NA values, to serve as placeholders for missing assays when combining SummarizedExperiment objects.

Value

A ConstantArray (or ConstantMatrix) object. (Note that ConstantMatrix extends ConstantArray.)

Author(s)

Aaron Lun

See Also

- DelayedArray objects.
- DelayedArray-utils for common operations on DelayedArray objects.
- RleArray objects for representing in-memory Run Length Encoded array-like datasets.

Examples

```
## This would ordinarily take up 8 TB of memory:
CM <- ConstantArray(c(1e6, 1e6), value=NA_real_)
CM

CM2 <-ConstantArray(c(4, 1e6), value=55)
rbind(CM, CM2)
```

DelayedAbind-class *DelayedAbind objects*

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedAbind class provides a formal representation of a *delayed* `abind()` *operation*. It is a concrete subclass of the DelayedNaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:

```
  DelayedOp
      ^
      |
DelayedNaryOp
      ^
      |
DelayedAbind
```

DelayedAbind objects are used inside a DelayedArray object to represent the *delayed* `abind()` *operations* carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedAbind'
is_noop(x)

## S4 method for signature 'DelayedAbind'
summary(object, ...)

## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedAbind'
dim(x)

## S4 method for signature 'DelayedAbind'
dimnames(x)

## S4 method for signature 'DelayedAbind'
extract_array(x, index)

## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedAbind'
is_sparse(x)
```

```
## S4 method for signature 'DelayedAbind'
extract_sparse_array(x, index)
```

Arguments

x, object	A DelayedAbind object.
index	See ?extract_array in the **S4Arrays** package for a description of the index argument.
...	Not used.

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- extract_array in the **S4Arrays** package.
- extract_sparse_array in the **SparseArray** package.

Examples

```
## DelayedAbind extends DelayedNaryOp which extends DelayedOp:
extends("DelayedAbind")

## ---------------------------------------------------------------------
## BASIC EXAMPLE
## ---------------------------------------------------------------------
m1 <- matrix(101:128, ncol=4)
m2 <- matrix(runif(16), ncol=4)
M1 <- DelayedArray(m1)
M2 <- DelayedArray(m2)
showtree(M1)
showtree(M2)

M3 <- rbind(M1, M2)
showtree(M3)
class(M3@seed)        # a DelayedAbind object

M4 <- cbind(t(M1), M2)
showtree(M4)
class(M4@seed)        # a DelayedAbind object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
## ---------------------------------------------------------------------
## DelayedAbind objects always propagate sparsity (granted that all the
## input arrays are sparse).

sm1 <- sparseMatrix(i=c(1, 1, 7, 7), j=c(1, 4, 1, 4),
                    x=c(11, 14, 71, 74), dims=c(7, 4))
```

```
SM1 <- DelayedArray(sm1)
sm2 <- sparseMatrix(i=c(1, 1, 4, 4), j=c(1, 4, 1, 4),
                    x=c(11, 14, 41, 44), dims=c(4, 4))
SM2 <- DelayedArray(sm2)
showtree(SM1)
showtree(SM2)
is_sparse(SM1)        # TRUE
is_sparse(SM2)        # TRUE

SM3 <- rbind(SM1, SM2)
showtree(SM3)
class(SM3@seed)       # a DelayedAbind object
is_sparse(SM3@seed)   # TRUE

SM4 <- cbind(SM2, t(SM1))
showtree(SM4)
class(SM4@seed)       # a DelayedAbind object
is_sparse(SM4@seed)   # TRUE

M5 <- rbind(SM2, M1)  # 2nd input array is not sparse!
showtree(M5)
class(M5@seed)        # a DelayedAbind object
is_sparse(M5@seed)    # FALSE

## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(M3@seed) == "DelayedAbind")
stopifnot(class(M4@seed) == "DelayedAbind")
stopifnot(class(SM3@seed) == "DelayedAbind")
stopifnot(is_sparse(SM3@seed))
stopifnot(class(SM4@seed) == "DelayedAbind")
stopifnot(is_sparse(SM4@seed))
stopifnot(class(M5@seed) == "DelayedAbind")
stopifnot(!is_sparse(M5@seed))
```

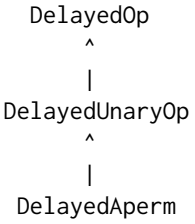
`DelayedAperm-class` *DelayedAperm objects*

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedAperm class provides a formal representation of a *delayed "extended* `aperm()`*" operation*, that is, of a delayed `aperm()` that can drop and/or add *ineffective* dimensions. Note that since only *ineffective* dimensions (i.e. dimensions with an extent of 1) can be dropped or added, the length of the output array is guaranteed to be the same as the length of the input array.

DelayedAperm is a concrete subclass of the DelayedUnaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:



DelayedAperm objects are used inside a DelayedArray object to represent the *delayed "extended* `aperm()`*" operations* carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedAperm'
is_noop(x)

## S4 method for signature 'DelayedAperm'
summary(object, ...)

## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedAperm'
dim(x)

## S4 method for signature 'DelayedAperm'
dimnames(x)

## S4 method for signature 'DelayedAperm'
extract_array(x, index)

## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedAperm'
is_sparse(x)

## S4 method for signature 'DelayedAperm'
extract_sparse_array(x, index)
```

Arguments

`x`, `object`	A DelayedAperm object.
`index`	See ?`extract_array` in the **S4Arrays** package for a description of the `index` argument.
`...`	Not used.

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- extract_array in the **S4Arrays** package.
- extract_sparse_array in the **SparseArray** package.

Examples

```
## DelayedAperm extends DelayedUnaryOp which extends DelayedOp:
extends("DelayedAperm")

## ---------------------------------------------------------------------
## BASIC EXAMPLES
## ---------------------------------------------------------------------
a0 <- array(1:20, dim=c(1, 10, 2))
A0 <- DelayedArray(a0)
showtree(A0)

A <- aperm(A0, perm=c(2, 3, 1))
showtree(A)
class(A@seed)       # a DelayedAperm object

M1 <- drop(A0)
showtree(M1)
class(M1@seed)      # a DelayedAperm object

M2 <- t(M1)
showtree(M2)
class(M2@seed)      # a DelayedAperm object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
## ---------------------------------------------------------------------
## DelayedAperm objects always propagate sparsity.

sa0 <- SparseArray(a0)
SA0 <- DelayedArray(sa0)
showtree(SA0)
is_sparse(SA0)      # TRUE

SA <- aperm(SA0, perm=c(2, 3, 1))
showtree(SA)
class(SA@seed)      # a DelayedAperm object
is_sparse(SA@seed)  # TRUE

## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(A@seed) == "DelayedAperm")
stopifnot(class(M1@seed) == "DelayedAperm")
```

```
stopifnot(class(M2@seed) == "DelayedAperm")
stopifnot(class(SA@seed) == "DelayedAperm")
stopifnot(is_sparse(SA@seed))
```

DelayedArray-class *DelayedArray objects*

Description

Wrapping an array-like object (typically an on-disk object) in a DelayedArray object allows one to perform common array operations on it without loading the object in memory. In order to reduce memory usage and optimize performance, operations on the object are either *delayed* or executed using a block processing mechanism.

Usage

```
DelayedArray(seed)  # constructor function
type(x)
```

Arguments

seed	An array-like object.
x	Typically a DelayedArray object. More generally type() is expected to work on any array-like object (that is, any object for which dim(x) is not NULL), or any ordinary vector (i.e. atomic or non-atomic).

In-memory versus on-disk realization

To *realize* a DelayedArray object (i.e. to trigger execution of the delayed operations carried by the object and return the result as an ordinary array), call as.array on it. However this realizes the full object at once *in memory* which could require too much memory if the object is big. A big DelayedArray object is preferrably realized *on disk* e.g. by calling writeHDF5Array on it (this function is defined in the **HDF5Array** package) or coercing it to an HDF5Array object with as(x, "HDF5Array"). Other on-disk backends can be supported. This uses a block processing strategy so that the full object is not realized at once in memory. Instead the object is processed block by block i.e. the blocks are realized in memory and written to disk one at a time. See ?writeHDF5Array in the **HDF5Array** package for more information about this.

Accessors

DelayedArray objects support the same set of getters as ordinary arrays i.e. dim(), length(), and dimnames(). In addition, they support type(), nseed(), seed(), and path().

type() is the DelayedArray equivalent of typeof() (or storage.mode()) for ordinary arrays and vectors. Note that, for convenience and consistency, type() also supports ordinary arrays and vectors. It should also support any array-like object, that is, any object x for which dim(x) is not NULL.

dimnames(), seed(), and path() also work as setters.

Subsetting

A DelayedArray object can be subsetted with `[` like an ordinary array, but with the following differences:

- *N-dimensional single bracket subsetting* (i.e. subsetting of the form `x[i_1, i_2, ..., i_n]` with one (possibly missing) subscript per dimension) returns a DelayedArray object where the subsetting is actually *delayed*. So it's a very light operation. One notable exception is when `drop=TRUE` and the result has only one dimension, in which case it is *realized* as an ordinary vector (atomic or list). Note that NAs in the subscripts are not supported.
- *1D-style single bracket subsetting* (i.e. subsetting of the form `x[i]`) only works if the subscript `i` is a numeric or logical vector, or a logical array-like object with the same dimensions as `x`, or a numeric matrix with one column per dimension in `x`. When `i` is a numeric vector, all the indices in it must be >= 1 and <= `length(x)`. NAs in the subscripts are not supported. This is NOT a delayed operation (block processing is triggered) i.e. the result is *realized* as an ordinary vector (atomic or list). One exception is when `x` has only one dimension and `drop` is set to `FALSE`, in which case the subsetting is *delayed*.

Subsetting with `[[` is supported but only the 1D-style form of it at the moment, that is, subsetting of the form `x[[i]]` where `i` is a *single* numeric value >= 1 and <= `length(x)`. It is equivalent to `x[i][[1]]`.

Subassignment to a DelayedArray object with `[<-` is also supported like with an ordinary array, but with the following restrictions:

- *N-dimensional subassignment* (i.e. subassignment of the form `x[i_1, i_2, ..., i_n] <- value` with one (possibly missing) subscript per dimension) only accepts a replacement value (a.k.a. right value) that is an array-like object (e.g. ordinary array, dgCMatrix object, DelayedArray object, etc...) or an ordinary vector (atomic or list) of length 1.
- *1D-style subassignment* (a.k.a. 1D-style subassignment, that is, subassignment of the form `x[i] <- value`) only works if the subscript `i` is a logical DelayedArray object of the same dimensions as `x` and if the replacement value is an ordinary vector (atomic or list) of length 1.
- *Filling with a vector*, that is, subassignment of the form `x[] <- v` where `v` is an ordinary vector (atomic or list), is only supported if the length of the vector is a divisor of `nrow(x)`.

These 3 forms of subassignment are implemented as *delayed* operations so are very light.

Single value replacement (`x[[...]] <- value`) is not supported yet.

See Also

- `showtree` for DelayedArray accessors `nseed`, `seed`, and `path`.
- `realize` for realizing a DelayedArray object in memory or on disk.
- `blockApply` and family for convenient block processing of an array-like object.
- DelayedArray-utils for common operations on DelayedArray objects.
- DelayedArray-stats for statistical functions on DelayedArray objects.
- matrixStats-methods for DelayedMatrix row/col summarization.
- DelayedMatrix-rowsum for `rowsum()` and `colsum()` methods for DelayedMatrix objects.
- DelayedMatrix-mult for DelayedMatrix multiplication and cross-product.

- ConstantArray objects for mimicking an array containing a constant value, without actually creating said array in memory.
- RleArray objects for representing in-memory Run Length Encoded array-like datasets.
- HDF5Array objects in the **HDF5Array** package.
- DataFrame objects in the **S4Vectors** package.
- array objects in base R.

Examples

```
## ---------------------------------------------------------------------
## A. WRAP AN ORDINARY ARRAY IN A DelayedArray OBJECT
## ---------------------------------------------------------------------
a <- array(runif(1500000), dim=c(10000, 30, 5))
A <- DelayedArray(a)
A
## The seed of a DelayedArray object is **always** treated as a
## "read-only" object so will never be modified by the operations
## we perform on A:
stopifnot(identical(a, seed(A)))
type(A)

## N-dimensional single bracket subsetting:
m <- a[11:20 , 5, -3]  # an ordinary matrix
M <- A[11:20 , 5, -3]  # a DelayedMatrix object
stopifnot(identical(m, as.array(M)))

## 1D-style single bracket subsetting:
A[11:20]
A[A <= 1e-5]
stopifnot(identical(a[a <= 1e-5], A[A <= 1e-5]))

## Subassignment:
A[A < 0.2] <- NA
a[a < 0.2] <- NA
stopifnot(identical(a, as.array(A)))

A[2:5, 1:2, ] <- array(1:40, c(4, 2, 5))
a[2:5, 1:2, ] <- array(1:40, c(4, 2, 5))
stopifnot(identical(a, as.array(A)))

## Other operations:
crazy <- function(x) (5 * x[ , , 1] ^ 3 + 1L) * log(x[, , 2])
b <- crazy(a)
head(b)

B <- crazy(A)  # very fast! (all operations are delayed)
B

cs <- colSums(b)
CS <- colSums(B)
stopifnot(identical(cs, CS))
```

```
## ---------------------------------------------------------------------
## B. WRAP A DataFrame OBJECT IN A DelayedArray OBJECT
## ---------------------------------------------------------------------
## Generate random coverage and score along an imaginary chromosome:
cov <- Rle(sample(20, 5000, replace=TRUE), sample(6, 5000, replace=TRUE))
score <- Rle(sample(100, nrun(cov), replace=TRUE), runLength(cov))

DF <- DataFrame(cov, score)
A2 <- DelayedArray(DF)
A2
seed(A2)  # 'DF'

## Coercion of a DelayedMatrix object to DataFrame produces a DataFrame
## object with Rle columns:
as(A2, "DataFrame")
stopifnot(identical(DF, as(A2, "DataFrame")))

t(A2)  # transposition is delayed so is very fast and memory-efficient
colSums(A2)

## ---------------------------------------------------------------------
## C. AN HDF5Array OBJECT IS A (PARTICULAR KIND OF) DelayedArray OBJECT
## ---------------------------------------------------------------------
library(HDF5Array)
A3 <- as(a, "HDF5Array")   # write 'a' to an HDF5 file
A3
is(A3, "DelayedArray")     # TRUE
seed(A3)                   # an HDF5ArraySeed object

B3 <- crazy(A3)            # very fast! (all operations are delayed)
B3                         # not an HDF5Array object anymore because
                           # now it carries delayed operations
CS3 <- colSums(B3)
stopifnot(identical(cs, CS3))

## ---------------------------------------------------------------------
## D. PERFORM THE DELAYED OPERATIONS
## ---------------------------------------------------------------------
as(B3, "HDF5Array")        # "realize" 'B3' on disk

## If this is just an intermediate result, you can either keep going
## with B3 or replace it with its "realized" version:
B3 <- as(B3, "HDF5Array")  # no more delayed operations on new 'B3'
seed(B3)
path(B3)

## For convenience, realize() can be used instead of explicit coercion.
## The current "automatic realization backend" controls where
## realization happens e.g. in memory if set to NULL or in an HDF5
## file if set to "HDF5Array":
D <- cbind(B3, exp(B3))
D
```

```
setAutoRealizationBackend("HDF5Array")
D <- realize(D)
D
## See '?setAutoRealizationBackend' for more information about
## "realization backends".

setAutoRealizationBackend()  # restore default (NULL)

## ---------------------------------------------------------------------
## E. MODIFY THE PATH OF A DelayedArray OBJECT
## ---------------------------------------------------------------------
## This can be useful if the file containing the array data is on a
## shared partition but the exact path to the partition depends on the
## machine from which the data is being accessed.
## For example:

## Not run:
library(HDF5Array)
A <- HDF5Array("/path/to/lab_data/my_precious_data.h5")
path(A)

## Operate on A...
## Now A carries delayed operations.
## Make sure path(A) still works:
path(A)

## Save A:
save(A, file="A.rda")

## A.rda should be small (it doesn't contain the array data).
## Send it to a co-worker that has access to my_precious_data.h5.

## Co-worker loads it:
load("A.rda")
path(A)

## A is broken because path(A) is incorrect for co-worker:
A  # error!

## Co-worker fixes the path (in this case this is better done using the
## dirname() setter rather than the path() setter):
dirname(A) <- "E:/other/path/to/lab_data"

## A "works" again:
A

## End(Not run)

## ---------------------------------------------------------------------
## F. WRAP A SPARSE MATRIX IN A DelayedArray OBJECT
## ---------------------------------------------------------------------
## Not run:
M <- 75000L
```

```
N <- 1800L
p <- sparseMatrix(sample(M, 9000000, replace=TRUE),
                  sample(N, 9000000, replace=TRUE),
                  x=runif(9000000), dims=c(M, N))
P <- DelayedArray(p)
P
p2 <- as(P, "sparseMatrix")
stopifnot(identical(p, p2))

## The following is based on the following post by Murat Tasan on the
## R-help mailing list:
##   https://stat.ethz.ch/pipermail/r-help/2017-May/446702.html

## As pointed out by Murat, the straight-forward row normalization
## directly on sparse matrix 'p' would consume too much memory:
row_normalized_p <- p / rowSums(p^2)  # consumes too much memory
## because the rowSums() result is being recycled (appropriately) into a
## *dense* matrix with dimensions equal to dim(p).

## Murat came up with the following solution that is very fast and
## memory-efficient:
row_normalized_p1 <- Diagonal(x=1/sqrt(Matrix::rowSums(p^2)))

## With a DelayedArray object, the straight-forward approach uses a
## block processing strategy behind the scene so it doesn't consume
## too much memory.

## First, let's see block processing in action:
DelayedArray:::set_verbose_block_processing(TRUE)
## and check the automatic block size:
getAutoBlockSize()

row_normalized_P <- P / sqrt(DelayedArray::rowSums(P^2))

## Increasing the block size increases the speed but also memory usage:
setAutoBlockSize(2e8)
row_normalized_P2 <- P / sqrt(DelayedArray::rowSums(P^2))
stopifnot(all.equal(row_normalized_P, row_normalized_P2))

## Back to sparse representation:
DelayedArray:::set_verbose_block_processing(FALSE)
row_normalized_p2 <- as(row_normalized_P, "sparseMatrix")
stopifnot(all.equal(row_normalized_p1, row_normalized_p2))

setAutoBlockSize()  # reset automatic block size to factory settings

## End(Not run)
```

DelayedArray-stats *Statistical functions on DelayedArray objects*

Description

Statistical functions on DelayedArray objects.

All these functions are implemented as delayed operations.

Usage

```
## --- The Normal Distribution ----- ##

## S4 method for signature 'DelayedArray'
dnorm(x, mean=0, sd=1, log=FALSE)
## S4 method for signature 'DelayedArray'
pnorm(q, mean=0, sd=1, lower.tail=TRUE, log.p=FALSE)
## S4 method for signature 'DelayedArray'
qnorm(p, mean=0, sd=1, lower.tail=TRUE, log.p=FALSE)

## --- The Binomial Distribution --- ##

## S4 method for signature 'DelayedArray'
dbinom(x, size, prob, log=FALSE)
## S4 method for signature 'DelayedArray'
pbinom(q, size, prob, lower.tail=TRUE, log.p=FALSE)
## S4 method for signature 'DelayedArray'
qbinom(p, size, prob, lower.tail=TRUE, log.p=FALSE)

## --- The Poisson Distribution ---- ##

## S4 method for signature 'DelayedArray'
dpois(x, lambda, log=FALSE)
## S4 method for signature 'DelayedArray'
ppois(q, lambda, lower.tail=TRUE, log.p=FALSE)
## S4 method for signature 'DelayedArray'
qpois(p, lambda, lower.tail=TRUE, log.p=FALSE)

## --- The Logistic Distribution --- ##

## S4 method for signature 'DelayedArray'
dlogis(x, location=0, scale=1, log=FALSE)
## S4 method for signature 'DelayedArray'
plogis(q, location=0, scale=1, lower.tail=TRUE, log.p=FALSE)
## S4 method for signature 'DelayedArray'
qlogis(p, location=0, scale=1, lower.tail=TRUE, log.p=FALSE)
```

Arguments

x, q, p	A DelayedArray object.
mean, sd, log, lower.tail, log.p, size, prob, lambda, location, scale	See ?stats::dnorm, ?stats::dbinom, ?stats::dpois, and ?stats::dlogis, for a description of these arguments.

See Also

- dnorm, dbinom, dpois, and dlogis in the **stats** package for the corresponding operations on ordinary arrays or matrices.
- matrixStats-methods for DelayedMatrix row/col summarization.
- DelayedArray objects.
- HDF5Array objects in the **HDF5Array** package.
- array objects in base R.

Examples

```
a <- array(4 * runif(1500000), dim=c(10000, 30, 5))
A <- DelayedArray(a)
A

A2 <- dnorm(A + 1)[ , , -3]  # very fast! (operations are delayed)
A2

a2 <- as.array(A2)           # "realize" 'A2' in memory (as an ordinary
                             # array)

DelayedArray(a2) == A2       # DelayedArray object of type "logical"
stopifnot(all(DelayedArray(a2) == A2))


library(HDF5Array)
A3 <- as(A2, "HDF5Array")    # "realize" 'A2' on disk (as an HDF5Array
                             # object)

A3 == A2                     # DelayedArray object of type "logical"
stopifnot(all(A3 == A2))

## See '?DelayedArray' for general information about DelayedArray objects
## and their "realization".
```

DelayedArray-utils *Common operations on DelayedArray objects*

Description

Common operations on DelayedArray objects.

Details

The operations currently supported on DelayedArray objects are:

Delayed operations:

- rbind and cbind

- all the members of the Ops, Math, and Math2 groups
- !
- is.na, is.finite, is.infinite, is.nan
- type<-
- lengths
- nchar, tolower, toupper, grepl, sub, gsub
- pmax2 and pmin2
- sweep
- scale (when the supplied center and scale are not TRUE)
- paste2, add_prefix, add_suffix
- statistical functions like dnorm, dbinom, dpois, and dlogis (for the Normal, Binomial, Poisson, and Logistic distribution, respectively) and related functions (documented in DelayedArray-stats)

Block-processed operations:

- anyNA, which, nzwhich
- unique, table
- all the members of the Summary group
- mean
- apply

Mix delayed and block-processed operations:

- scale (when the supplied center and/or scale are TRUE)

See Also

- cbind in the **base** package for rbind/cbind'ing ordinary arrays.
- arbind and acbind in this package (**DelayedArray**) for binding ordinary arrays of arbitrary dimensions along their rows or columns.
- is.na, !, table, mean, apply, and %*% in the **base** package for the corresponding operations on ordinary arrays or matrices.
- DelayedArray-stats for statistical functions on DelayedArray objects.
- matrixStats-methods for DelayedMatrix row/col summarization.
- DelayedArray objects.
- HDF5Array objects in the **HDF5Array** package.
- S4groupGeneric in the **methods** package for the members of the Ops, Math, and Math2 groups.
- sweep and scale in the **base** package.
- paste2 in the **BiocGenerics** package.

Examples

```
## ---------------------------------------------------------------------
## BIND DelayedArray OBJECTS
## ---------------------------------------------------------------------
## DelayedArray objects can be bound along their 1st (rows) or 2nd
## (columns) dimension with rbind() or cbind(). These operations are
## equivalent to arbind() and acbind(), respectively, and are all
## delayed.

## On 2D objects:
library(HDF5Array)
toy_h5 <- system.file("extdata", "toy.h5", package="HDF5Array")
h5ls(toy_h5)

M1 <- HDF5Array(toy_h5, "M1")
M2 <- HDF5Array(toy_h5, "M2")

M12 <- rbind(M1, t(M2))            # delayed
M12
colMeans(M12)                      # block-processed

## On objects with more than 2 dimensions:
example(arbind)  # to create arrays a1, a2, a3

A1 <- DelayedArray(a1)
A2 <- DelayedArray(a2)
A3 <- DelayedArray(a3)
A123 <- rbind(A1, A2, A3)          # delayed
A123

## On 1D objects:
v1 <- array(11:15, 5, dimnames=list(LETTERS[1:5]))
v2 <- array(letters[1:3])
V1 <- DelayedArray(v1)
V2 <- DelayedArray(v2)
V12 <- rbind(V1, V2)
V12

## Not run: cbind(V1, V2)  # Error! (the objects to cbind() must have at least 2
               # dimensions)

## End(Not run)

## Note that base::rbind() and base::cbind() do something completely
## different on ordinary arrays that are not matrices. They treat them
## as if they were vectors:
rbind(a1, a2, a3)
cbind(a1, a2, a3)
rbind(v1, v2)
cbind(v1, v2)

## Also note that DelayedArray objects of arbitrary dimensions can be
```

```
## stored inside a DataFrame object as long as they all have the same
## first dimension (nrow()):
DF <- DataFrame(M=I(tail(M1, n=5)), A=I(A3), V=I(V1))
DF[-3, ]
DF2 <- rbind(DF, DF)
DF2$V

## Sanity checks:
m1 <- as.matrix(M1)
m2 <- as.matrix(M2)
stopifnot(identical(rbind(m1, t(m2)), as.matrix(M12)))
stopifnot(identical(arbind(a1, a2, a3), as.array(A123)))
stopifnot(identical(arbind(v1, v2), as.array(V12)))
stopifnot(identical(rbind(DF$M, DF$M), DF2$M))
stopifnot(identical(rbind(DF$A, DF$A), DF2$A))
stopifnot(identical(rbind(DF$V, DF$V), DF2$V))

## ---------------------------------------------------------------------
## MORE OPERATIONS
## ---------------------------------------------------------------------

M1 >= 0.5 & M1 < 0.75             # delayed
log(M1)                           # delayed
pmax2(M2, 0)                      # delayed

type(M2) <- "integer"             # delayed
M2

## table() is block-processed:
a4 <- array(sample(50L, 2000000L, replace=TRUE), c(200, 4, 2500))
A4 <- as(a4, "HDF5Array")
table(A4)
a5 <- array(sample(20L, 2000000L, replace=TRUE), c(200, 4, 2500))
A5 <- as(a5, "HDF5Array")
table(A5)

A4 - 2 * A5                       # delayed
table(A4 - 2 * A5)                # block-processed

## range() is block-processed:
range(A4 - 2 * A5)
range(M1)

cmeans <- colMeans(M2)            # block-processed
sweep(M2, 2, cmeans)              # delayed
scale(M2)                         # delayed & block-processed
scale(M2, center=FALSE, scale=10)  # delayed

paste2(A3, letters[1:5])          # delayed
A6 <- add_prefix("ID", A3)        # delayed
add_suffix(A6, ".fasta")          # delayed
```

DelayedMatrix-mult *DelayedMatrix multiplication and cross-product*

Description

Like ordinary matrices in base R, DelayedMatrix objects and derivatives can be multiplied with the `%*%` operator. They also support `crossprod()` and `tcrossprod()`.

Details

Note that matrix multiplication is not delayed: the output matrix is realized block by block. The *automatic realization backend* controls where realization happens e.g. in memory as an ordinary matrix if not set (i.e. set to `NULL`), or in an HDF5 file if set to `"HDF5Array"`. See `?setAutoRealizationBackend` for more information about realization backends.

Value

The object returned by matrix multiplication involving at least one DelayedMatrix object will be either:

- An ordinary matrix if the *automatic realization backend* is `NULL` (the default).
- A DelayedMatrix object if the *automatic realization backend* is not `NULL`. In this case, the returned DelayedMatrix object will be either *pristine* or made of several *pristine* DelayedMatrix objects bound together (via `rbind()` or `cbind()`, both are delayed operations).

  For example, if the *automatic realization backend* is `"HDF5Array"`, then the returned DelayedMatrix object will be either an HDF5Array object, or it will be a DelayedMatrix object made of several HDF5Array objects bound together.

See Also

- `%*%` and `crossprod` in base R.
- `getAutoRealizationBackend` and `setAutoRealizationBackend` for getting and setting the *automatic realization backend*.
- matrixStats-methods for DelayedMatrix row/col summarization.
- DelayedMatrix-rowsum for `rowsum()` and `colsum()` methods for DelayedMatrix objects.
- DelayedArray objects.
- `writeHDF5Array` in the **HDF5Array** package for writing an array-like object to an HDF5 file and other low-level utilities to control the location of automatically created HDF5 datasets.
- HDF5Array objects in the **HDF5Array** package.

Examples

```
library(HDF5Array)
toy_h5 <- system.file("extdata", "toy.h5", package="HDF5Array")
h5ls(toy_h5)
M1 <- HDF5Array(toy_h5, "M1")

m <- matrix(runif(50000), ncol=nrow(M1))

## Set backend to NULL for in-memory realization (this is the default):
setAutoRealizationBackend()
p1 <- m %*% M1  # an ordinary matrix

## Set backend to HDF5Array for realization in HDF5 file:
setAutoRealizationBackend("HDF5Array")
P2 <- m %*% M1  # an HDF5Array object
P2
path(P2)  # HDF5 file where the result got written

## Sanity checks:
stopifnot(
  is.matrix(p1),
  all.equal(p1, m %*% as.matrix(M1)),
  is(P2, "HDF5Array"),
  all.equal(as.matrix(P2), p1)
)
setAutoRealizationBackend()  # restore default (NULL)
```

DelayedMatrix-rowsum *rowsum() and colsum() on a DelayedMatrix object*

Description

Like ordinary matrices in base R, DelayedMatrix objects and derivatives support `rowsum()` and `colsum()`.

Details

Note that the `rowsum()` and `colsum()` operations are not delayed: the output matrix is realized block by block. The *automatic realization backend* controls where realization happens e.g. in memory as an ordinary matrix if not set (i.e. set to `NULL`), or in an HDF5 file if set to `"HDF5Array"`. See `?setAutoRealizationBackend` for more information about realization backends.

Value

The object returned by the `rowsum()` or `colsum()` method for DelayedMatrix objects will be either:

- An ordinary matrix if the *automatic realization backend* is `NULL` (the default).

- A DelayedMatrix object if the *automatic realization backend* is not NULL. In this case, the returned DelayedMatrix object will be either *pristine* or made of several *pristine* DelayedMatrix objects bound together (via rbind() or cbind(), both are delayed operations).

  For example, if the *automatic realization backend* is "HDF5Array", then the returned DelayedMatrix object will be either an HDF5Array object, or it will be a DelayedMatrix object made of several HDF5Array objects bound together.

See Also

- rowsum in base R.
- S4Arrays::rowsum in the **S4Arrays** package for the rowsum() and colsum() S4 generic functions.
- getAutoRealizationBackend and setAutoRealizationBackend for getting and setting the *automatic realization backend*.
- matrixStats-methods for DelayedMatrix row/col summarization.
- DelayedMatrix-mult for DelayedMatrix multiplication and cross-product.
- DelayedArray objects.
- writeHDF5Array in the **HDF5Array** package for writing an array-like object to an HDF5 file and other low-level utilities to control the location of automatically created HDF5 datasets.
- HDF5Array objects in the **HDF5Array** package.

Examples

```
library(HDF5Array)
set.seed(123)
m0 <- matrix(runif(14400000), ncol=2250,
             dimnames=list(NULL, sprintf("C%04d", 1:2250)))
M0 <- writeHDF5Array(m0, chunkdim=c(200, 250))
dimnames(M0) <- dimnames(m0)

## --- rowsum() ---

group <- sample(90, nrow(M0), replace=TRUE)  # define groups of rows
rs <- rowsum(M0, group)
rs[1:5, 1:8]
rs2 <- rowsum(M0, group, reorder=FALSE)
rs2[1:5, 1:8]

## Let's see block processing in action:
DelayedArray:::set_verbose_block_processing(TRUE)
setAutoBlockSize(2e6)
rs3 <- rowsum(M0, group)
setAutoBlockSize()
DelayedArray:::set_verbose_block_processing(FALSE)

## Sanity checks:
stopifnot(all.equal(rowsum(m0, group), rs))
stopifnot(all.equal(rowsum(m0, group, reorder=FALSE), rs2))
stopifnot(all.equal(rs, rs3))
```

```
## --- colsum() ---

group <- sample(30, ncol(M0), replace=TRUE)  # define groups of cols
cs <- colsum(M0, group)
cs[1:5, 1:7]
cs2 <- colsum(M0, group, reorder=FALSE)
cs2[1:5, 1:7]

## Sanity checks:
stopifnot(all.equal(colsum(m0, group), cs))
stopifnot(all.equal(cs, t(rowsum(t(m0), group))))
stopifnot(all.equal(cs, t(rowsum(t(M0), group))))
stopifnot(all.equal(colsum(m0, group, reorder=FALSE), cs2))
stopifnot(all.equal(cs2, t(rowsum(t(m0), group, reorder=FALSE))))
stopifnot(all.equal(cs2, t(rowsum(t(M0), group, reorder=FALSE))))
```

DelayedNaryIsoOp-class *DelayedNaryIsoOp objects*

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedNaryIsoOp class provides a formal representation of a *delayed N-ary isometric operation*. It is a concrete subclass of the DelayedNaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:

```
DelayedOp
    ^
    |
DelayedNaryOp
    ^
    |
DelayedNaryIsoOp
```

DelayedNaryIsoOp objects are used inside a DelayedArray object to represent the *delayed N-ary isometric operation* carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedNaryIsoOp'
summary(object, ...)

## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
```

```
## S4 method for signature 'DelayedNaryIsoOp'
dim(x)

## S4 method for signature 'DelayedNaryIsoOp'
dimnames(x)

## S4 method for signature 'DelayedNaryIsoOp'
extract_array(x, index)

## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedNaryIsoOp'
is_sparse(x)

## S4 method for signature 'DelayedNaryIsoOp'
extract_sparse_array(x, index)
```

Arguments

x, object	A DelayedNaryIsoOp object.
index	See ?extract_array in the **S4Arrays** package for a description of the index argument.
...	Not used.

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- extract_array in the **S4Arrays** package.
- extract_sparse_array in the **SparseArray** package.

Examples

```
## DelayedNaryIsoOp extends DelayedNaryOp which extends DelayedOp:
extends("DelayedNaryIsoOp")

## ---------------------------------------------------------------------
## BASIC EXAMPLE
## ---------------------------------------------------------------------
m1 <- matrix(101:130, ncol=5)
m2 <- matrix(runif(30), ncol=5)
M1 <- DelayedArray(m1)
M2 <- DelayedArray(m2)
showtree(M1)
showtree(M2)

M <- M1 / M2
```

```
showtree(M)
class(M@seed)        # a DelayedNaryIsoOp object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
## ---------------------------------------------------------------------
sm1 <- sparseMatrix(i=c(1, 6), j=c(1, 4), x=c(11, 64), dims=6:5)
SM1 <- DelayedArray(sm1)
sm2 <- sparseMatrix(i=c(2, 6), j=c(1, 5), x=c(21, 65), dims=6:5)
SM2 <- DelayedArray(sm2)
showtree(SM1)
showtree(SM2)
is_sparse(SM1)       # TRUE
is_sparse(SM2)       # TRUE

SM3 <- SM1 - SM2
showtree(SM3)
class(SM3@seed)      # a DelayedNaryIsoOp object
is_sparse(SM3@seed)  # TRUE

M4 <- SM1 / SM2
showtree(M4)
class(M4@seed)       # a DelayedNaryIsoOp object
is_sparse(M4@seed)   # FALSE

## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(M@seed) == "DelayedNaryIsoOp")
stopifnot(class(SM3@seed) == "DelayedNaryIsoOp")
stopifnot(is_sparse(SM3@seed))
stopifnot(class(M4@seed) == "DelayedNaryIsoOp")
stopifnot(!is_sparse(M4@seed))
```

`DelayedOp-class` *DelayedOp objects*

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

In a DelayedArray object, the delayed operations are stored as a tree where the leaves are operands and the nodes are the operations. Each node in the tree is a DelayedOp derivative representing a particular delayed operation.

DelayedOp is a virtual class with 8 concrete subclasses. Each subclass provides a formal representation for a particular kind of delayed operation.

Usage

```
is_noop(x)
```

Arguments

x	A DelayedSubset, DelayedAperm, or DelayedSetDimnames object.

Details

8 types of nodes are currently supported. Each type is a DelayedOp subclass:

```
Node type                          Represented operation
-----------------------------------------------------------------
DelayedOp (VIRTUAL)
-----------------------------------------------------------------
* DelayedUnaryOp (VIRTUAL)
  o DelayedSubset                 Multi-dimensional single bracket
                                  subsetting.
  o DelayedAperm                  Extended aperm() (can drop and/or
                                  add ineffective dimensions).
  o DelayedUnaryIsoOp (VIRTUAL)   Unary op that preserves the
                                  geometry.
    - DelayedUnaryIsoOpStack      Simple ops stacked together.
    - DelayedUnaryIsoOpWithArgs   One op with vector-like arguments
                                  along the dimensions of the input.
    - DelayedSubassign            Multi-dimensional single bracket
                                  subassignment.
    - DelayedSetDimnames          Set/replace the dimnames.
-----------------------------------------------------------------
* DelayedNaryOp (VIRTUAL)
  o DelayedNaryIsoOp              N-ary op that preserves the
                                  geometry.
  o DelayedAbind                  abind()
-----------------------------------------------------------------
```

All DelayedOp objects must comply with the *seed contract* i.e. they must support `dim()`, `dimnames()`, and `extract_array()`. See ?`extract_array` in the **S4Arrays** package for more information about the *seed contract*. This makes them de facto array-like objects. However, end users will never interact with them directly, except for the root of the tree which is the DelayedArray object itself and the only node in the tree that they are able to see and touch.

`is_noop()` can only be called on a DelayedSubset, DelayedAperm, or DelayedSetDimnames object at the moment, and will return `TRUE` if the object represents a no-op.

Note

The DelayedOp virtual class and its 8 concrete subclasses are used inside a DelayedArray object to represent delayed operations carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

See Also

- DelayedOp concrete subclasses: DelayedSubset, DelayedAperm, DelayedUnaryIsoOpStack, DelayedUnaryIsoOpWithArgs, DelayedSubassign, DelayedSetDimnames, DelayedNaryIsoOp, and DelayedAbind.
- DelayedArray objects.
- `showtree` to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- `simplify` to simplify the tree of delayed operations carried by a DelayedArray object.
- `extract_array` in the **S4Arrays** package.

`DelayedSetDimnames-class`
DelayedSetDimnames objects

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedSetDimnames class provides a formal representation of a *delayed "set dimnames" operation*. It is a concrete subclass of the DelayedUnaryIsoOp virtual class, which itself is a subclass of the DelayedUnaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:

```
DelayedOp
    ^
    |
DelayedUnaryOp
    ^
    |
DelayedUnaryIsoOp
    ^
    |
DelayedSetDimnames
```

DelayedSetDimnames objects are used inside a DelayedArray object to represent the *delayed "set dimnames" operations* carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedSetDimnames'
is_noop(x)

## S4 method for signature 'DelayedSetDimnames'
summary(object, ...)
```

```
## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## DelayedSetDimnames objects inherit the default dim()
## and extract_array() methods defined for DelayedUnaryIsoOp
## derivatives, but overwite their dimnames() method.

## S4 method for signature 'DelayedSetDimnames'
dimnames(x)

## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## DelayedSetDimnames objects inherit the default
## is_sparse() and extract_sparse_array() methods defined
## for DelayedUnaryIsoOp derivatives.
```

Arguments

x, object	A DelayedSetDimnames object.
...	Not used.

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.

Examples

```
## DelayedSetDimnames extends DelayedUnaryIsoOp, which extends
## DelayedUnaryOp, which extends DelayedOp:
extends("DelayedSetDimnames")

## ---------------------------------------------------------------------
## BASIC EXAMPLE
## ---------------------------------------------------------------------
m0 <- matrix(1:30, ncol=5, dimnames=list(letters[1:6], NULL))
M2 <- M1 <- M0 <- DelayedArray(m0)
showtree(M0)

dimnames(M1) <- list(NULL, LETTERS[1:5])
showtree(M1)
class(M1@seed)      # a DelayedSetDimnames object

colnames(M2) <- LETTERS[1:5]
showtree(M2)
class(M2@seed)      # a DelayedSetDimnames object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
```

```
## ---------------------------------------------------------------------
## DelayedSetDimnames objects always propagate sparsity.

sm0 <- sparseMatrix(i=c(1, 4), j=c(1, 3), x=c(11, 43), dims=4:3)
SM <- SM0 <- DelayedArray(sm0)
showtree(SM0)
is_sparse(SM0)      # TRUE

dimnames(SM) <- list(letters[1:4], LETTERS[1:3])
showtree(SM)
class(SM@seed)      # a DelayedSetDimnames object
is_sparse(SM@seed)  # TRUE

## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(M1@seed) == "DelayedSetDimnames")
stopifnot(class(M2@seed) == "DelayedSetDimnames")
stopifnot(class(SM@seed) == "DelayedSetDimnames")
stopifnot(is_sparse(SM@seed))
```

`DelayedSubassign-class` *DelayedSubassign objects*

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedSubassign class provides a formal representation of a *delayed multi-dimensional single bracket subassignment*. It is a concrete subclass of the DelayedUnaryIsoOp virtual class, which itself is a subclass of the DelayedUnaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:

```
    DelayedOp
        ^
        |
 DelayedUnaryOp
        ^
        |
DelayedUnaryIsoOp
        ^
        |
DelayedSubassign
```

DelayedSubassign objects are used inside a DelayedArray object to represent the *delayed multi-dimensional single bracket subassignments* carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedSubassign'
is_noop(x)

## S4 method for signature 'DelayedSubassign'
summary(object, ...)

## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## DelayedSubassign objects inherit the default dim()
## and dimnames() methods defined for DelayedUnaryIsoOp
## derivatives, but overwite their extract_array() method.

## S4 method for signature 'DelayedSubassign'
extract_array(x, index)

## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedSubassign'
is_sparse(x)

## S4 method for signature 'DelayedSubassign'
extract_sparse_array(x, index)
```

Arguments

x, object	A DelayedSubassign object.
index	See ?extract_array in the **S4Arrays** package for a description of the index argument.
...	Not used.

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- extract_array in the **S4Arrays** package.
- extract_sparse_array in the **SparseArray** package.

Examples

```
## DelayedSubassign extends DelayedUnaryIsoOp, which extends
## DelayedUnaryOp, which extends DelayedOp:
extends("DelayedSubassign")

## ---------------------------------------------------------------------
## BASIC EXAMPLE
## ---------------------------------------------------------------------
```

```
m0 <- matrix(1:30, ncol=5)
M2 <- M1 <- M0 <- DelayedArray(m0)
showtree(M0)

M1[2:5, 5:4] <- 100
showtree(M1)
class(M1@seed)        # a DelayedSubassign object

M2[2:5, 5:4] <- matrix(101:108, ncol=2)
showtree(M2)
class(M2@seed)        # a DelayedSubassign object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
## ---------------------------------------------------------------------

## DelayedSubassign objects don't propagate sparsity at the moment, that
## is, is_sparse() always returns FALSE on them.

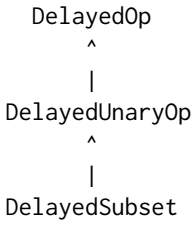
## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(M1@seed) == "DelayedSubassign")
stopifnot(class(M2@seed) == "DelayedSubassign")
```

`DelayedSubset-class` *DelayedSubset objects*

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedSubset class provides a formal representation of a *delayed multi-dimensional single bracket subsetting operation*. It is a concrete subclass of the DelayedUnaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:



DelayedSubset objects are used inside a DelayedArray object to represent the *delayed multi-dimensional single bracket subsetting operations* carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedSubset'
is_noop(x)

## S4 method for signature 'DelayedSubset'
summary(object, ...)

## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedSubset'
dim(x)

## S4 method for signature 'DelayedSubset'
dimnames(x)

## S4 method for signature 'DelayedSubset'
extract_array(x, index)

## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedSubset'
is_sparse(x)

## S4 method for signature 'DelayedSubset'
extract_sparse_array(x, index)
```

Arguments

x, object	A DelayedSubset object.
index	See ?extract_array in the **S4Arrays** package for a description of the index argument.
...	Not used.

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- extract_array in the **S4Arrays** package.
- extract_sparse_array in the **SparseArray** package.

Examples

```
## DelayedSubset extends DelayedUnaryOp which extends DelayedOp:
extends("DelayedSubset")

## ---------------------------------------------------------------------
```

```
## BASIC EXAMPLE
## ---------------------------------------------------------------------
a0 <- array(1:60, dim=5:3)
A0 <- DelayedArray(a0)
showtree(A0)

A <- A0[2:1, -4, 3, drop=FALSE]
showtree(A)
class(A@seed)        # a DelayedSubset object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
## ---------------------------------------------------------------------
sm0 <- sparseMatrix(i=c(1, 4), j=c(1, 3), x=c(11, 43), dims=4:3)
SM0 <- DelayedArray(sm0)
showtree(SM0)
is_sparse(SM0)       # TRUE

SM1 <- SM0[-1, 3:2, drop=FALSE]
showtree(SM1)
class(SM1@seed)      # a DelayedSubset object
is_sparse(SM1@seed)  # TRUE

## Duplicated indices break structural sparsity.
M2 <- SM0[-1, c(3:2, 2), drop=FALSE]
showtree(M2)
class(M2@seed)       # a DelayedSubset object
is_sparse(M2@seed)   # FALSE

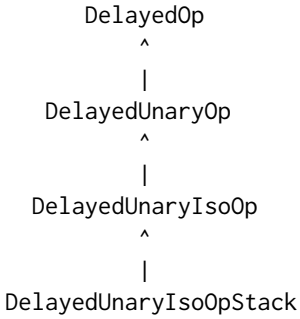
## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(A@seed) == "DelayedSubset")
stopifnot(class(SM1@seed) == "DelayedSubset")
stopifnot(is_sparse(SM1@seed))
stopifnot(class(M2@seed) == "DelayedSubset")
stopifnot(!is_sparse(M2@seed))
```

DelayedUnaryIsoOpStack-class *DelayedUnaryIsoOpStack objects*

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedUnaryIsoOpStack class provides a formal representation of a *stack of delayed unary isometric operations*, that is, of a group of delayed unary isometric operations stacked (a.k.a. piped) together. It is a concrete subclass of the DelayedUnaryIsoOp virtual class, which itself is a subclass of the DelayedUnaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:



DelayedUnaryIsoOpStack objects are used inside a DelayedArray object to represent groups of delayed unary isometric operations carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedUnaryIsoOpStack'
summary(object, ...)

## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## DelayedUnaryIsoOpStack objects inherit the default dim()
## and dimnames() methods defined for DelayedUnaryIsoOp
## derivatives, but overwite their extract_array() method.

## S4 method for signature 'DelayedUnaryIsoOpStack'
extract_array(x, index)

## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedUnaryIsoOpStack'
is_sparse(x)

## S4 method for signature 'DelayedUnaryIsoOpStack'
extract_sparse_array(x, index)
```

Arguments

x, object	A DelayedUnaryIsoOpStack object.
index	See ?extract_array in the **S4Arrays** package for a description of the index argument.
...	Not used.

Details

A DelayedUnaryIsoOpStack object is used to represent the delayed version of an operation of the form:

```
out <- a |> OP1 |> OP2 |> ... |> OPk
```

where:

- OP1, OP2, ..., OPk are isometric array transformations i.e. operations that return an array with the same dimensions as the input array.
- a is the input array.
- The output (out) is an array of same dimensions as a.

In addition, each operation (OP) in the pipe must satisfy the property that each value in the output array must be determined **solely** by the corresponding value in the input array. In other words:

```
a |> OP |> `[`(i_1, i_2, ..., i_n)   # i.e. OP(a)[i_1, i_2, ..., i_n]
```

must be equal to:

```
a |> `[`(i_1, i_2, ..., i_n) |> OP   # i.e. OP(a[i_1, i_2, ..., i_n])
```

for any valid multidimensional index (i_1, i_2, ..., i_n).

We refer to this property as the *locality principle*.

Concrete examples:

1. Things like is.na(), is.finite(), logical negation (!), nchar(), tolower().
2. Most functions in the Math and Math2 groups e.g. log(), sqrt(), abs(), ceiling(), round(), etc... Notable exceptions are the cum*() functions (cummin(), cummax(), cumsum(), and cumprod()): they don't satisfy the *locality principle*.
3. Operations in the Ops group when one operand is an array and the other a scalar e.g. a + 10, 2 ^ a, a <= 0.5, etc...

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- extract_array in the **S4Arrays** package.
- extract_sparse_array in the **SparseArray** package.

Examples

```
## DelayedUnaryIsoOpStack extends DelayedUnaryIsoOp, which extends
## DelayedUnaryOp, which extends DelayedOp:
extends("DelayedUnaryIsoOpStack")

## ---------------------------------------------------------------------
## BASIC EXAMPLE
```

```
## ---------------------------------------------------------------------
m0 <- matrix(runif(12), ncol=3)
M0 <- DelayedArray(m0)
showtree(M0)

M <- log(1 + M0) / 10
showtree(M)
class(M@seed)        # a DelayedUnaryIsoOpStack object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
## ---------------------------------------------------------------------
sm0 <- sparseMatrix(i=c(1, 4), j=c(1, 3), x=c(11, 43), dims=4:3)
SM0 <- DelayedArray(sm0)
showtree(SM0)
is_sparse(SM0)       # TRUE

M1 <- SM0 - 11
showtree(M1)
class(M1@seed)       # a DelayedUnaryIsoOpStack object
is_sparse(M1@seed)   # FALSE

SM2 <- 10 * SM0
showtree(SM2)
class(SM2@seed)      # a DelayedUnaryIsoOpStack object
is_sparse(SM2@seed)  # TRUE

M3 <- SM0 / 0
showtree(M3)
class(M3@seed)       # a DelayedUnaryIsoOpStack object
is_sparse(M3@seed)   # FALSE

SM4 <- log(1 + SM0) / 10
showtree(SM4)
class(SM4@seed)      # a DelayedUnaryIsoOpStack object
is_sparse(SM4@seed)  # TRUE

SM5 <- 2 ^ SM0 - 1
showtree(SM5)
class(SM5@seed)      # a DelayedUnaryIsoOpStack object
is_sparse(SM5@seed)  # TRUE

## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(M@seed) == "DelayedUnaryIsoOpStack")
stopifnot(class(M1@seed) == "DelayedUnaryIsoOpStack")
stopifnot(!is_sparse(M1@seed))
stopifnot(class(SM2@seed) == "DelayedUnaryIsoOpStack")
stopifnot(is_sparse(SM2@seed))
stopifnot(class(M3@seed) == "DelayedUnaryIsoOpStack")
stopifnot(!is_sparse(M3@seed))
stopifnot(class(SM4@seed) == "DelayedUnaryIsoOpStack")
```

```
stopifnot(is_sparse(SM4@seed))
stopifnot(class(SM5@seed) == "DelayedUnaryIsoOpStack")
stopifnot(is_sparse(SM5@seed))
```

DelayedUnaryIsoOpWithArgs-class
DelayedUnaryIsoOpWithArgs objects

Description

NOTE: This man page is about DelayedArray internals and is provided for developers and advanced users only.

The DelayedUnaryIsoOpWithArgs class provides a formal representation of a *delayed unary isometric operation with vector-like arguments going along the dimensions of the input array*. It is a concrete subclass of the DelayedUnaryIsoOp virtual class, which itself is a subclass of the DelayedUnaryOp virtual class, which itself is a subclass of the DelayedOp virtual class:

```
                DelayedOp
                    ^
                    |
              DelayedUnaryOp
                    ^
                    |
            DelayedUnaryIsoOp
                    ^
                    |
      DelayedUnaryIsoOpWithArgs
```

DelayedUnaryIsoOpWithArgs objects are used inside a DelayedArray object to represent the *delayed unary isometric operations with vector-like arguments going along the dimensions of the input array* carried by the object. They're never exposed to the end user and are not intended to be manipulated directly.

Usage

```
## S4 method for signature 'DelayedUnaryIsoOpWithArgs'
summary(object, ...)

## ~ ~ ~ Seed contract ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## DelayedUnaryIsoOpWithArgs objects inherit the default dim()
## and dimnames() methods defined for DelayedUnaryIsoOp
## derivatives, but overwite their extract_array() method.

## S4 method for signature 'DelayedUnaryIsoOpWithArgs'
extract_array(x, index)
```

```
## ~ ~ ~ Propagation of sparsity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

## S4 method for signature 'DelayedUnaryIsoOpWithArgs'
is_sparse(x)

## S4 method for signature 'DelayedUnaryIsoOpWithArgs'
extract_sparse_array(x, index)
```

Arguments

x, object	A DelayedUnaryIsoOpWithArgs object.
index	See ?extract_array in the **S4Arrays** package for a description of the index argument.
...	Not used.

Details

A DelayedUnaryIsoOpWithArgs object is used to represent the delayed version of an operation of the form:

```
out <- OP(L1, L2, ..., a, R1, R2, ...)
```

where:

- OP is an isometric array transformation i.e. a transformation that returns an array with the same dimensions as the input array.
- a is the input array.
- L1, L2, etc... are the left arguments.
- R1, R2, etc... are the right arguments.
- The output (out) is an array of same dimensions as a.

Some of the arguments (left or right) can go along the dimensions of the input array. For example if a is a 12 x 150 x 5 array, argument L2 is considered to go along the 3rd dimension if its length is 5 and if the result of:

```
OP(L1, L2[k], ..., a[ , , k, drop=FALSE], R1, R2, ...)
```

is the same as out[, , k, drop=FALSE] for any index k.

More generally speaking, if, say, arguments L2, L3, R1, and R2 go along the 3rd, 1st, 2nd, and 1st dimensions, respectively, then each value in the output array (a[i, j, k]) must be determined solely by the corresponding values in the input array (a[i, j, k]) and arguments (L2[k], L3[i], R1[j], R2[i]). In other words, out[i, j, k] must be equal to:

```
OP(L1, L2[k], L3[i], ..., a[i, j, k], R1[j], R2[i], ...)
```

for any 1 <= i <= 12, 1 <= j <= 150, and 1 <= k <= 5.

We refer to this property as the *locality principle*.

Concrete examples:

1. Addition (or any operation in the Ops group) of an array a and an atomic vector v of length dim(a)[[1]]:
   - `+`(a, v): OP is `+`, right argument goes along the 1st dimension.
   - `<=`(a, v): OP is `<=`, right argument goes along the 1st dimension.
   - `&`(v, a): OP is `&`, left argument goes along the 1st dimension.
2. scale(x, center=v1, scale=v2): OP is scale, right arguments center and scale go along the 2nd dimension.

Note that if OP has no argument that goes along a dimension of the input array, then the delayed operation is better represented with a DelayedUnaryIsoOpStack object.

See Also

- DelayedOp objects.
- showtree to visualize the nodes and access the leaves in the tree of delayed operations carried by a DelayedArray object.
- extract_array in the **S4Arrays** package.
- extract_sparse_array in the **SparseArray** package.

Examples

```
## DelayedUnaryIsoOpWithArgs extends DelayedUnaryIsoOp, which extends
## DelayedUnaryOp, which extends DelayedOp:
extends("DelayedUnaryIsoOpWithArgs")

## ---------------------------------------------------------------------
## BASIC EXAMPLE
## ---------------------------------------------------------------------
m0 <- matrix(runif(12), ncol=3)
M0 <- DelayedArray(m0)
showtree(M0)

M <- M0 + 101:104
showtree(M)
class(M@seed)        # a DelayedUnaryIsoOpWithArgs object

## ---------------------------------------------------------------------
## PROPAGATION OF SPARSITY
## ---------------------------------------------------------------------
sm0 <- sparseMatrix(i=c(1, 4), j=c(1, 3), x=c(11, 43), dims=4:3)
SM0 <- DelayedArray(sm0)
showtree(SM0)
is_sparse(SM0)       # TRUE

M1 <- SM0 + 101:104
```

```
showtree(M1)
class(M1@seed)       # a DelayedUnaryIsoOpWithArgs object
is_sparse(M1@seed)   # FALSE

SM2 <- SM0 * 101:104
showtree(SM2)
class(SM2@seed)      # a DelayedUnaryIsoOpWithArgs object
is_sparse(SM2@seed)  # TRUE

SM3 <- SM0 * c(101:103, 0)
showtree(SM3)
class(SM3@seed)      # a DelayedUnaryIsoOpWithArgs object
is_sparse(SM3@seed)  # TRUE

M4 <- SM0 * c(101:103, NA)
showtree(M4)
class(M4@seed)       # a DelayedUnaryIsoOpWithArgs object
is_sparse(M4@seed)   # FALSE

M5 <- SM0 * c(101:103, Inf)
showtree(M5)
class(M5@seed)       # a DelayedUnaryIsoOpWithArgs object
is_sparse(M5@seed)   # FALSE

SM6 <- SM0 / 101:104
showtree(SM6)
class(SM6@seed)      # a DelayedUnaryIsoOpWithArgs object
is_sparse(SM6@seed)  # TRUE

M7 <- SM0 / c(101:103, 0)
showtree(M7)
class(M7@seed)       # a DelayedUnaryIsoOpWithArgs object
is_sparse(M7@seed)   # FALSE

M8 <- SM0 / c(101:103, NA)
showtree(M8)
class(M8@seed)       # a DelayedUnaryIsoOpWithArgs object
is_sparse(M8@seed)   # FALSE

SM9 <- SM0 / c(101:103, Inf)
showtree(SM9)
class(SM9@seed)      # a DelayedUnaryIsoOpWithArgs object
is_sparse(SM9@seed)  # TRUE

M10 <- 101:104 / SM0
showtree(M10)
class(M10@seed)      # a DelayedUnaryIsoOpWithArgs object
is_sparse(M10@seed)  # FALSE

## ---------------------------------------------------------------------
## ADVANCED EXAMPLE
## ---------------------------------------------------------------------
## Not ready yet!
```

```
#op <- DelayedArray:::new_DelayedUnaryIsoOpWithArgs(m0,
#          scale,
#          Rargs=list(center=c(1, 0, 100), scale=c(10, 1, 1)),
#          Ralong=c(2, 2))

## ---------------------------------------------------------------------
## SANITY CHECKS
## ---------------------------------------------------------------------
stopifnot(class(M@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(class(M1@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(!is_sparse(M1@seed))
stopifnot(class(SM2@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(is_sparse(SM2@seed))
stopifnot(class(SM3@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(is_sparse(SM3@seed))
stopifnot(class(M4@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(!is_sparse(M4@seed))
stopifnot(class(M5@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(!is_sparse(M5@seed))
stopifnot(class(SM6@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(is_sparse(SM6@seed))
stopifnot(class(M7@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(!is_sparse(M7@seed))
stopifnot(class(M8@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(!is_sparse(M8@seed))
stopifnot(class(SM9@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(is_sparse(SM9@seed))
stopifnot(class(M10@seed) == "DelayedUnaryIsoOpWithArgs")
stopifnot(!is_sparse(M10@seed))
```

`makeCappedVolumeBox` *Utilities to make capped volume boxes*

Description

`makeCappedVolumeBox` returns the dimensions of the biggest multidimensional box (a.k.a. hyperrectangle) that satisfies 3 constraints: (1) its volume is capped, (2) it fits in the *constraining box*, (3) it has the specified shape.

`makeRegularArrayGridOfCappedLengthViewports` makes a RegularArrayGrid object with grid elements that are capped volume boxes with the specified constraints.

These are low-level utilities used internally to support `defaultAutoGrid` and family.

Usage

```
makeCappedVolumeBox(maxvol, maxdim, shape=c("hypercube",
                                            "scale",
                                            "first-dim-grows-first",
                                            "last-dim-grows-first"))
```

```
makeRegularArrayGridOfCappedLengthViewports(refdim,
                            viewport_len,
                            viewport_shape=c("hypercube",
                                             "scale",
                                             "first-dim-grows-first",
                                             "last-dim-grows-first"))
```

Arguments

`maxvol`	The maximum volume of the box to return.
`maxdim`	The dimensions of the constraining box.
`shape`	The shape of the box to return.
`refdim`	The dimensions of the reference array of the grid to return.
`viewport_len`	The maximum length of the elements (a.k.a. viewports) of the grid to return.
`viewport_shape`	The shape of the elements (a.k.a. viewports) of the grid to return.

Details

`makeCappedVolumeBox` returns the dimensions of a box that satisfies the following constraints:

1. The volume of the box is as close as possibe to (but no bigger than) `maxvol`.
2. The box fits in the *constraining box* i.e. in the box whose dimensions are specified via `maxdim`.
3. The box has a non-zero volume if the *constraining box* has a non-zero volume.
4. The shape of the box is as close as possible to the requested shape.

The supported shapes are:

- `hypercube`: The box should be as close as possible to an *hypercube* (a.k.a. *n-cube*), that is, the ratio between its biggest and smallest dimensions should be as close as possible to 1.
- `scale`: The box should have the same proportions as the *constraining box*.
- `first-dim-grows-first`: The box will be grown along its 1st dimension first, then along its 2nd dimension, etc...
- `last-dim-grows-first`: Like `first-dim-grows-first` but starting along the last dimension.

See Also

- `defaultAutoGrid` and family to create automatic grids to use for block processing of array-like objects.
- ArrayGrid in the **S4Arrays** package for the formal representation of grids and viewports.

Examples

```
## ------------------------------------------------------------------------
## makeCappedVolumeBox()
## ------------------------------------------------------------------------

maxdim <- c(50, 12)  # dimensions of the "constraining box"

## "hypercube" shape:
makeCappedVolumeBox(40, maxdim)
makeCappedVolumeBox(120, maxdim)
makeCappedVolumeBox(125, maxdim)
makeCappedVolumeBox(200, maxdim)

## "scale" shape:
makeCappedVolumeBox(40, maxdim, shape="scale")
makeCappedVolumeBox(160, maxdim, shape="scale")

## "first-dim-grows-first" and "last-dim-grows-first" shapes:
makeCappedVolumeBox(120, maxdim, shape="first-dim-grows-first")
makeCappedVolumeBox(149, maxdim, shape="first-dim-grows-first")
makeCappedVolumeBox(150, maxdim, shape="first-dim-grows-first")

makeCappedVolumeBox(40, maxdim, shape="last-dim-grows-first")
makeCappedVolumeBox(59, maxdim, shape="last-dim-grows-first")
makeCappedVolumeBox(60, maxdim, shape="last-dim-grows-first")

## ------------------------------------------------------------------------
## makeRegularArrayGridOfCappedLengthViewports()
## ------------------------------------------------------------------------

grid1a <- makeRegularArrayGridOfCappedLengthViewports(maxdim, 40)
grid1a
as.list(grid1a)  # turn the grid into a list of ArrayViewport objects
table(lengths(grid1a))
stopifnot(maxlength(grid1a) <= 40)  # sanity check

grid1b <- makeRegularArrayGridOfCappedLengthViewports(maxdim, 40,
                                          "first-dim-grows-first")
grid1b
as.list(grid1b)  # turn the grid into a list of ArrayViewport objects
table(lengths(grid1b))
stopifnot(maxlength(grid1b) <= 40)  # sanity check

grid2a <- makeRegularArrayGridOfCappedLengthViewports(maxdim, 120)
grid2a
as.list(grid2a)  # turn the grid into a list of ArrayViewport objects
table(lengths(grid2a))
stopifnot(maxlength(grid2a) <= 120)  # sanity check

grid2b <- makeRegularArrayGridOfCappedLengthViewports(maxdim, 120,
                                          "first-dim-grows-first")
grid2b
```

```
as.list(grid2b)  # turn the grid into a list of ArrayViewport objects
table(lengths(grid2b))
stopifnot(maxlength(grid2b) <= 120)  # sanity check

grid3a <- makeRegularArrayGridOfCappedLengthViewports(maxdim, 200)
grid3a
as.list(grid3a)  # turn the grid into a list of ArrayViewport objects
table(lengths(grid3a))
stopifnot(maxlength(grid3a) <= 200)  # sanity check

grid3b <- makeRegularArrayGridOfCappedLengthViewports(maxdim, 200,
                                          "first-dim-grows-first")
grid3b
as.list(grid3b)  # turn the grid into a list of ArrayViewport objects
table(lengths(grid3b))
stopifnot(maxlength(grid3b) <= 200)  # sanity check
```

`matrixStats-methods` *DelayedMatrix row/col summarization*

Description

Only a small number of row/col summarization methods are provided by the **DelayedArray** package.

See the **DelayedMatrixStats** package for an extensive set of row/col summarization methods.

Usage

```
## N.B.: Showing ONLY the col*() methods (usage of row*() methods is
## the same):

## S4 method for signature 'DelayedMatrix'
colSums(x, na.rm=FALSE, dims=1)

## S4 method for signature 'DelayedMatrix'
colMeans(x, na.rm=FALSE, dims=1)

## S4 method for signature 'DelayedMatrix'
colMins(x, rows=NULL, cols=NULL, na.rm=FALSE, useNames=TRUE)

## S4 method for signature 'DelayedMatrix'
colMaxs(x, rows=NULL, cols=NULL, na.rm=FALSE, useNames=TRUE)

## S4 method for signature 'DelayedMatrix'
colRanges(x, rows=NULL, cols=NULL, na.rm=FALSE, useNames=TRUE)

## S4 method for signature 'DelayedMatrix'
colVars(x, rows=NULL, cols=NULL, na.rm=FALSE, center=NULL, useNames=TRUE)
```

Arguments

x	A DelayedMatrix object.
na.rm, useNames, center	See man pages for the corresponding generics in the **MatrixGenerics** package (e.g. ?MatrixGenerics::rowVars) for a description of these arguments.
dims, rows, cols	These arguments are not supported. Don't use them.

Details

All these operations are block-processed.

See Also

- The **DelayedMatrixStats** package for more row/col summarization methods for DelayedMatrix objects.
- The man pages for the various generic functions defined in the **MatrixGenerics** package e.g. MatrixGenerics::colVars etc...
- DelayedMatrix-rowsum for rowsum() and colsum() methods for DelayedMatrix objects.
- DelayedMatrix-mult for DelayedMatrix multiplication and cross-product.
- DelayedArray objects.

Examples

```
library(HDF5Array)
toy_h5 <- system.file("extdata", "toy.h5", package="HDF5Array")
h5ls(toy_h5)

M1 <- HDF5Array(toy_h5, "M1")
M2 <- HDF5Array(toy_h5, "M2")

M12 <- rbind(M1, t(M2))  # delayed

## All these operations are block-processed.

rsums <- rowSums(M12)
csums <- colSums(M12)

rmeans <- rowMeans(M12)
cmeans <- colMeans(M12)

rmins <- rowMins(M12)
cmins <- colMins(M12)

rmaxs <- rowMaxs(M12)
cmaxs <- colMaxs(M12)

rranges <- rowRanges(M12)
cranges <- colRanges(M12)
```

```
rvars <- rowVars(M12, center=rmeans)
cvars <- colVars(M12, center=cmeans)

## Sanity checks:
m12 <- rbind(as.matrix(M1), t(as.matrix(M2)))
stopifnot(
  identical(rsums, rowSums(m12)),
  identical(csums, colSums(m12)),
  identical(rmeans, rowMeans(m12)),
  identical(cmeans, colMeans(m12)),
  identical(rmins, rowMins(m12)),
  identical(cmins, colMins(m12)),
  identical(rmaxs, rowMaxs(m12)),
  identical(cmaxs, colMaxs(m12)),
  identical(rranges, cbind(rmins, rmaxs, deparse.level=0)),
  identical(cranges, cbind(cmins, cmaxs, deparse.level=0)),
  all.equal(rvars, rowVars(m12)),
  all.equal(cvars, colVars(m12))
)
```

`RealizationSink` *RealizationSink objects*

Description

Use a RealizationSink object in combination with `write_block()` to write blocks of array data to disk.

RealizationSink is a virtual class with various concrete subclasses that support writing data into specific formats.

`sinkApply()` is a convenience function for walking on a RealizationSink object, typically for the purpose of filling it with blocks of data.

Note that `write_block()` is typically used inside the callback function passed to `sinkApply()`.

Usage

```
## Walk on a RealizationSink derivative:
sinkApply(sink, FUN, ..., grid=NULL, verbose=NA)

## Backend-agnostic RealizationSink constructor:
AutoRealizationSink(dim, dimnames=NULL, type="double", as.sparse=FALSE)

## Get/set the "automatic realization backend":
getAutoRealizationBackend()
setAutoRealizationBackend(BACKEND=NULL)
registeredRealizationBackends()
```

Arguments

sink	A **writable** array-like object, typically a RealizationSink derivative. Some important notes: • DelayedArray objects are NEVER writable, even when they don't carry delayed operations (e.g. HDF5Array objects from the **HDF5Array** package), and even when they don't carry delayed operations **and** have all their data in memory (e.g. RleArray objects). In other words, there are NO exceptions. • RealizationSink is a **virtual** class so sink will always be a RealizationSink **derivative**, that is, an object that belongs to a **concrete** subclass of the RealizationSink class (e.g. an HDF5RealizationSink object from the **HDF5Array** package). • RealizationSink derivatives are considered array-like objects i.e. they have dimensions and possibly dimnames. Although write_block() and sinkApply() will typically be used on a RealizationSink derivative, they can also be used on an ordinary array or other writable in-memory array-like objects like dgCMatrix objects from the **Matrix** package.
FUN	The callback function to apply to each **viewport** of the grid used to walk on sink. sinkApply() will perform sink <- FUN(sink, viewport, ...) on each viewport, so FUN must take at least two arguments, typically sink and viewport (but the exact names can differ). The function is expected to return its 1st argument (sink) possibly modified (e.g. when FUN contains a call to write_block(), which is typically the case).
...	Additional arguments passed to FUN.
grid	The grid used for the walk, that is, an ArrayGrid object that defines the viewports to walk on. It must be compatible with the geometry of sink. If not specified, an automatic grid is created by calling defaultSinkAutoGrid(sink), and used. See ?defaultSinkAutoGrid for more information.
verbose	Whether block processing progress should be displayed or not. If set to NA (the default), verbosity is controlled by DelayedArray:::get_verbose_block_processing(). Setting verbose to TRUE or FALSE overrides this.
dim	The dimensions (specified as an integer vector) of the RealizationSink derivative to create.
dimnames	The dimnames (specified as a list of character vectors or NULLs) of the RealizationSink derivative to create.
type	The type of the data that will be written to the RealizationSink derivative to create.
as.sparse	Whether the data should be written as sparse or not to the RealizationSink derivative to create. Not all *realization backends* support this.
BACKEND	NULL (the default), or a single string specifying the name of a realization backend e.g. "HDF5Array" or "RleArray" etc...

Details

*** The RealizationSink API ***

The DelayedArray package provides a simple API for writing blocks of array data to disk (or to memory): the "RealizationSink API". This API allows the developper to write code that is agnostic about the particular on-disk (or in-memory) format being used to store the data.

Here is how to use it:

1. Create a realization sink.
2. Write blocks of array data to the realization sink with one or several calls to `write_block()`.
3. Close the realization sink with `close()`.
4. Coerce the realization sink to DelayedArray.

A realization sink is formally represented by a RealizationSink derivative. Note that RealizationSink is a virtual class with various concrete subclasses like HDF5RealizationSink from the **HDF5Array** package, or RleRealizationSink. Each subclass implements the "RealizationSink API" for a specific realization backend.

To create a realization sink, use the specific constructor function. This function should be named as the class itself e.g. `HDF5RealizationSink()`.

To create a realization sink in a backend-agnostic way, use `AutoRealizationSink()`. It will create a RealizationSink derivative for the current *automatic realization backend* (see below).

Once writing to the realization sink is completed, the RealizationSink derivative must be closed (with `close(sink)`), then coerced to DelayedArray (with `as(sink, "DelayedArray")`. What specific DelayedArray derivative this coercion will return depends on the specific class of the RealizationSink derivative. For example, if `sink` is an HDF5RealizationSink object from the **HDF5Array** package, then `as(sink, "DelayedArray")` will return an HDF5Array instance (the HDF5Array class is a DelayedArray subclass).

*** The *automatic realization backend* ***

The *automatic realization backend* is a user-controlled global setting that indicates what specific RealizationSink derivative `AutoRealizationSink()` should return. In the context of block processing of a DelayedArray object, this controls where/how realization happens e.g. as an ordinary array if not set (i.e. set to `NULL`), or as an HDF5Array object if set to `"HDF5Array"`, or as an RleArray object if set to `"RleArray"`, etc...

Use `getAutoRealizationBackend()` or `setAutoRealizationBackend()` to get or set the *automatic realization backend*.

Use `registeredRealizationBackends()` to get the list of realization backends that are currently registered.

*** Cross realization backend compatibility ***

Two important things to keep in mind for developers aiming at writing code that is compatible across realization backends:

- Realization backends don't necessarily support concurrent writing.

  More precisely: Even though it is safe to assume that any DelayedArray object will support concurrent `read_block()` calls, it is not so safe to assume that any RealizationSink derivative will support concurrent calls to `write_block()`. For example, at the moment, HDF5RealizationSink objects do not support concurrent writing.

This means that in order to remain compatible across realization backends, code that contains calls to `write_block()` should NOT be parallelized.

- Some realization backends are "linear write only", that is, they don't support *random write access*, only *linear write access*.

  Such backends will provide a relization sink where the blocks of data must be written in linear order (i.e. by ascending rank). Furthermore, the geometry of the blocks must also be compatible with *linear write access*, that is, they must have a "first-dim-grows-first" shape. Concretely this means that the grid used to walk on the relization sink must be created with something like:

  ```
  colAutoGrid(sink)
  ```

  for a two-dimensional sink, or with something like:

  ```
  defaultSinkAutoGrid(sink)
  ```

  for a sink with an arbitrary number of dimensions.

  See `?defaultSinkAutoGrid` for more information.

  For obvious reasons, "linear write only" realization backends do not support concurrent writing.

Value

For `sinkApply()`, its 1st argument (`sink`) possibly modified (e.g. when callback function `FUN` contains a call to `write_block()`, which is typically the case).

For `AutoRealizationSink()`, a RealizationSink derivative with the class associated with the current *automatic realization backend*.

For `getAutoRealizationBackend`, `NULL` (no backend set yet) or a single string specifying the name of the *automatic realization backend* currently in use.

For `registeredRealizationBackends`, a data frame with 1 row per registered realization backend.

See Also

- `read_block` and `write_block` in the **S4Arrays** package.
- ArrayGrid in the **S4Arrays** package for the formal representation of grids and viewports.
- `defaultSinkAutoGrid` to create an automatic grid on a RealizationSink derivative.
- `blockApply` and family for convenient block processing of an array-like object.
- HDF5RealizationSink objects in the **HDF5Array** package.
- HDF5-dump-management in the **HDF5Array** package to control the location and physical properties of automatically created HDF5 datasets.
- RleArray objects.
- DelayedArray objects.
- array objects in base R.

Examples

```
## ------------------------------------------------------------------------
## USING THE "RealizationSink API": EXAMPLE 1
## ------------------------------------------------------------------------

## -- STEP 1 --
## Create a realization sink. Note that instead of creating a
## realization sink by calling a backend-specific sink constructor
## (e.g. HDF5Array::HDF5RealizationSink), we set the "automatic
## realization backend" to "HDF5Array" and use backend-agnostic
## constructor AutoRealizationSink():
setAutoRealizationBackend("HDF5Array")
sink <- AutoRealizationSink(c(35L, 50L, 8L))
dim(sink)

## -- STEP 2 --
## Define the grid of viewports to walk on. Here we define a grid made
## of very small viewports on 'sink'. Note that, for real-world use cases,
## block processing will typically use grids made of much bigger
## viewports, usually obtained with defaultSinkAutoGrid().
## Also please note that this grid would not be compatible with "linear
## write only" realization backends. See "Cross realization backend
## compatibility" above in this man page for more information.
sink_grid <- RegularArrayGrid(dim(sink), spacings=c(20, 20, 4))

## -- STEP 3 --
## Walk on the grid, and, for each viewport, write random data to it.
for (bid in seq_along(sink_grid)) {
    viewport <- sink_grid[[bid]]
    block <- array(runif(length(viewport)), dim=dim(viewport))
    sink <- write_block(sink, viewport, block)
}

## -- An alternative to STEP 3 --
FUN <- function(sink, viewport) {
    block <- array(runif(length(viewport)), dim=dim(viewport))
    write_block(sink, viewport, block)
}
sink <- sinkApply(sink, FUN, grid=sink_grid, verbose=TRUE)

## -- STEP 4 --
## Close the sink and turn it into a DelayedArray object:
close(sink)
A <- as(sink, "DelayedArray")
A

setAutoRealizationBackend()  # restore default (NULL)

## ------------------------------------------------------------------------
## USING THE "RealizationSink API": EXAMPLE 2
## ------------------------------------------------------------------------
```

```
## Say we have a 3D array and want to collapse its 3rd dimension by
## summing the array elements that are stacked vertically, that is, we
## want to compute the matrix M obtained by doing sum(A[i, j, ]) for all
## valid i and j. This is very easy to do with an ordinary array:
collapse_3rd_dim <- function(a) apply(a, MARGIN=1:2, sum)

## or, in a slightly more efficient way:
collapse_3rd_dim <- function(a) {
    m <- matrix(0, nrow=nrow(a), ncol=ncol(a))
    for (z in seq_len(dim(a)[[3]]))
        m <- m + a[ , , z]
    m
}

## With a toy 3D array:
a <- array(runif(8000), dim=c(25, 40, 8))
dim(collapse_3rd_dim(a))
stopifnot(identical(sum(a), sum(collapse_3rd_dim(a))))  # sanity check

## Now say that A is so big that even M wouldn't fit in memory. This is
## a situation where we'd want to compute M block by block:

## -- STEP 1 --
## Create the 2D realization sink:
setAutoRealizationBackend("HDF5Array")
sink <- AutoRealizationSink(dim(a)[1:2])
dim(sink)

## -- STEP 2 --
## Define two grids: one for 'sink' and one for 'a'. Since we're going
## to walk on the two grids simultaneously, read a block from 'a' and
## write it to 'sink', we need to make sure that we define grids that
## are "aligned". More precisely, the two grids must have the same number
## of viewports, and the viewports in one must correspond to the viewports
## in the other one:
sink_grid <- colAutoGrid(sink, ncol=10)
a_spacings <- c(dim(sink_grid[[1L]]), dim(a)[[3]])
a_grid <- RegularArrayGrid(dim(a), spacings=a_spacings)
dims(sink_grid)  # dimensions of the individual viewports
dims(a_grid)     # dimensions of the individual viewports

## Let's check that our two grids are actually "aligned":
stopifnot(identical(length(sink_grid), length(a_grid)))
stopifnot(identical(dims(sink_grid), dims(a_grid)[ , 1:2, drop=FALSE]))

## -- STEP 3 --
## Walk on the two grids simultaneously:
for (bid in seq_along(sink_grid)) {
    ## Read block from 'a'.
    a_viewport <- a_grid[[bid]]
    block <- read_block(a, a_viewport)
    ## Collapse it.
    block <- collapse_3rd_dim(block)
```

```
    ## Write the collapsed block to 'sink'.
    sink_viewport <- sink_grid[[bid]]
    sink <- write_block(sink, sink_viewport, block)
}

## -- An alternative to STEP 3 --
FUN <- function(sink, sink_viewport) {
    ## Read block from 'a'.
    bid <- currentBlockId()
    a_viewport <- a_grid[[bid]]
    block <- read_block(a, a_viewport)
    ## Collapse it.
    block <- collapse_3rd_dim(block)
    ## Write the collapsed block to 'sink'.
    write_block(sink, sink_viewport, block)
}
sink <- sinkApply(sink, FUN, grid=sink_grid, verbose=TRUE)

## -- STEP 4 --
## Close the sink and turn it into a DelayedArray object:
close(sink)
M <- as(sink, "DelayedArray")
M

## Sanity check:
stopifnot(identical(collapse_3rd_dim(a), as.array(M)))

setAutoRealizationBackend()  # restore default (NULL)

## ---------------------------------------------------------------------
## USING THE "RealizationSink API": AN ADVANCED EXAMPLE
## ---------------------------------------------------------------------

## Say we have 2 matrices with the same number of columns. Each column
## represents a biological sample:
library(HDF5Array)
R <- as(matrix(runif(75000), ncol=1000), "HDF5Array")   # 75 rows
G <- as(matrix(runif(250000), ncol=1000), "HDF5Array")  # 250 rows

## Say we want to compute the matrix U obtained by applying the same
## binary functions FUN() to all samples i.e. U is defined as:
##
##   U[ , j] <- FUN(R[ , j], G[ , j]) for 1 <= j <= 1000
##
## Note that FUN() should return a vector of constant length, say 200,
## so U will be a 200x1000 matrix. A naive implementation would be:
##
##   pFUN <- function(r, g) {
##       stopifnot(ncol(r) == ncol(g))  # sanity check
##       sapply(seq_len(ncol(r)), function(j) FUN(r[ , j], g[ , j]))
##   }
##
## But because U is going to be too big to fit in memory, we can't
```

```
## just do pFUN(R, G). So we want to compute U block by block and
## write the blocks to disk as we go. The blocks will be made of full
## columns. Also since we need to walk on 2 matrices at the same time
## (R and G), we can't use blockApply() or blockReduce() so we'll use
## a "for" loop.

## Before we get to the "for" loop, we need 4 things:

## 1. Two grids of blocks, one on R and one on G. The blocks in the
##    two grids must contain the same number of columns. We arbitrarily
##    choose to use blocks of 150 columns:
R_grid <- colAutoGrid(R, ncol=150)
G_grid <- colAutoGrid(G, ncol=150)

## 2. The function pFUN(). It will take 2 blocks as input, 1 from R
##    and 1 from G, apply FUN() to all the samples in the blocks,
##    and return a matrix with one columns per sample:
pFUN <- function(r, g) {
    stopifnot(ncol(r) == ncol(g))  # sanity check
    ## Return a matrix with 200 rows with random values. Completely
    ## artificial sorry. A realistic example would actually need to
    ## apply the same binary function to r[ ,j] and g[ , j] for
    ## 1 <= j <= ncol(r).
    matrix(runif(200 * ncol(r)), nrow=200)
}

## 3. A RealizationSink derivative where to write the matrices returned
##    by pFUN() as we go:
setAutoRealizationBackend("HDF5Array")
U_sink <- AutoRealizationSink(c(200L, 1000L))

## 4. Finally, we create a grid on U_sink with viewports that contain
##    the same number of columns as the corresponding blocks in R and G:
U_grid <- colAutoGrid(U_sink, ncol=150)

## Note that the three grids should have the same number of viewports:
stopifnot(length(U_grid) == length(R_grid))
stopifnot(length(U_grid) == length(G_grid))

## 5. Now we can proceed. We use a "for" loop to walk on R and G
##    simultaneously, block by block, apply pFUN(), and write the
##    output of pFUN() to U_sink:
for (bid in seq_along(U_grid)) {
    R_block <- read_block(R, R_grid[[bid]])
    G_block <- read_block(G, G_grid[[bid]])
    U_block <- pFUN(R_block, G_block)
    U_sink <- write_block(U_sink, U_grid[[bid]], U_block)
}

## An alternative to the "for" loop is to use sinkApply():
FUN <- function(U_sink, U_viewport) {
    bid <- currentBlockId()
    R_block <- read_block(R, R_grid[[bid]])
```

```
    G_block <- read_block(G, G_grid[[bid]])
    U_block <- pFUN(R_block, G_block)
    write_block(U_sink, U_viewport, U_block)
}
U_sink <- sinkApply(U_sink, FUN, grid=U_grid, verbose=TRUE)

close(U_sink)
U <- as(U_sink, "DelayedArray")
U

setAutoRealizationBackend()  # restore default (NULL)

## ---------------------------------------------------------------------
## VERY BASIC (BUT ALSO VERY ARTIFICIAL) USAGE OF THE
## read_block()/write_block() COMBO
## ---------------------------------------------------------------------

###### On an ordinary matrix ######
m1 <- matrix(1:30, ncol=5)

## Define a viewport on 'm1':
block1_dim <- c(4, 3)
viewport1 <- ArrayViewport(dim(m1), IRanges(c(3, 2), width=block1_dim))

## Read/tranform/write:
block1 <- read_block(m1, viewport1)
write_block(m1, viewport1, block1 + 1000L)

## Define another viewport on 'm1':
viewport1b <- ArrayViewport(dim(m1), IRanges(c(1, 3), width=block1_dim))

## Read/tranform/write:
write_block(m1, viewport1b, block1 + 1000L)

## No-op:
m <- write_block(m1, viewport1, read_block(m1, viewport1))
stopifnot(identical(m1, m))

########## On a 3D array ##########
a3 <- array(1:60, 5:3)

## Define a viewport on 'a3':
block3_dim <- c(2, 4, 1)
viewport3 <- ArrayViewport(dim(a3), IRanges(c(1, 1, 3), width=block3_dim))

## Read/tranform/write:
block3 <- read_block(a3, viewport3)
write_block(a3, viewport3, block3 + 1000L)

## Define another viewport on 'a3':
viewport3b <- ArrayViewport(dim(a3), IRanges(c(3, 1, 3), width=block3_dim))

## Read/tranform/write:
```

```
write_block(a3, viewport3b, block3 + 1000L)

## No-op:
a <- write_block(a3, viewport3, read_block(a3, viewport3))
stopifnot(identical(a3, a))

## ---------------------------------------------------------------------
## LESS BASIC (BUT STILL VERY ARTIFICIAL) USAGE OF THE
## read_block()/write_block() COMBO
## ---------------------------------------------------------------------

grid1 <- RegularArrayGrid(dim(m1), spacings=c(3L, 2L))
grid1
length(grid1)  # number of blocks defined by the grid
read_block(m1, grid1[[3L]])  # read 3rd block
read_block(m1, grid1[[1L, 3L]])

## Walk on the grid, colum by column:
m1a <- m1
for (bid in seq_along(grid1)) {
    viewport <- grid1[[bid]]
    block <- read_block(m1a, viewport)
    block <- bid * 1000L + block
    m1a <- write_block(m1a, viewport, block)
}
m1a

## Walk on the grid, row by row:
m1b <- m1
for (i in seq_len(dim(grid1)[[1]])) {
  for (j in seq_len(dim(grid1)[[2]])) {
    viewport <- grid1[[i, j]]
    block <- read_block(m1b, viewport)
    block <- (i * 10L + j) * 1000L + block
    m1b <- write_block(m1b, viewport, block)
  }
}
m1b

## ---------------------------------------------------------------------
## registeredRealizationBackends() AND FAMILY
## ---------------------------------------------------------------------

getAutoRealizationBackend()  # no backend set yet

registeredRealizationBackends()
setAutoRealizationBackend("HDF5Array")
getAutoRealizationBackend()  # backend is set to "HDF5Array"
registeredRealizationBackends()

getHDF5DumpChunkLength()
setHDF5DumpChunkLength(500L)
getHDF5DumpChunkShape()
```

```
sink <- AutoRealizationSink(c(120L, 50L))
class(sink)  # HDF5-specific realization sink
dim(sink)
chunkdim(sink)

grid <- defaultSinkAutoGrid(sink, block.length=600)
for (bid in seq_along(grid)) {
    viewport <- grid[[bid]]
    block <- 101 * bid + runif(length(viewport))
    dim(block) <- dim(viewport)
    sink <- write_block(sink, viewport, block)
}

close(sink)
A <- as(sink, "DelayedArray")
A

setAutoRealizationBackend()  # restore default (NULL)
```

`realize` *Realize an object in memory or on disk*

Description

`realize()` is an S4 generic function.

The default `realize()` method handles the array case. It will realize the array-like object (typically a DelayedArray object) in memory or on disk, depending on the *realization backend* specified via its `BACKEND` argument,

Usage

```
realize(x, ...)

## S4 method for signature 'ANY'
realize(x, BACKEND=getAutoRealizationBackend())
```

Arguments

`x`	An array-like object (typically a DelayedArray object) for the default method. Other types of objects can be supported via additional methods. For example, the **SummarizedExperiment** package defines a method for SummarizedExperiment objects (see ?`realize,SummarizedExperiment-method`).
`...`	Additional arguments passed to methods.
`BACKEND`	`NULL` or a single string specifying the name of a *realization backend*. By default, the *automatic realization backend* will be used. This is the backend returned by `getAutoRealizationBackend()`.

Details

The default `realize()` method realizes an array-like object `x` in memory if `BACKEND` is `NULL`, otherwise on disk.

Note that, when `BACKEND` is not `NULL`, `x` gets realized as a "pristine" DelayedArray object (e.g. an HDF5Array object), that is, as a DelayedArray object that carries no delayed operations. This means that, if `x` is itself a DelayedArray object, then the returned object is another DelayedArray object semantically equivalent to `x` where the delayed operations carried by `x` have been realized.

Value

A "pristine" DelayedArray object if `BACKEND` is not `NULL`.

Otherwise, an ordinary matrix or array, or a SparseArray object.

See Also

- `getAutoRealizationBackend` and `setAutoRealizationBackend` for getting and setting the *automatic realization backend*.
- DelayedArray objects.
- RleArray objects.
- HDF5Array objects in the **HDF5Array** package.
- SparseArray objects implemented in the **SparseArray** package.
- array objects in base R.

Examples

```
## ---------------------------------------------------------------------
## In-memory realization
## ---------------------------------------------------------------------

a <- array(1:24, dim=4:2)
realize(a, BACKEND=NULL)  # no-op

A <- DelayedArray(a)
realize(log(A), BACKEND=NULL)  # same as 'as.array(log(A))'

## Sanity checks:
stopifnot(identical(realize(a, BACKEND=NULL), a))
stopifnot(identical(realize(log(A), BACKEND=NULL), log(a)))

## ---------------------------------------------------------------------
## On-disk realization
## ---------------------------------------------------------------------

library(HDF5Array)

realize(log(A), BACKEND="HDF5Array")  # same as 'as(log(A), "HDF5Array")'

## ---------------------------------------------------------------------
```

```
## Omitting the 'BACKEND' argument
## ---------------------------------------------------------------------

## When 'BACKEND' is not specified, the "automatic realization backend"
## is used. This backend is controlled via setAutoRealizationBackend().

toy_h5 <- system.file("extdata", "toy.h5", package="HDF5Array")
h5ls(toy_h5)
M1 <- HDF5Array(toy_h5, "M1")
M2 <- HDF5Array(toy_h5, "M2")
M3 <- rbind(log(M1), t(M2)) + 0.5
M3

## Set the "automatic realization backend" to NULL for in-memory
## realization (as ordinary array or SparseArray object):
setAutoRealizationBackend(NULL)
m3 <- realize(M3)  # in-memory realization

registeredRealizationBackends()

setAutoRealizationBackend("RleArray")
realize(M3)  # realization as RleArray object

setAutoRealizationBackend("HDF5Array")
realize(M3)  # on-disk realization (as HDF5Array object)

setAutoRealizationBackend()  # restore default (NULL)
```

`RleArray-class` *RleArray objects*

Description

The RleArray class is a DelayedArray subclass for representing an in-memory Run Length Encoded array-like dataset.

All the operations available for DelayedArray objects work on RleArray objects.

Usage

```
## Constructor function:
RleArray(data, dim, dimnames, chunksize=NULL)
```

Arguments

`data`	An Rle object, or an ordinary list of Rle objects, or an RleList object, or a DataFrame object where all the columns are Rle objects. More generally speaking, `data` can be any list-like object where all the list elements are Rle objects.
`dim`	The dimensions of the object to be created, that is, an integer vector of length one or more giving the maximal indices in each dimension.

`dimnames` The *dimnames* of the object to be created. Must be `NULL` or a list of length the number of dimensions. Each list element must be either `NULL` or a character vector along the corresponding dimension.

`chunksize` Experimental. Don't use!

Value

An RleArray (or RleMatrix) object. (Note that RleMatrix extends RleArray.)

See Also

- Rle and DataFrame objects in the **S4Vectors** package and RleList objects in the **IRanges** package.
- DelayedArray objects.
- DelayedArray-utils for common operations on DelayedArray objects.
- `realize` for realizing a DelayedArray object in memory or on disk.
- ConstantArray objects for mimicking an array containing a constant value, without actually creating said array in memory.
- HDF5Array objects in the **HDF5Array** package.
- The RleArraySeed helper class.

Examples

```
## ---------------------------------------------------------------------
## A. BASIC EXAMPLE
## ---------------------------------------------------------------------

data <- Rle(sample(6L, 500000, replace=TRUE), 8)
a <- array(data, dim=c(50, 20, 4000))  # array() expands the Rle object
                                       # internally with as.vector()

A <- RleArray(data, dim=c(50, 20, 4000))  # Rle object is NOT expanded
A

object.size(a)
object.size(A)

stopifnot(identical(a, as.array(A)))

as(A, "Rle")  # deconstruction

toto <- function(x) (5 * x[ , , 1] ^ 3 + 1L) * log(x[, , 2])
m1 <- toto(a)
head(m1)

M1 <- toto(A)  # very fast! (operations are delayed)
M1

stopifnot(identical(m1, as.array(M1)))
```

```
cs <- colSums(m1)
CS <- colSums(M1)
stopifnot(identical(cs, CS))

## Coercing a DelayedMatrix object to DataFrame produces a DataFrame
## object with Rle columns:
as(M1, "DataFrame")

## ---------------------------------------------------------------------
## B. MAKING AN RleArray OBJECT FROM A LIST-LIKE OBJECT OF Rle OBJECTS
## ---------------------------------------------------------------------

## From a DataFrame object:
DF <- DataFrame(A=Rle(sample(3L, 100, replace=TRUE)),
                B=Rle(sample(3L, 100, replace=TRUE)),
                C=Rle(sample(3L, 100, replace=TRUE) - 0.5),
                row.names=sprintf("ID%03d", 1:100))

M2 <- RleArray(DF)
M2

A3 <- RleArray(DF, dim=c(25, 6, 2))
A3

M4 <- RleArray(DF, dim=c(25, 12), dimnames=list(LETTERS[1:25], NULL))
M4

## From an ordinary list:
## If all the supplied Rle objects have the same length and if the 'dim'
## argument is not specified, then the RleArray() constructor returns an
## RleMatrix object with 1 column per Rle object. If the 'dimnames'
## argument is not specified, then the names on the list are propagated
## as the colnames of the returned object.
data <- as.list(DF)
M2b <- RleArray(data)
A3b <- RleArray(data, dim=c(25, 6, 2))
M4b <- RleArray(data, dim=c(25, 12), dimnames=list(LETTERS[1:25], NULL))

data2 <- list(Rle(sample(3L, 9, replace=TRUE)) * 11L,
              Rle(sample(3L, 15, replace=TRUE)))
## Not run:
  RleArray(data2)  # error! (cannot infer the dim)

## End(Not run)
RleArray(data2, dim=c(4, 6))

## From an RleList object:
data <- RleList(data)
M2c <- RleArray(data)
A3c <- RleArray(data, dim=c(25, 6, 2))
M4c <- RleArray(data, dim=c(25, 12), dimnames=list(LETTERS[1:25], NULL))
```

```
data2 <- RleList(data2)
## Not run:
  RleArray(data2)  # error! (cannot infer the dim)

## End(Not run)
RleArray(data2, dim=4:2)

## Sanity checks:
data0 <- as.vector(unlist(DF, use.names=FALSE))
m2 <- matrix(data0, ncol=3, dimnames=dimnames(M2))
stopifnot(identical(m2, as.matrix(M2)))
rownames(m2) <- NULL
stopifnot(identical(m2, as.matrix(M2b)))
stopifnot(identical(m2, as.matrix(M2c)))
a3 <- array(data0, dim=c(25, 6, 2))
stopifnot(identical(a3, as.array(A3)))
stopifnot(identical(a3, as.array(A3b)))
stopifnot(identical(a3, as.array(A3c)))
m4 <- matrix(data0, ncol=12, dimnames=dimnames(M4))
stopifnot(identical(m4, as.matrix(M4)))
stopifnot(identical(m4, as.matrix(M4b)))
stopifnot(identical(m4, as.matrix(M4c)))

## ---------------------------------------------------------------------
## C. COERCING FROM RleList OR DataFrame TO RleMatrix
## ---------------------------------------------------------------------

## Coercing an RleList object to RleMatrix only works if all the list
## elements in the former have the same length.
x <- RleList(A=Rle(sample(3L, 20, replace=TRUE)),
             B=Rle(sample(3L, 20, replace=TRUE)))
M <- as(x, "RleMatrix")
stopifnot(identical(x, as(M, "RleList")))

x <- DataFrame(A=x[[1]], B=x[[2]], row.names=letters[1:20])
M <- as(x, "RleMatrix")
stopifnot(identical(x, as(M, "DataFrame")))

## ---------------------------------------------------------------------
## D. CONSTRUCTING A LARGE RleArray OBJECT
## ---------------------------------------------------------------------

## The RleArray() constructor does not accept a "long" Rle object (i.e.
## an object of length > .Machine$integer.max) at the moment:
## Not run:
  RleArray(Rle(5, 3e9), dim=c(3, 1e9))  # error!

## End(Not run)

## The workaround is to supply a list of Rle objects instead:

toy_Rle <- function() {
  run_lens <- c(sample(4), sample(rep(c(1:19, 40) * 3, 6e4)), sample(4))
```

```
  run_vals <- sample(700, length(run_lens), replace=TRUE) / 5
  Rle(run_vals, run_lens)
}
rle_list <- lapply(1:80, function(j) toy_Rle())  # takes about 20 sec.

## Cumulative length of all the Rle objects is > .Machine$integer.max:
sum(lengths(rle_list))  # 3.31e+09

## Feed 'rle_list' to the RleArray() constructor:
dim <- c(14395, 320, 719)
A <- RleArray(rle_list, dim)
A

## Because all the Rle objects in 'rle_list' have the same length, we
## can call RleArray() on it without specifying the 'dim' argument. This
## returns an RleMatrix object where each column corresponds to an Rle
## object in 'rle_list':
M <- RleArray(rle_list)
M
stopifnot(identical(as(rle_list, "RleList"), as(M, "RleList")))

## ---------------------------------------------------------------------
## E. CHANGING THE TYPE OF AN RleArray OBJECT FROM "double" TO "integer"
## ---------------------------------------------------------------------

## An RleArray object is an in-memory object so it can be useful to
## reduce its memory footprint. For an object of type "double" this can
## be done by changing its type to "integer" (integers are half the size
## of doubles in memory). Of course this only makes sense if this results
## in a loss of precision that is acceptable.
## On an ordinary array (or matrix) 'a', this is simply a matter of
## doing 'storage.mode(a) <- "integer"'. However, with a DelayedArray
## object, things are a little bit different. Let's do this on a subset
## of the RleMatrix object 'M' created in the previous section.

M1 <- as(M[1:6e5, ], "RleMatrix")
rm(M)

## First of all, it's important to be aware that object.size() (from
## package utils) is NOT reliable on RleArray objects! This is because
## the data in an RleArray object is stored in an environment and
## object.size() stubbornly refuses to take the content of an environment
## into account when computing its size:
object.size(list2env(list(aa=1:10)))   # 56 bytes
object.size(list2env(list(aa=1:1e6)))  # always 56 bytes!

## So we'll use obj_size() instead (from package lobstr):
library(lobstr)
obj_size(list2env(list(aa=1:10)))   # 264 B
obj_size(list2env(list(aa=1:1e6)))  # 4 MB
obj_size(list2env(list(aa=as.double(1:1e6))))  # 8 MB

obj_size(M1)  # 16.7 MB
```

```
type(M1) <- "integer"  # Delayed!
M1                     # Note the class: it's no longer RleMatrix!
                       # (That's because the object now carries delayed
                       # operations.)

## Because changing the type is a delayed operation, the memory footprint
## of the object has not changed yet (remember that the original data in
## a DelayedArray object is stored in its "seed" and its seed is never
## modified **in-place**, that is, no operation on the object will ever
## modify its seed):
obj_size(M1)  # Still the same (well, a very tiny more, because the
              # object is now carrying one more delayed operation,
              # the `type<-` operation)

## To effectively reduce the memory footprint of the object, a new object
## needs to be created. This is achieved simply by **realizing** M1 as a
## (new) RleArray object. Note that this realization will use block
## processing:

DelayedArray:::set_verbose_block_processing(TRUE)  # See block processing
                                                   # in action.
getAutoBlockSize()      # Automatic block size (100 Mb by default).
setAutoBlockSize(20e6)  # Set automatic block size to 20 Mb.

M2 <- as(M1, "RleArray")
DelayedArray:::set_verbose_block_processing(FALSE)
setAutoBlockSize()      # Reset automatic block size to factory settings.


M2
obj_size(M2)  # 6.91 MB (Less than half the original size! This is
              # because RleArray objects use some internal tricks to
              # reduce memory footprint even more when the data in
              # their seed is of type "integer".)

## Finally note that the 2-step approach described here (i.e.
## type(A) <- "integer" followed by realization) is generic and works
## on any kind of DelayedArray object or derivative. In particular,
## after doing 'type(A) <- "integer"', 'A' can be realized as anything
## as long as the realization backend is supported (e.g. could be
## 'as(A, "HDF5Array")' or 'as(A, "TENxMatrix")') and realization will
## always use block processing so the array data will never be fully
## loaded in memory.
```

RleArraySeed-class *RleArraySeed objects*

Description

RleArraySeed is a low-level helper class for representing an in-memory Run Length Encoded array-like dataset. RleArraySeed objects are not intended to be used directly. Most end users should create and manipulate RleArray objects instead. See ?RleArray for more information.

Details

No operation can be performed directly on an RleArraySeed object. It first needs to be wrapped in a DelayedArray object. The result of this wrapping is an RleArray object (an RleArray object is just an RleArraySeed object wrapped in a DelayedArray object).

See Also

- RleArray objects.
- Rle objects in the **S4Vectors** package.

---

showtree *Visualize and access the leaves of a tree of delayed operations*

Description

showtree can be used to visualize the tree of delayed operations carried by a DelayedArray object.

Use nseed, seed, or path to access the number of seeds, the seed, or the seed path of a DelayedArray object, respectively.

Use seedApply to apply a function to the seeds of a DelayedArray object.

Usage

```
showtree(x, show.node.dim=TRUE)

nseed(x)            # seed counter
seed(x)             # seed getter and setter
path(object, ...)   # path getter and setter

seedApply(x, FUN, ...)
```

Arguments

x, object	Typically a DelayedArray object but can also be a DelayedOp object or a list where each element is a DelayedArray or DelayedOp object.
show.node.dim	TRUE or FALSE. If TRUE (the default), the nodes dimensions and data type are displayed.
FUN	The function to be applied to each leaf in x.
...	Optional arguments to FUN for seedApply(). Additional arguments passed to methods for path().

Value

The number of seeds contained in `x` for `nseed`.

The seed contained in `x` for `seed`.

The path of the seed contained in `object` for `path`.

A list of length `nseed(x)` for `seedApply`.

See Also

- `simplify` to simplify the tree of delayed operations carried by a DelayedArray object.
- DelayedOp objects.
- DelayedArray objects.

Examples

```
## ---------------------------------------------------------------------
## showtree(), nseed(), and seed()
## ---------------------------------------------------------------------
m1 <- matrix(runif(150), nrow=15, ncol=10)
M1 <- DelayedArray(m1)
showtree(M1)
seed(M1)

M2 <- log(t(M1[5:1, c(TRUE, FALSE)] + 10))[-1, ]
showtree(M2)

## In the above example, the tree is linear i.e. all the operations
## are represented by unary nodes. The simplest way to know if a
## tree is linear is by counting its leaves with nseed():
nseed(M2)  # only 1 leaf means the tree is linear
seed(M2)

dimnames(M1) <- list(letters[1:15], LETTERS[1:10])
showtree(M1)

m2 <- matrix(1:20, nrow=10)
Y <- cbind(t(M1[ , 10:1]), DelayedArray(m2), M1[6:15, "A", drop=FALSE])
showtree(Y)
showtree(Y, show.node.dim=FALSE)
nseed(Y)  # the tree is not linear

Z <- t(Y[10:1, ])[1:15, ] + 0.4 * M1
showtree(Z)
nseed(Z)  # the tree is not linear

## ---------------------------------------------------------------------
## seedApply()
## ---------------------------------------------------------------------
seedApply(Y, class)
seedApply(Y, dim)
```

simplify *Simplify a tree of delayed operations*

Description

NOTE: The tools documented in this man page are primarily intended for developers or advanced users curious about the internals of the **DelayedArray** package. End users typically don't need them for their regular use of DelayedArray objects.

In a DelayedArray object, the delayed operations are stored as a tree of DelayedOp objects. See `?DelayedOp` for more information about this tree.

`simplify` can be used to simplify the tree of delayed operations in a DelayedArray object.

`isPristine` can be used to know whether a DelayedArray object is *pristine* or not. A DelayedArray object is considered *pristine* when it carries no delayed operation. Note that an object that carries delayed operations that do nothing (e.g. `A + 0`) is not considered *pristine*.

`contentIsPristine` can be used to know whether the delayed operations in a DelayedArray object *touch* its array elements or not.

`netSubsetAndAperm` returns an object that represents the *net subsetting* and *net dimension rearrangement* of all the delayed operations in a DelayedArray object.

Usage

```
simplify(x, incremental=FALSE)

isPristine(x, ignore.dimnames=FALSE)
contentIsPristine(x)
netSubsetAndAperm(x, as.DelayedOp=FALSE)
```

Arguments

`x`	Typically a DelayedArray object but can also be a DelayedOp object (except for `isPristine`).
`incremental`	For internal use.
`ignore.dimnames`	`TRUE` or `FALSE`. When `TRUE`, the object is considered *pristine* even if its dimnames have been modified and no longer match the dimnames of its seed (in which case the object carries a single delayed operations of type DelayedSetDimnames).
`as.DelayedOp`	`TRUE` or `FALSE`. Controls the form of the returned object. See details below.

Details

`netSubsetAndAperm` is only supported on a DelayedArray object `x` with a single seed i.e. if `nseed(x) == 1`.

The mapping between the array elements of `x` and the array elements of its seed is affected by the following delayed operations carried by `x`: `[`, `drop()`, and `aperm()`. `x` can carry any number of

each of these operations in any order but their net result can always be described by a *net subsetting* followed by a *net dimension rearrangement*.

`netSubsetAndAperm(x)` returns an object that represents the *net subsetting* and *net dimension rearrangement*. The `as.DelayedOp` argument controls in what form this object should be returned:

- If `as.DelayedOp` is `FALSE` (the default), the returned object is a list of subscripts that describes the *net subsetting*. The list contains one subscript per dimension in the seed. Each subscript can be either a vector of positive integers or a `NULL`. A `NULL` indicates a *missing subscript*. In addition, if `x` carries delayed operations that rearrange its dimensions (i.e. operations that drop and/or permute some of the original dimensions), the *net dimension rearrangement* is described in a `dimmap` attribute added to the list. This attribute is an integer vector parallel to `dim(x)` that reports how the dimensions of `x` are mapped to the dimensions of its seed.
- If `as.DelayedOp` is `TRUE`, the returned object is a linear tree with 2 DelayedOp nodes and a leaf node. The leaf node is the seed of `x`. Walking the tree from the seed, the 2 DelayedOp nodes are of type DelayedSubset and DelayedAperm, in that order (this reflects the order in which the operations apply). More precisely, the returned object is a DelayedAperm object with one child (the DelayedSubset object), and one grandchid (the seed of `x`). The DelayedSubset and DelayedAperm nodes represent the *net subsetting* and *net dimension rearrangement*, respectively. Either or both of them can be a no-op.

Note that the returned object describes how the array elements of `x` map to their corresponding array element in `seed(x)`.

Value

The simplified object for `simplify`.

`TRUE` or `FALSE` for `contentIsPristine`.

An ordinary list (possibly with the `dimmap` attribute on it) for `netSubsetAndAperm`. Unless `as.DelayedOp` is set to `TRUE`, in which case a DelayedAperm object is returned (see Details section above for more information).

See Also

- `showtree` to visualize and access the leaves of a tree of delayed operations carried by a DelayedArray object.
- DelayedOp objects.
- DelayedArray objects.

Examples

```
## ---------------------------------------------------------------------
## Simplification of the tree of delayed operations
## ---------------------------------------------------------------------
m1 <- matrix(runif(150), nrow=15, ncol=10)
M1 <- DelayedArray(m1)
showtree(M1)

## By default, the tree of delayed operations carried by a DelayedArray
## object gets simplified each time a delayed operation is added to it.
```

```
## This can be disabled via a global option:
options(DelayedArray.simplify=FALSE)
M2 <- log(t(M1[5:1, c(TRUE, FALSE)] + 10))[-1, ]
showtree(M2)  # linear tree

## Note that as part of the simplification process, some operations
## can be reordered:
options(DelayedArray.simplify=TRUE)
M2 <- log(t(M1[5:1, c(TRUE, FALSE)] + 10))[-1, ]
showtree(M2)  # linear tree

options(DelayedArray.simplify=FALSE)

dimnames(M1) <- list(letters[1:15], LETTERS[1:10])
showtree(M1)  # linear tree

m2 <- matrix(1:20, nrow=10)
Y <- cbind(t(M1[ , 10:1]), DelayedArray(m2), M1[6:15, "A", drop=FALSE])
showtree(Y)   # non-linear tree

Z <- t(Y[10:1, ])[1:15, ] + 0.4 * M1
showtree(Z)   # non-linear tree

Z@seed@seeds
Z@seed@seeds[[2]]@seed                      # reaching to M1
Z@seed@seeds[[1]]@seed@seed@seed@seed@seed  # reaching to Y

## ---------------------------------------------------------------------
## isPristine()
## ---------------------------------------------------------------------
m <- matrix(1:20, ncol=4, dimnames=list(letters[1:5], NULL))
M <- DelayedArray(m)

isPristine(M)                # TRUE
isPristine(log(M))           # FALSE
isPristine(M + 0)            # FALSE
isPristine(t(M))             # FALSE
isPristine(t(t(M)))          # TRUE
isPristine(cbind(M, M))      # FALSE
isPristine(cbind(M))         # TRUE

dimnames(M) <- NULL
isPristine(M)                # FALSE
isPristine(M, ignore.dimnames=TRUE)  # TRUE
isPristine(t(t(M)), ignore.dimnames=TRUE)  # TRUE
isPristine(cbind(M, M), ignore.dimnames=TRUE)  # FALSE

## ---------------------------------------------------------------------
## contentIsPristine()
## ---------------------------------------------------------------------
a <- array(1:40, c(4, 5, 2))
A <- DelayedArray(a)
```

```
stopifnot(contentIsPristine(A))
stopifnot(contentIsPristine(A[1, , ]))
stopifnot(contentIsPristine(t(A[1, , ])))
stopifnot(contentIsPristine(cbind(A[1, , ], A[2, , ])))
dimnames(A) <- list(LETTERS[1:4], letters[1:5], NULL)
stopifnot(contentIsPristine(A))

contentIsPristine(log(A))     # FALSE
contentIsPristine(A - 11:14)  # FALSE
contentIsPristine(A * A)      # FALSE

## ---------------------------------------------------------------------
## netSubsetAndAperm()
## ---------------------------------------------------------------------
a <- array(1:40, c(4, 5, 2))
M <- aperm(DelayedArray(a)[ , -1, ] / 100)[ , , 3] + 99:98
M
showtree(M)

netSubsetAndAperm(M)  # 1st dimension was dropped, 2nd and 3rd
                      # dimension were permuted (transposition)

op2 <- netSubsetAndAperm(M, as.DelayedOp=TRUE)
op2                   # 2 nested delayed operations
op1 <- op2@seed
class(op1)            # DelayedSubset
class(op2)            # DelayedAperm
op1@index
op2@perm

DelayedArray(op2)     # same as M from a [, drop(), and aperm() point of
                      # view but the individual array elements are now
                      # reset to their original values i.e. to the values
                      # they have in the seed
stopifnot(contentIsPristine(DelayedArray(op2)))

## A simple function that returns TRUE if a DelayedArray object carries
## no "net subsetting" and no "net dimension rearrangement":
is_aligned_with_seed <- function(x)
{
    if (nseed(x) != 1L)
        return(FALSE)
    op2 <- netSubsetAndAperm(x, as.DelayedOp=TRUE)
    op1 <- op2@seed
    is_noop(op1) && is_noop(op2)
}

M <- DelayedArray(a[ , , 1])
is_aligned_with_seed(log(M + 11:14) > 3)           # TRUE
is_aligned_with_seed(M[4:1, ])                     # FALSE
is_aligned_with_seed(M[4:1, ][4:1, ])              # TRUE
is_aligned_with_seed(t(M))                         # FALSE
is_aligned_with_seed(t(t(M)))                      # TRUE
```

```
is_aligned_with_seed(t(0.5 * t(M[4:1, ])[ , 4:1]))  # TRUE

options(DelayedArray.simplify=TRUE)
```

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