

# Package ‘BiocParallel’

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**biocViews** Infrastructure

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**VignetteBuilder** knitr

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BiocParallel-package    *Bioconductor facilities for parallel evaluation*

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## Description

This package provides modified versions and novel implementation of functions for parallel evaluation, tailored to use with Bioconductor objects.

## Details

This package uses code from the [parallel](#) package,

## Author(s)

Author: Bioconductor Package Maintainer [cre], Martin Morgan [aut], Valerie Obenchain [aut], Michel Lang [aut], Ryan Thompson [aut]

Maintainer: Bioconductor Package Maintainer <maintainer@bioconductor.org>

---

BatchJobsParam-class    *Enable parallelization on batch systems*

---

## Description

This class is used to parameterize scheduler options on managed high-performance computing clusters.

## Usage

```
BatchJobsParam(workers, catch.errors = TRUE, cleanup = TRUE,
  work.dir = getwd(), stop.on.error = TRUE, seed = NULL,
  resources = NULL, conffile = NULL, cluster.functions = NULL,
  progressbar = TRUE, jobname = "BPJOB",
  reg.pars=list(seed=seed, work.dir=work.dir),
  conf.pars=list(conffile=conffile, cluster.functions=cluster.functions),
  submit.pars=list(resources=resources),
  ...)
```

**Arguments**

workers	integer(1) Number of workers to divide tasks (e.g., elements in the first argument of <code>bplapply</code> ) between. On Multicore and SSH backends, this defaults to all available nodes. On managed (e.g., slurm, SGE) clusters workers defaults to NA, meaning that the number of workers equals the number of tasks. See argument <code>n.chunks</code> in <code>chunk</code> and <code>submitJobs</code> for more information.
catch.errors	DEPRECATED. logical(1) Flag to determine in apply-like functions (see e.g. <code>bplapply</code> ) whether to quit with an error as soon as one application fails or encapsulation of function calls in <code>try</code> blocks which triggers a resume mechanism (see <code>bpresume</code> ). Defaults to TRUE.
cleanup	logical(1) BatchJobs creates temporary directories in the <code>work.dir</code> . If cleanup is set to TRUE (default), the directories are removed from the file systems automatically. Set this to FALSE whenever it might become necessary to utilize any special functionality provided by BatchJobs. To retrieve the registry, call <code>loadRegistry</code> on the temporary directory.
work.dir	character(1) Directory to store temporary files. Note that this must be shared across computational nodes if you use a distributed computing backend. Default is the current working directory of R, see <code>getwd</code> . Ignored when <code>reg.pars</code> is provided.
stop.on.error	logical(1) Stop all jobs as soon as one jobs fails ( <code>stop.on.error == TRUE</code> ) or wait for all jobs to terminate. Default is TRUE.
seed	integer(1L) Set an initial seed for the RNG. See <code>makeRegistry</code> for more information. Default is NULL where a random seed is chosen upon initialization. Ignored when <code>reg.pars</code> is provided.
resources	list() List of job specific resources passed to <code>submitJobs</code> . Default is NULL where the resources defined in the configuration are used. Ignored when <code>submit.pars</code> is provided.
conffile	character(1) URI to a custom BatchJobs configuration file used for execution. Default is NULL which relies on BatchJobs to handle configuration files. Ignored when <code>conf.pars</code> is provided.
cluster.functions	ClusterFunctions Specify a specific cluster backend using one of the constructors provided by BatchJobs, see <code>ClusterFunctions</code> . Default is NULL where the default cluster functions defined in the configuration are used. Ignored when <code>conf.pars</code> is provided.
progressbar	logical(1) Suppress the progress bar used in BatchJobs and be less verbose. Default is FALSE.
jobname	character(1) Job name that is prepended to the output log and result files. Default is "BPJOB".
reg.pars	list() List of parameters passed to <code>BatchJobs::makeRegistry()</code> . When present, user-supplied arguments <code>seed</code> and <code>work.dir</code> to <code>BatchJobsParam</code> are ignored.
conf.pars	list() List of parameters passed to <code>BatchJobs::setConfig()</code> . When present, user-supplied arguments <code>conffile</code> , <code>cluster.functions</code> to <code>BatchJobsParam</code> are ignored.
submit.pars	list() List of parameters passed to <code>BatchJobs::submitJobs</code> . When present, user-supplied argument <code>resources</code> to <code>BatchJobsParam</code> is ignored. <code>submitJobs</code> parameters <code>reg</code> , <code>id</code> cannot be set.
...	Addition arguments, currently not handled.

**BatchJobsParam constructor**

Return an object with specified values. The object may be saved to disk or reused within a session.

**Methods**

The following generics are implemented and perform as documented on the corresponding help page: [bpworkers](#), [bpnworkers](#), [bpstart](#), [bpstop](#), [bpisup](#), [bpbackend](#), [bpbackend<-](#)

**Author(s)**

Michel Lang, <mailto:michellang@gmail.com>

**See Also**

`getClass("BiocParallelParam")` for additional parameter classes.  
`register` for registering parameter classes for use in parallel evaluation.

**Examples**

```
p <- BatchJobsParam(progressbar=FALSE)
bplapply(1:10, sqrt, BPPARAM=p)

## Not run:
## see vignette for additional explanation
funs <- makeClusterFunctionsSLURM("~/slurm.tpl")
param <- BatchJobsParam(4, cluster.functions=funs)
register(param)
bplapply(1:10, function(i) sqrt)

## End(Not run)
```

---

BiocParallelParam-class

*BiocParallelParam objects*

---

**Description**

The `BiocParallelParam` virtual class stores configuration parameters for parallel execution. Concrete subclasses include `SnowParam`, `MulticoreParam`, `BatchJobsParam`, and `DoparParam` and `SerialParam`.

**Details**

`BiocParallelParam` is the virtual base class on which other parameter objects build. There are 5 concrete subclasses:

- `SnowParam`: distributed memory computing
- `MulticoreParam`: shared memory computing
- `BatchJobsParam`: scheduled cluster computing
- `DoparParam`: foreach computing
- `SerialParam`: non-parallel execution

The parameter objects hold configuration parameters related to the method of parallel execution such as shared memory, independent memory or computing with a cluster scheduler.

## Construction

The BiocParallelParam class is virtual and has no constructor. Instances of the subclasses can be created with the following:

- `SnowParam()`
- `MulticoreParam()`
- `BatchJobsParam()`
- `DoparParam()`
- `SerialParam()`

## Accessors

**Back-end control:** In the code below BPPARAM is a BiocParallelParam object.

`bpworkers(x), bpworkers(x, ...)`: `integer(1)` or `character()`. Gets the number or names of the back-end workers. The setter is supported for `SnowParam` and `MulticoreParam` only.

`bpnworkers(x)`: `integer(1)`. Gets the number of the back-end workers.

`bptasks(x), bptasks(x) <- value`: `integer(1)`. Get or set the number of tasks for a job. value must be a scalar integer  $\geq 0$ L. This argument applies to `SnowParam` and `MulticoreParam` only; `DoparParam` and `BatchJobsParam` have their own approach to dividing a job among workers.

We define a job as a single call to a function such as `bplapply`, `bpmapply` etc. A task is the division of the `X` argument into chunks. When `tasks == 0` (default), `X` is divided by the number of workers. This approach distributes `X` in (approximately) equal chunks.

A `tasks` value of  $> 0$  dictates the total number of tasks. Values can range from 1 (all of `X` to a single worker) to the length of `X` (each element of `X` to a different worker).

When the length of `X` is less than the number of workers each element of `X` is sent to a worker and `tasks` is ignored. Another case where the `tasks` value is ignored is when using the `bpiterate` function; the number of tasks are defined by the number of data chunks returned by the `ITER` function.

`bpstart(x)`: `logical(1)`. Starts the back-end, if necessary.

`bpstop(x)`: `logical(1)`. Stops the back-end, if necessary and possible.

`bpisup(x)`: `logical(1)`. Tests whether the back-end is available for processing, returning a scalar logical value. `bp*` functions such as `bplapply` automatically start the back-end if necessary.

`bpbackend(x), bpbackend(x) <- value`: Gets or sets the parallel bpbackend. Not all backends can be retrieved; see `showMethods("backend")`.

`bplog(x), bplog(x) <- value`: Get or enable logging, if available. value must be a `logical(1)`.

`bpthreshold(x), bpthreshold(x) <- value`: Get or set the logging threshold. value must be a `character(1)` string of one of the levels defined in the `futile.logger` package: "TRACE", "DEBUG", "INFO", "WARN", "ERROR", or "FATAL".

`bptimeout(x), bptimeout(x) <- value`: `numeric(1)` Time (in seconds) allowed for worker to complete a task. This value is passed to `base::setTimeLimit()` as both the `cpu` and `elapsed` arguments. If the computation exceeds timeout an error is thrown with message 'reached elapsed time limit'.

`bpprogressbar(x), bpprogressbar(x) <- value`: Get or set the value to enable text progress bar. value must be a `logical(1)`.

`bpjobname(x), bpjobname(x) <- value`: Get or set the job name.

**Error Handling:** In the code below BPPARAM is a BiocParallelParam object.

`bpCatchErrors(x)`, `bpCatchErrors(x) <- value: logical()`. DEPRECATED Controls if errors are caught and returned with completed results.

`catch.errors` determines whether errors are caught and returned with other results. When TRUE, all computations are attempted and output contains both errors and successfully completed results. When FALSE, the job is terminated as soon as the first error is hit and only the error message is returned (no results); this is the default behavior of the parent packages, e.g., `parallel`, `snow`, `foreach`.

`bpstopOnError(x)`, `bpstopOnError(x) <- value: logical()`. Controls if the job stops when an error is hit.

`stop.on.error` controls whether the job stops after an error is thrown. When TRUE, the output contains all successfully completed results up to and including the error. When `stop.on.error == TRUE` all computations stop once the error is hit. When FALSE, the job runs to completion and successful results are returned along with any error messages.

## Methods

**Evaluation:** In the code below BPPARAM is a `BiocParallelParam` object. Full documentation for these functions are on separate man pages: see `?bpmapapply`, `?bplapply`, `?bpvec`, `?bpiterate` and `?bpaggregate`.

```
bpmapapply(FUN, ..., MoreArgs=NULL, SIMPLIFY=TRUE, USE.NAMES=TRUE,
bplapply(X, FUN, ..., BPPARAM=bpparam())
bpvec(X, FUN, ..., AGGREGATE=c, BPPARAM=bpparam())
bpiterate(ITER, FUN, ..., BPPARAM=bpparam())
bpaggregate(x, data, FUN, ..., BPPARAM=bpparam())
```

BPPARAM=bpparam()

**Other:** In the code below BPPARAM is a `BiocParallelParam` object.

```
show(x)
```

## Author(s)

Martin Morgan and Valerie Obenchain.

## See Also

- [SnowParam](#) for computing in distributed memory
- [MulticoreParam](#) for computing in shared memory
- [BatchJobsParam](#) for computing with cluster schedulers
- [DoparParam](#) for computing with foreach
- [SerialParam](#) for non-parallel execution

## Examples

```
getClass("BiocParallelParam")

## For examples see ?SnowParam, ?MulticoreParam, ?BatchJobsParam
## and ?SerialParam.
```

bpaggregate

*Apply a function on subsets of data frames*

## Description

This is a parallel version of [aggregate](#).

## Usage

```
## S4 method for signature 'formula,BiocParallelParam'
bpaggregate(x, data, FUN, ...,
            BPRED0=list(), BPPARAM=bpparam())

## S4 method for signature 'data.frame,BiocParallelParam'
bpaggregate(x, by, FUN, ...,
            simplify=TRUE, BPRED0=list(), BPPARAM=bpparam())

## S4 method for signature 'matrix,BiocParallelParam'
bpaggregate(x, by, FUN, ...,
            simplify=TRUE, BPRED0=list(), BPPARAM=bpparam())

## S4 method for signature 'ANY,missing'
bpaggregate(x, ..., BPRED0=list(), BPPARAM=bpparam())
```

## Arguments

x	A <code>data.frame</code> , <code>matrix</code> or a <code>formula</code> .
by	A list of factors by which x is split; applicable when x is <code>data.frame</code> or <code>matrix</code> .
data	A <code>data.frame</code> ; applicable when x is a <code>formula</code> .
FUN	Function to apply.
...	Additional arguments for FUN.
simplify	If set to <code>TRUE</code> , the return values of FUN will be simplified using <a href="#">simplify2array</a> .
BPPARAM	An optional <a href="#">BiocParallelParam</a> instance determining the parallel back-end to be used during evaluation.
BPRED0	A list of output from <code>bpaggregate</code> with one or more failed elements. When a list is given in BPRED0, <code>bpok</code> is used to identify errors, tasks are rerun and inserted into the original results.

## Details

`bpaggregate` is a generic with methods for `data.frame`, `matrix` and `formula` objects. x is divided into subsets according to factors in `by`. Data chunks are sent to the workers, FUN is applied and results are returned as a `data.frame`.

The function is similar in spirit to [aggregate](#) from the `stats` package but [aggregate](#) is not explicitly called. The `bpaggregate` `formula` method reformulates the call and dispatches to the `data.frame` method which in turn distributes data chunks to workers with `bplapply`.

**Value**

See [aggregate](#).

**Author(s)**

Martin Morgan <mailto:mtmorgan@fhcrc.org>.

**Examples**

```
if (require(Rsamtools) && require(GenomicAlignments)) {

  fl <- system.file("extdata", "ex1.bam", package="Rsamtools")
  param <- ScanBamParam(what = c("flag", "mapq"))
  gal <- readGAlignments(fl, param=param)

  ## Report the mean map quality by range cutoff:
  cutoff <- rep(0, length(gal))
  cutoff[start(gal) > 1000 & start(gal) < 1500] <- 1
  cutoff[start(gal) > 1500] <- 2
  bpaggregate(as.data.frame(mcols(gal)$mapq), list(cutoff = cutoff), mean)

}
```

---

bpiterate

---

*Parallel iteration over an indeterminate number of data chunks*


---

**Description**

bpiterate iterates over an indeterminate number of data chunks (e.g., records in a file). Each chunk is processed by parallel workers in an asynchronous fashion; as each worker finishes it receives a new chunk. Data are traversed a single time.

**Usage**

```
bpiterate(ITER, FUN, ..., BPPARAM=bpparam())

## S4 method for signature 'ANY,ANY,missing'
bpiterate(ITER, FUN, ..., BPPARAM=bpparam())

## S4 method for signature 'ANY,ANY,BiocParallelParam'
bpiterate(ITER, FUN, ..., BPPARAM=bpparam())
```

**Arguments**

ITER	A function with no arguments that returns an object to process, generally a chunk of data from a file. When no objects are left (i.e., end of file) it should return NULL and continue to return NULL regardless of the number of times it is invoked after reaching the end of file. This function is run on the master.
FUN	A function to process the object returned by ITER; run on parallel workers separate from the master. When BPPARAM is a MulticoreParam, FUN is ‘decorated’ with additional arguments and therefore must have ... in the signature.



BPPARAM	An optional <a href="#">BiocParallelParam</a> instance determining the parallel back-end to be used during evaluation, or a list of <a href="#">BiocParallelParam</a> instances, to be applied in sequence for nested calls to <code>bpiterate</code> .
...	<p>Arguments to other methods, specifically named arguments for FUN, or REDUCE or init.</p> <ul style="list-style-type: none"> <li>• <code>REDUCE</code>: Optional function that combines (reduces) output from FUN. As each worker returns, the data are combined with the REDUCE function. REDUCE takes 2 arguments; one is the current result and the other is the output of FUN from a worker that just finished.</li> <li>• <code>init</code>: Optional initial value for REDUCE; must be of the same type as the object returned from FUN. When supplied, <code>reduce.in.order</code> is set to <code>TRUE</code>.</li> <li>• <code>reduce.in.order</code>: Logical. When <code>TRUE</code>, REDUCE is applied to the results from the workers in the same order the tasks were sent out.</li> </ul>

## Details

Supported for `SnowParam` and `MulticorParam`.

`bpiterate` iterates through an unknown number of data chunks, dispatching chunks to parallel workers as they become available. In contrast, other `bp*apply` functions such as `bplapply` or `bpmapply` require the number of data chunks to be specified ahead of time. This quality makes `bpiterate` useful for iterating through files of unknown length.

ITER serves up chunks of data until the end of the file is reached at which point it returns `NULL`. Note that ITER should continue to return `NULL` regardless of the number of times it is invoked after reaching the end of the file. FUN is applied to each object (data chunk) returned by ITER.

## Value

By default, a list the same length as the number of chunks in `ITER()`. When REDUCE is used, the return is consistent with application of the reduction.

## Author(s)

Valerie Obenchain <mailto:vobencha@fhcrc.org>.

## See Also

- [bpvec](#) for parallel, vectorized calculations.
- [bplapply](#) for parallel, lapply-like calculations.
- [BiocParallelParam](#) for details of BPPARAM.

## Examples

```
## Not run:
if (require(Rsamtools) && require(RNaseqData.HNRNPC.bam.chr14) &&
    require(GenomicAlignments) && require(ShortRead)) {

  ## -----
  ## Iterate through a BAM file
  ## -----

  ## Select a single file and set 'yieldSize' in the BamFile object.
  fl <- RNaseqData.HNRNPC.bam.chr14_BAMFILES[[1]]
```

```

bf <- BamFile(fl, yieldSize = 300000)

## bamIterator() is initialized with a BAM file and returns a function.
## The return function requires no arguments and iterates through the
## file returning data chunks the size of yieldSize.
bamIterator <- function(bf) {
  done <- FALSE
  if (!isOpen( bf))
    open(bf)

  function() {
    if (done)
      return(NULL)
    yld <- readGAlignments(bf)
    if (length(yld) == 0L) {
      close(bf)
      done <-< TRUE
      NULL
    } else yld
  }
}

## FUN counts reads in a region of interest.
roi <- GRanges("chr14", IRanges(seq(19e6, 107e6, by = 10e6), width = 10e6))
counter <- function(reads, roi, ...) {
  countOverlaps(query = roi, subject = reads)
}

## Initialize the iterator.
ITER <- bamIterator(bf)

## The number of chunks returned by ITER() determines the result length.
bpparam <- MulticoreParam(workers = 3)
bpiterate(ITER, counter, roi = roi, BPPARAM = bpparam)

## Re-initialize the iterator and combine on the fly with REDUCE:
ITER <- bamIterator(bf)
bpparam <- MulticoreParam(workers = 3)
bpiterate(ITER, counter, REDUCE = sum, roi = roi, BPPARAM = bpparam)

## -----
## Iterate through a FASTA file
## -----

## Set data chunk size with 'n' in the FastqStreamer object.
sp <- SolexaPath(system.file('extdata', package = 'ShortRead'))
fl <- file.path(analysisPath(sp), "s_1_sequence.txt")

## Create an iterator that returns data chunks the size of 'n'.
fastqIterator <- function(fqs) {
  done <- FALSE
  if (!isOpen(fqs))
    open(fqs)

  function() {
    if (done)
      return(NULL)
  }
}

```

```

        yld <- yield(fqs)
        if (length(yld) == 0L) {
            close(fqs)
            done <-< TRUE
            NULL
        } else yld
    }
}

## The process function summarizes the number of times each sequence occurs.
summary <- function(reads, ...) {
    ShortRead::tables(reads, n = 0)$distribution
}

## Create a param.
bpparam <- SnowParam(workers = 2)

## Initialize the streamer and iterator.
fqs <- FastqStreamer(fl, n = 100)
ITER <- fastqIterator(fqs)
bpiterate(ITER, summary, BPPARAM = bpparam)

## Results from the workers are combined on the fly when REDUCE is used.
## Collapsing the data in this way can substantially reduce memory
## requirements.
fqs <- FastqStreamer(fl, n = 100)
ITER <- fastqIterator(fqs)
bpiterate(ITER, summary, REDUCE = merge, all = TRUE, BPPARAM = bpparam)

}

## End(Not run)

```

bplapply

*Parallel lapply-like functionality*

## Description

bplapply applies FUN to each element of X. Any type of object X is allowed, provided length, [, and [[ methods are available. The return value is a list of length equal to X, as with [lapply](#).

## Usage

```
bplapply(X, FUN, ..., BPRED0 = list(), BPPARAM=bpparam())
```

## Arguments

X	Any object for which methods length, [, and [[ are implemented.
FUN	The function to be applied to each element of X.
...	Additional arguments for FUN, as in <a href="#">lapply</a> .
BPPARAM	An optional <a href="#">BiocParallelParam</a> instance determining the parallel back-end to be used during evaluation, or a list of <a href="#">BiocParallelParam</a> instances, to be applied in sequence for nested calls to <b>BiocParallel</b> functions.

**BPRED0** A list of output from `bplapply` with one or more failed elements. When a list is given in `BPRED0`, `bpok` is used to identify errors, tasks are rerun and inserted into the original results.

### Details

See `showMethods{bplapply}` for additional methods, e.g., `method?bplapply("MulticoreParam")`.

### Value

See [lapply](#).

### Author(s)

Martin Morgan <mailto:mtmorgan@fhcrc.org>. Original code as attributed in [mclapply](#).

### See Also

- [bpvec](#) for parallel, vectorized calculations.
- [BiocParallelParam](#) for possible values of `BPPARAM`.

### Examples

```
showMethods("bplapply")

## ten tasks (1:10) so ten calls to FUN default registered parallel
## back-end. Compare with bpvec.
fun <- function(v) {
  message("working") ## 10 tasks
  sqrt(v)
}
bplapply(1:10, fun)
```

---

bploop

*Internal Functions for SNOW-style Parallel Evaluation*

---

### Description

The functions documented on this page are primarily for use within **BiocParallel** to enable SNOW-style parallel evaluation, using communication between manager and worker nodes through sockets.

### Usage

```
## S3 method for class 'SOCKnode'
bploop(manager, ...)

## S3 method for class 'SOCK0node'
bploop(manager, ...)

## S3 method for class 'MPInode'
bploop(manager, ...)
```

```
## S3 method for class 'lapply'
bploop(manager, X, FUN, ARGFUN, BPPARAM, ...)

## S3 method for class 'iterate'
bploop(manager, ITER, FUN, ARGFUN, BPPARAM,
        REDUCE, init, reduce.in.order, ...)
```

### Arguments

manager	An object representing the manager node. For workers, this is the node to which the worker will communicate. For managers, this is the form of iteration – lapply or iterate.
X	A vector of jobs to be performed.
FUN	A function to apply to each job.
ARGFUN	A function accepting an integer value indicating the job number, and returning the job-specific arguments to FUN.
BPPARAM	An instance of a BiocParallelParam class.
ITER	A function used to generate jobs. No more jobs are available when ITER() returns NULL.
REDUCE	(Optional) A function combining two values returned by FUN into a single value.
init	(Optional) Initial value for reduction.
reduce.in.order	(Optional) logical(1) indicating that reduction must occur in the order jobs are dispatched (TRUE) or that reduction can occur in the order jobs are completed (FALSE).
...	Additional arguments, ignored in all cases.

### Details

Workers enter a loop. They wait to receive a message (R list) from the manager. The message contains a type element, with evaluation as follows:

**“EXEC”** Execute the R code in the message, returning the result to the manager.

**“DONE”** Signal termination to the manager, terminate the worker.

Managers under lapply dispatch pre-determined jobs, X, to workers, collecting the results from and dispatching new jobs to the first available worker. The manager returns a list of results, in a one-to-one correspondence with the order of jobs supplied, when all jobs have been evaluated.

Managers under iterate dispatch an undetermined number of jobs to workers, collecting previous jobs from and dispatching new jobs to the first available worker. Dispatch continues until available jobs are exhausted. The return value is by default a list of results in a one-to-one correspondence with the order of jobs supplied. The return value is influenced by REDUCE, init, and reduce.in.order.

### Author(s)

Valerie Obenchain, Martin Morgan. Derived from similar functionality in the **snow** and **parallel** packages.

### Examples

```
## These functions are not meant to be called by the end user.
```

bpmapply

*Parallel mapply-like functionality***Description**

bpmapply applies FUN to first elements of ..., the second elements and so on. Any type of object in ... is allowed, provided length, [, and [[ methods are available. The return value is a list of length equal to the length of all objects provided, as with [mapply](#).

**Usage**

```
bpmapply(FUN, ..., MoreArgs=NULL, SIMPLIFY=TRUE, USE.NAMES=TRUE,
         BPRED0=list(), BPPARAM=bpparam())

## S4 method for signature 'ANY,missing'
bpmapply(FUN, ..., MoreArgs=NULL, SIMPLIFY=TRUE,
         USE.NAMES=TRUE, BPRED0=list(), BPPARAM=bpparam())

## S4 method for signature 'ANY,BiocParallelParam'
bpmapply(FUN, ..., MoreArgs=NULL,
         SIMPLIFY=TRUE, USE.NAMES=TRUE, BPRED0=list(), BPPARAM=bpparam())
```

**Arguments**

FUN	The function to be applied to each element passed via ....
...	Objects for which methods length, [, and [[ are implemented. All objects must have the same length or shorter objects will be replicated to have length equal to the longest.
MoreArgs	List of additional arguments to FUN.
SIMPLIFY	If TRUE the result will be simplified using <a href="#">simplify2array</a> .
USE.NAMES	If TRUE the result will be named.
BPPARAM	An optional <a href="#">BiocParallelParam</a> instance defining the parallel back-end to be used during evaluation.
BPRED0	A list of output from bpmapply with one or more failed elements. When a list is given in BPRED0, bpok is used to identify errors, tasks are rerun and inserted into the original results.

**Details**

See `showMethods{bpmapply}` for additional methods, e.g., `method?bpmapply("MulticoreParam")`.

**Value**

See [mapply](#).

**Author(s)**

Michel Lang . Original code as attributed in [mclapply](#).

**See Also**

- [bpvec](#) for parallel, vectorized calculations.
- [BiocParallelParam](#) for possible values of BPPARAM.

**Examples**

```
showMethods("bpmapapply")

fun <- function(greet, who) {
  paste(Sys.getpid(), greet, who)
}
greet <- c("morning", "night")
who <- c("sun", "moon")

param <- bpparam()
original <- bpworkers(param)
bpworkers(param) <- 2
result <- bpmapapply(fun, greet, who, BPPARAM = param)
cat(paste(result, collapse="\n"), "\n")
bpworkers(param) <- original
```

bpok

*Resume computation with partial results***Description**

Identifies unsuccessful results returned from `bplapply`, `bpmapapply`, `bpvec`, `bpaggregate` or `bpvectorize`.  
`bpresume` and `bplatererror` have been deprecated.

**Usage**

```
bpok(x)

## Deprected:
bpresume(expr)
bplatererror()
```

**Arguments**

<code>x</code>	Results returned from a call to <code>bp*lapply</code> .
<code>expr</code>	A expression to be re-evaluated. If the original error was due to input error, <code>X</code> should be modified. If hardware limitations or failure caused the error this expression may be the same as the original.

## Details

- bpok Returns a logical() vector: FALSE for any jobs that resulted in an error. x is the result list output by bplapply, bpmapply, bpvec, bpaggregate or bpvectorize.
- bpresume THIS FUNCTION IS DEPRECATED. The resume mechanism allows computations with errors to be re-attempted and is triggered when the argument catch.errors is TRUE.  
Unsuccessful results returned from bp\*lapply can be identified with bpok. Failure may have been due to faulty input or hardware error. Incomplete portions of the job can be reattempted with bpresume. New results are merged with the previous and returned to the user.
- bplastererror THIS FUNCTION IS DEPRECATED. Use attr on the output of bp\*apply to see traceback. See examples.

## Author(s)

Michel Lang, Martin Morgan and Valerie Obenchain

## Examples

```
## -----
## Catch errors:
## -----

## By default 'stop.on.error' is TRUE in BiocParallelParam objects.
SnowParam(workers = 2)

## If 'stop.on.error' is TRUE an ill-fated bplapply() simply stops,
## displaying the error message.
param <- SnowParam(workers = 2, stop.on.error = TRUE)
tryCatch({
  bplapply(list(1, "two", 3), sqrt, BPPARAM = param)
}, error=identity)

## If 'stop.on.error' is FALSE then the computation continues. Errors
## are signalled but the full evaluation can be retrieved
param <- SnowParam(workers = 2, stop.on.error = FALSE)
X <- list(1, "two", 3)
result <- bpttry(bplapply(X, sqrt, BPPARAM = param))
result

## Check for errors:
fail <- !bpok(result)
fail

## Access the traceback with attr():
tail(attr(result[[2]], "traceback"), 5)

## -----
## Resume calculations:
## -----

## The 'resume' mechanism is triggered by supplying a list of partial
## results as 'BPRED0'. Data elements that failed are rerun and merged
## with previous results.
```



```
## A call of sqrt() on the character "2" returns an error.
param <- SnowParam(workers = 2, stop.on.error = FALSE)
X <- list(1, "two", 3)
result <- bpttry(bplapply(X, sqrt, BPPARAM = param))

## Fix the input data by changing the character "2" to a numeric 2:
X_mod <- list(1, 2, 3)

## Repeat the original call to bplapply() with the partial results as 'BPRED0':
bplapply(X_mod, sqrt, BPPARAM = param , BPRED0 = result)
```

bpschedule

*Schedule back-end Params***Description**

Use functions on this page to influence scheduling of parallel processing.

**Usage**

```
bpschedule(x)
```

**Arguments**

x	An instance of a BiocParallelParam class, e.g., <a href="#">MulticoreParam</a> , <a href="#">SnowParam</a> , <a href="#">DoparParam</a> .
...	x can be missing, in which case the default back-end (see <a href="#">register</a> ) is used. Additional arguments, perhaps used by methods.

**Details**

bpschedule returns a logical(1) indicating whether the parallel evaluation should occur at this point.

**Value**

bpschedule returns a scalar logical.

**Author(s)**

Martin Morgan <mailto:mtmorgan@fhcrc.org>.

**See Also**

[BiocParallelParam](#) for possible values of x.

**Examples**

```
bpschedule(SnowParam()) # TRUE
bpschedule(MulticoreParam(2)) # FALSE on windows

p <- MulticoreParam()
bpschedule(p) # TRUE
bplapply(1:2, function(i, p) {
  bpschedule(p) # FALSE
}, p = p, BPPARAM=p)
```

bpttry

*Try expression evaluation, recovering from bpttry signals***Description**

This function is meant to be used as a wrapper around `bplapply()` and friends, returning the evaluated expression rather than signalling an error.

**Usage**

```
bpttry(expr, ..., bplist_error, bperror)
```

**Arguments**

expr	An R expression; see <a href="#">tryCatch</a> .
bplist_error	A ‘handler’ function of a single argument, used to catch <code>bplist_error</code> conditions signalled by <code>expr</code> . A <code>bplist_error</code> condition is signalled when an element of <code>bplapply</code> and other iterations contain a evaluation that failed. When missing, the default retrieves the “result” attribute from the error, containing the partially evaluated results. Setting <code>bplist_error=identity</code> returns the evaluated condition. Setting <code>bplist_error=stop</code> passes the condition to other handlers, notably the handler provided by <code>bperror</code> .
bperror	A ‘handler’ function of a single argument, use to catch <code>bperror</code> conditions signalled by <code>expr</code> . A <code>bperror</code> is a base class to all errors signaled by <b>BiocParallel</b> code. When missing, the default returns the condition without signalling an error.
...	Additional named handlers passed to <code>tryCatch()</code> . These user-provided handlers are evaluated before default handlers <code>bplist_error</code> , <code>bperror</code> .

**Value**

The partially evaluated list of results.

**Author(s)**

Martin Morgan <[martin.morgan@roswellpark.org](mailto:martin.morgan@roswellpark.org)>

**See Also**

[tryCatch](#), [bplapply](#).

**Examples**

```
param = registered()[[1]]
param
X = list(1, "2", 3)
bpttry(bplapply(X, sqrt)) # bplist_error handler
bpttry(bplapply(X, sqrt), bplist_error=identity) # bperror handler
```

---

bpvalidate	<i>Tools for developing functions for parallel execution in distributed memory</i>
------------	--

---

## Description

bpvalidate interrogates the function environment and search path to locate undefined symbols.

## Usage

```
bpvalidate(fun)
```

## Arguments

fun	The function to be checked.
-----	-----------------------------

## Details

bpvalidate tests if a function can be run in a distributed memory environment (e.g., SOCK clusters, Windows machines). bpvalidate looks in the environment of fun, in the NAMESPACE exports of libraries loaded in fun, and along the search path to identify any symbols outside the scope of fun. bpvalidate can be used to check functions passed to the bp\* family of functions in BiocParallel or other packages that support parallel evaluation on clusters such as snow, BatchJobs, Rmpi, etc.

**testing package functions** The environment of a function defined inside a package is the NAMESPACE of the package. It is important to test these functions as they will be called from within the package, with the appropriate environment. Specifically, do not copy/paste the function into the workspace; once this is done the GlobalEnv becomes the function environment. To test a package function, load the package then call the function by name (myfun) or explicitly (mypkg::myfun) if not exported.

**testing workspace functions** The environment of a function defined in the workspace is the GlobalEnv. Because these functions do not have an associated package NAMESPACE, the functions and variables used in the body must be explicitly passed or defined. See examples. Defining functions in the workspace is often done during development or testing. If the function is later moved inside a package, it can be rewritten in a more lightweight form by taking advantage of imported symbols in the package NAMESPACE.

NOTE: bpvalidate does not currently work on Generics.

## Value

A list of length 2 with named elements 'inPath' and 'unknown'.

- inPath A named list of symbols and where they were found. These symbols were found on the search path instead of the function environment and should probably be imported in the NAMESPACE or otherwise defined in the package.
- unknown A vector of symbols not found in the function environment or the search path.

## Author(s)

Martin Morgan <mailto:mtmorgan@fhcrc.org> and Valerie Obenchain <mailto:vobencha@fhcrc.org>.

## Examples

```
## -----
## Testing package functions
## -----

## Not run:
library(myPkg)

## Test exported functions by name or the double colon:
bpvalidate(myExportedFun)
bpvalidate(myPkg::myExportedFun)

## Non-exported functions are called with the triple colon:
bpvalidate(myPkg:::myInternalFun)

## End(Not run)

## -----
## Testing workspace functions
## -----

## Functions defined in the workspace have the .GlobalEnv as their
## environment. Often the symbols used inside the function body
## are not defined in .GlobalEnv and must be passed explicitly.

## Loading libraries:
## In 'fun1' countBam() is flagged as unknown:
fun1 <- function(fl, ...) {
  countBam(fl)
bpvalidate(fun1)

## countBam() is not defined in .GlobalEnv and must be passed as
## an argument or made available by loading the library.
fun2 <- function(fl, ...) {
  library(Rsamtools)
  countBam(fl)
}
bpvalidate(fun2)

## Passing arguments:
## 'param' is defined in the workspace but not passed to 'fun3'.
## bpvalidate() flags 'param' as being found 'inPath' which means
## it is not defined in the function environment or inside the function.
library(Rsamtools)
param <- ScanBamParam(flag=scanBamFlag(isMinusStrand=FALSE))

fun3 <- function(fl, ...) {
  library(Rsamtools)
  countBam(fl, param=param)
}
bpvalidate(fun3)

## 'param' is explicitly passed by adding it as a formal argument.
fun4 <- function(fl, ..., param) {
  library(Rsamtools)
```

```

    countBam(fl, param=param)
  }
  bpvalidate(fun4)

## The corresponding call to a bp* function includes 'param':
## Not run: bplapply(files, fun4, param=param, BPPARAM=SnowParam(2))

```

bpvec

*Parallel, vectorized evaluation*

## Description

bpvec applies FUN to subsets of X. Any type of object X is allowed, provided length, and [ are defined on X. FUN is a function such that length(FUN(X)) == length(X). The objects returned by FUN are concatenated by AGGREGATE (c() by default). The return value is FUN(X).

## Usage

```
bpvec(X, FUN, ..., AGGREGATE=c, BPRED0=list(), BPPARAM=bpparam())
```

## Arguments

X	Any object for which methods length and [ are implemented.
FUN	A function to be applied to subsets of X. The relationship between X and FUN(X) is 1:1, so that length(FUN(X, ...)) == length(X). The return value of separate calls to FUN are concatenated with AGGREGATE.
...	Additional arguments for FUN.
AGGREGATE	A function taking any number of arguments ... called to reduce results (elements of the ... argument of AGGREGATE from parallel jobs. The default, c, concatenates objects and is appropriate for vectors; rbind might be appropriate for data frames.
BPPARAM	An optional <a href="#">BiocParallelParam</a> instance determining the parallel back-end to be used during evaluation, or a list of <a href="#">BiocParallelParam</a> instances, to be applied in sequence for nested calls to <b>BiocParallel</b> functions.
BPRED0	A list of output from bpvec with one or more failed elements. When a list is given in BPRED0, bpok is used to identify errors, tasks are rerun and inserted into the original results.

## Details

This method creates a vector of indices for X that divide the elements as evenly as possible given the number of bpworkers() and bptasks() of BPPARAM. Indices and data are passed to bplapply for parallel evaluation.

The distinction between bpvec and bplapply is that bplapply applies FUN to each element of X separately whereas bpvec assumes the function is vectorized, e.g., c(FUN(x[1]), FUN(x[2])) is equivalent to FUN(x[1:2]). This approach can be more efficient than bplapply but requires the assumption that FUN takes a vector input and creates a vector output of the same length as the input which does not depend on partitioning of the vector. This behavior is consistent with parallel::pvec and the ?pvec man page should be consulted for further details.

**Value**

The result should be identical to FUN(X, ...) (assuming that AGGREGATE is set appropriately).

When evaluation of individual elements of X results in an error, the result is a list with the same geometry (i.e., lengths()) as the split applied to X to create chunks for parallel evaluation; one or more elements of the list contain a bpererror element, indicating that the vectorized calculation failed for at least one of the index values in that chunk.

An error is also signaled when FUN(X) does not return an object of the same length as X; this condition is only detected when the number of elements in X is greater than the number of workers.

**Author(s)**

Martin Morgan <mailto:mtmorgan@fhcrc.org>.

**See Also**

[bplapply](#) for parallel lapply.

[BiocParallelParam](#) for possible values of BPPARAM.

[pvec](#) for background.

**Examples**

```
showMethods("bpvec")

## ten tasks (1:10), called with as many back-end elements are specified
## by BPPARAM. Compare with bplapply
fun <- function(v) {
  message("working")
  sqrt(v)
}
system.time(result <- bpvec(1:10, fun))
result

## invalid FUN -- length(class(X)) is not equal to length(X)
bpttry(bpvec(1:2, class, BPPARAM=SerialParam()))
```

---

bpvectorize

---

*Transform vectorized functions into parallelized, vectorized function*


---

**Description**

This transforms a vectorized function into a parallel, vectorized function. Any function FUN can be used, provided its parallelized argument (by default, the first argument) has a length and [ method defined, and the return value of FUN can be concatenated with c.

**Usage**

```
bpvectorize(FUN, ..., BPRED0=list(), BPPARAM=bpparam())

## S4 method for signature 'ANY,ANY'
bpvectorize(FUN, ..., BPRED0=list(), BPPARAM=bpparam())
```

```
## S4 method for signature 'ANY,missing'
bpvectorize(FUN, ..., BPRED0=list(),
            BPPARAM=bpparam())
```

## Arguments

FUN	A function whose first argument has a length and can be subset <code>[]</code> , and whose evaluation would benefit by splitting the argument into subsets, each one of which is independently transformed by FUN. The return value of FUN must support concatenation with <code>c</code> .
...	Additional arguments to parallization, unused.
BPPARAM	An optional <a href="#">BiocParallelParam</a> instance determining the parallel back-end to be used during evaluation.
BPRED0	A list of output from bpvectorize with one or more failed elements. When a list is given in BPRED0, bpok is used to identify errors, tasks are rerun and inserted into the original results.

## Details

The result of bpvectorize is a function with signature `...;` arguments to the returned function are the original arguments FUN. BPPARAM is used for parallel evaluation.

When BPPARAM is a class for which no method is defined (e.g., [SerialParam](#)), FUN(X) is used.

See `showMethods{bpvectorize}` for additional methods, if any.

## Value

A function taking the same arguments as FUN, but evaluated using [bpvec](#) for parallel evaluation across available cores.

## Author(s)

Ryan Thompson <mailto:rct@thompsonclan.org>

## See Also

[bpvec](#)

## Examples

```
psqrt <- bpvectorize(sqrt) ## default parallelization
psqrt(1:10)
```

---

DoparParam-class	<i>Enable parallel evaluation using registered dopar backend</i>
------------------	--

---

## Description

This class is used to dispatch parallel operations to the dopar backend registered with the foreach package.

## Usage

```
DoparParam(catch.errors = TRUE, stop.on.error=TRUE)
```

## Arguments

catch.errors	DEPRECATED logical(1) Flag to determine in apply-like functions (see e.g. <a href="#">bplapply</a> ) whether to quit with an error as soon as one application fails or encapsulation of function calls in <a href="#">try</a> blocks which triggers a resume mechanism (see <a href="#">bpresume</a> ). Defaults to TRUE.
stop.on.error	logical(1) Stop all jobs as soon as one jobs fails (stop.on.error == TRUE) or wait for all jobs to terminate. Default is TRUE.

## Details

DoparParam can be used for shared or non-shared memory computing depending on what backend is loaded. The doSNOW package supports non-shared memory, doParallel supports both shared and non-shared. When not specified, the default number of workers in DoparParam is determined by getDoParWorkers(). See the foreach package vignette for details using the different backends:

<http://cran.r-project.org/web/packages/foreach/vignettes/foreach.pdf>

## DoparParam constructor

Return a proxy object that dispatches parallel evaluation to the registered foreach parallel backend.

There are no options to the constructor. All configuration should be done through the normal interface to the foreach parallel backends.

## Methods

The following generics are implemented and perform as documented on the corresponding help page (e.g., [?bpisup](#)): [bpworkers](#), [bpnworkers](#), [bpstart](#), [bpstop](#), [bpisup](#), [bpbackend](#), [bpbackend<-](#), [bpvec](#).

## Author(s)

Martin Morgan <mailto:mtmorgan@fhcrc.org>

## See Also

`getClass("BiocParallelParam")` for additional parameter classes.

`register` for registering parameter classes for use in parallel evaluation.

`foreach-package` for the parallel backend infrastructure used by this param class.



## Examples

```
## Not run:
# First register a parallel backend with foreach
library(doParallel)
registerDoParallel(2)

p <- DoparParam()
bplapply(1:10, sqrt, BPPARAM=p)
bpvec(1:10, sqrt, BPPARAM=p)

register(DoparParam(), default=TRUE)

## End(Not run)
```

---

MulticoreParam-class    *Enable multi-core parallel evaluation*

---

## Description

This class is used to parameterize single computer multicore parallel evaluation on non-Windows computers. `multicoreWorkers()` chooses the number of workers based on operating system (Windows only supports 1 core), global user preference (`options(mc.cores=...)`), or the minimum of 8 and the number of detected cores (`detectCores()`).

## Usage

```
## constructor
## -----

MulticoreParam(workers = multicoreWorkers(), tasks = 0L,
               catch.errors = TRUE, stop.on.error = TRUE,
               progressbar = FALSE, RNGseed = NULL,
               timeout = 30L * 24L * 60L * 60L,
               log = FALSE, threshold = "INFO", logdir = NA_character_,
               resultdir = NA_character_, jobname = "BPJOB", ...)

## detect workers
## -----

multicoreWorkers()
```

## Arguments

<code>workers</code>	<code>integer(1)</code> Number of workers. Defaults to all cores available as determined by <code>detectCores</code> .
<code>tasks</code>	<code>integer(1)</code> . The number of tasks per job. value must be a scalar integer $\geq 0L$ .  In this documentation a job is defined as a single call to a function, such as <code>bplapply</code> , <code>bpmapply</code> etc. A task is the division of the X argument into chunks.

	When <code>tasks == 0</code> (default), <code>X</code> is divided as evenly as possible over the number of workers.
	A <code>tasks</code> value of <code>&gt; 0</code> specifies the exact number of tasks. Values can range from 1 (all of <code>X</code> to a single worker) to the length of <code>X</code> (each element of <code>X</code> to a different worker).
	When the length of <code>X</code> is less than the number of workers each element of <code>X</code> is sent to a worker and <code>tasks</code> is ignored.
<code>catch.errors</code>	DEPRECATED. <code>logical(1)</code> Enable the catching of errors and warnings.
<code>stop.on.error</code>	<code>logical(1)</code> Enable stop on error.
<code>progressbar</code>	<code>logical(1)</code> Enable progress bar (based on <code>plyr:::progress_text</code> ).
<code>RNGseed</code>	<code>integer(1)</code> Seed for random number generation. When not <code>NULL</code> , this value is passed to <code>parallel::clusterSetRNGStream</code> to generate random number streams on each worker.
<code>timeout</code>	<code>numeric(1)</code> Time (in seconds) allowed for worker to complete a task. This value is passed to <code>base::setTimeLimit()</code> as both the <code>cpu</code> and <code>elapsed</code> arguments. If the computation exceeds <code>timeout</code> an error is thrown with message 'reached elapsed time limit'.
<code>log</code>	<code>logical(1)</code> Enable logging.
<code>threshold</code>	<code>character(1)</code> Logging threshold as defined in <code>futile.logger</code> .
<code>logdir</code>	<code>character(1)</code> Log files directory. When not provided, log messages are returned to <code>stdout</code> .
<code>resultdir</code>	<code>character(1)</code> Job results directory. When not provided, results are returned as an R object (list) to the workspace.
<code>jobname</code>	<code>character(1)</code> Job name that is prepended to log and result files. Default is "BPJOB".
<code>...</code>	Additional arguments passed to <code>makeCluster</code>

## Details

`MulticoreParam` is used for shared memory computing. Under the hood the cluster is created with `makeCluster(..., type = "FORK")` from the `parallel` package. If not specified, the default number of workers is determined by `multicoreWorkers()`, which is `parallel::detectCores() - 2`. Machines with 3 or less cores are assigned a single worker.

A FORK transport starts workers with the `mcfork` function and communicates between master and workers using socket connections. `mcfork` builds on `fork()` and thus a Linux cluster is not supported. Because FORK clusters are Posix based they are not supported on Windows. When `MulticoreParam` is created/used in Windows it defaults to `SerialParam` which is the equivalent of using a single worker.

**error handling:** The `catch.errors` field has been deprecated.

By default all computations are attempted and partial results are returned with any error messages.

- `catch.errors` (DEPRECATED) determines whether errors are caught and returned with other results. When `TRUE`, all computations are attempted and output contains both errors and successfully completed results. When `FALSE`, the job is terminated as soon as the first error is hit and only the error message is returned (no results); this is the default behavior of the parent packages, e.g., `parallel`, `snow`, `foreach`.

- `stop.on.error` A logical. Stops all jobs as soon as one job fails or wait for all jobs to terminate. When FALSE, the return value is a list of successful results along with error messages as 'conditions'.
- The `bpok(x)` function returns a `logical()` vector that is FALSE for any jobs that threw an error. The input `x` is a list output from a `bp*apply` function such as `bplapply` or `bpmapply`.

**logging:** When `log = TRUE` the `futile.logger` package is loaded on the workers. All log messages written in the `futile.logger` format are captured by the logging mechanism and returned real-time (i.e., as each task completes) instead of after all jobs have finished.

Messages sent to `stdout` and `stderr` are returned to the workspace by default. When `log = TRUE` these are diverted to the log output. Those familiar with the `outfile` argument to `makeCluster` can think of `log = FALSE` as equivalent to `outfile = NULL`; providing a `logdir` is the same as providing a name for `outfile` except that `BiocParallel` writes a log file for each task.

The log output includes additional statistics such as memory use and task runtime. Memory use is computed by calling `gc(reset=TRUE)` before code evaluation and `gc()` (no reset) after. The output of the second `gc()` call is sent to the log file. There are many ways to track memory use - this particular approach was taken because it is consistent with how the `BatchJobs` package reports memory on the workers.

**log and result files:** Results and logs can be written to a file instead of returned to the workspace. Writing to files is done from the master as each task completes. Options can be set with the `logdir` and `resultdir` fields in the constructor or with the accessors, `bplogdir` and `bpresultdir`.

**random number generation:** `MulticoreParam` and `SnowParam` use the random number generation support from the `parallel` package. These params are snow-derived clusters so the arguments for multicore-derived functions such as `mc.set.seed` and `mc.reset.stream` do not apply.

Random number generation is controlled through the `param` argument, `RNGseed` which is passed to `parallel::clusterSetRNGStream`. `clusterSetRNGStream` uses the L'Ecuyer-CMRG random number generator and distributes streams to the members of a cluster. If `RNGseed` is not NULL it serves as the seed to the streams, otherwise the streams are set from the current seed of the master process after selecting the L'Ecuyer generator. See `?clusterSetRNGStream` for more details.

## Constructor

```
MulticoreParam(workers = multicoreWorkers(), tasks = 0L, catch.errors = TRUE)
```

Return an object representing a FORK cluster. The cluster is not created until `bpstart` is called. Named arguments in ... are passed to `makeCluster`.

## Accessors: Logging and results

In the following code, `x` is a `MulticoreParam` object.

```
bpprogress(x), bpprogress(x) <- value: Get or set the value to enable text progress bar.
value must be a logical(1).

bpjobname(x), bpjobname(x) <- value: Get or set the job name.

bpRNGseed(x), bpRNGseed(x) <- value: Get or set the seed for random number generation.
value must be a numeric(1).

bplog(x), bplog(x) <- value: Get or set the value to enable logging. value must be a
logical(1).
```

`bpthreshold(x)`, `bpthreshold(x) <- value`: Get or set the logging threshold. value must be a `character(1)` string of one of the levels defined in the `futile.logger` package: “TRACE”, “DEBUG”, “INFO”, “WARN”, “ERROR”, or “FATAL”.

`bplogdir(x)`, `bplogdir(x) <- value`: Get or set the directory for the log file. value must be a `character(1)` path, not a file name. The file is written out as `LOGFILE.out`. If no `logdir` is provided and `bplog=TRUE` log messages are sent to `stdout`.

`bpresultdir(x)`, `bpresultdir(x) <- value`: Get or set the directory for the result files. value must be a `character(1)` path, not a file name. Separate files are written for each job with the prefix `JOB` (e.g., `JOB1`, `JOB2`, etc.). When no `resultdir` is provided the results are returned to the session as `list`.

### Accessors: Back-end control

In the code below `x` is a `MulticoreParam` object. See the `?BiocParallelParam` man page for details on these accessors.

```
bpworkers(x)
bpnworkers(x)
bptasks(x), bptasks(x) <- value
bpstart(x)
bpstop(x)
bpisup(x)
bpbackend(x), bpbackend(x) <- value
```

### Accessors: Error Handling

In the code below `x` is a `MulticoreParam` object. See the `?BiocParallelParam` man page for details on these accessors.

```
bpcatchErrors(x), bpcatchErrors(x) <- value
bpstopOnError(x), bpstopOnError(x) <- value
```

### Methods: Evaluation

In the code below `BPPARAM` is a `MulticoreParam` object. Full documentation for these functions are on separate man pages: see `?bpmapapply`, `?bpmaplapply`, `?bpvec`, `?bpiterate` and `?bpaggregate`.

```
bpmapapply(FUN, ..., MoreArgs=NULL, SIMPLIFY=TRUE, USE.NAMES=TRUE, BPPARAM=bpparam())
bpmaplapply(X, FUN, ..., BPPARAM=bpparam())
bpvec(X, FUN, ..., AGGREGATE=c, BPPARAM=bpparam())
bpiterate(ITER, FUN, ..., BPPARAM=bpparam())
bpaggregate(x, data, FUN, ..., BPPARAM=bpparam())
```

### Methods: Other

In the code below `x` is a `MulticoreParam` object.

`show(x)`: Displays the `MulticoreParam` object.

### Author(s)

Martin Morgan <mailto:mtmorgan@fhcrc.org> and Valerie Obenchain

**See Also**

- register for registering parameter classes for use in parallel evaluation.
- [SnowParam](#) for computing in distributed memory
- [BatchJobsParam](#) for computing with cluster schedulers
- [DoparParam](#) for computing with foreach
- [SerialParam](#) for non-parallel evaluation

**Examples**

```
## -----
## Job configuration:
## -----

## MulticoreParam supports shared memory computing. The object fields
## control the division of tasks, error handling, logging and
## result format.
bpparam <- MulticoreParam()
bpparam

## By default the param is created with the maximum available workers
## determined by multicoreWorkers().
multicoreWorkers()

## Fields are modified with accessors of the same name:
bplog(bpparam) <- TRUE
bpresultdir(bpparam) <- "/myResults/"
bpparam

## -----
## Logging:
## -----

## When 'log == TRUE' the workers use a custom script (in BiocParallel)
## that enables logging and access to other job statistics. Log messages
## are returned as each job completes rather than waiting for all to finish.

## In 'fun', a value of 'x = 1' will throw a warning, 'x = 2' is ok
## and 'x = 3' throws an error. Because 'x = 1' sleeps, the warning
## should return after the error.

X <- 1:3
fun <- function(x) {
  if (x == 1) {
    Sys.sleep(2)
    if (TRUE & c(TRUE, TRUE)) ## warning
      x
  } else if (x == 2) {
    x ## ok
  } else if (x == 3) {
    sqrt("FOO") ## error
  }
}

## By default logging is off. Turn it on with the bplog()<- setter
## or by specifying 'log = TRUE' in the constructor.
```

```

bpparam <- MulticoreParam(3, log = TRUE, stop.on.error = FALSE)
res <- tryCatch({
  bplapply(X, fun, BPPARAM=bpparam)
}, error=identity)
res

## When a 'logdir' location is given the messages are redirected to a file:
## Not run:
bplogdir(bpparam) <- tempdir()
bplapply(X, fun, BPPARAM = bpparam)
list.files(bplogdir(bpparam))

## End(Not run)

## -----
## Managing results:
## -----

## By default results are returned as a list. When 'resultdir' is given
## files are saved in the directory specified by job, e.g., 'TASK1.Rda',
## 'TASK2.Rda', etc.
## Not run:
bpparam <- MulticoreParam(2, resultdir = tempdir(), stop.on.error = FALSE)
bplapply(X, fun, BPPARAM = bpparam)
list.files(bpresultdir(bpparam))

## End(Not run)

## -----
## Error handling:
## -----

## When 'stop.on.error' is TRUE the job is terminated as soon as an
## error is hit. When FALSE, all computations are attempted and partial
## results are returned along with errors. In this example the number of
## 'tasks' is set to equal the length of 'X' so each element is run
## separately. (Default behavior is to divide 'X' evenly over workers.)

## All results along with error:
bpparam <- MulticoreParam(2, tasks = 4, stop.on.error = FALSE)
res <- bpttry(bplapply(list(1, "two", 3, 4), sqrt, BPPARAM = bpparam))
res

## Calling bpok() on the result list returns TRUE for elements with no error.
bpok(res)

## -----
## Random number generation:
## -----

## Random number generation is controlled with the 'RNGseed' field.
## This seed is passed to parallel::clusterSetRNGStream
## which uses the L'Ecuyer-CMRG random number generator and distributes
## streams to members of the cluster.

bpparam <- MulticoreParam(3, RNGseed = 7739465)
bplapply(seq_len(bpnworkers(bpparam)), function(i) rnorm(1), BPPARAM = bpparam)

```

---

register

---

*Maintain a global registry of available back-end Params*


---

## Description

Use functions on this page to add to or query a registry of back-ends, including the default for use when no BPPARAM object is provided to functions.

## Usage

```
register(BPPARAM, default=TRUE)
registered(bpparamClass)
bpparam(bpparamClass)
```

## Arguments

BPPARAM	An instance of a <code>BiocParallelParam</code> class, e.g., <a href="#">MulticoreParam</a> , <a href="#">SnowParam</a> , <a href="#">DoparParam</a> .
default	Make this the default <code>BiocParallelParam</code> for subsequent evaluations? If FALSE, the argument is placed at the lowest priority position.
bpparamClass	When present, the text name of the <code>BiocParallelParam</code> class (e.g., “ <code>MulticoreParam</code> ”) to be retrieved from the registry. When absent, a list of all registered instances is returned.

## Details

The registry is a list of back-ends with configuration parameters for parallel evaluation. The first list entry is the default and is used by `BiocParallel` functions when no BPPARAM argument is supplied.

At load time the registry is populated with default backends. On Windows these are `SnowParam` and `SerialParam` and on non-Windows `MulticoreParam`, `SnowParam` and `SerialParam`. When `snowWorkers()` or `multicoreWorkers` returns a single core, only `SerialParam` is registered.

The `BiocParallelParam` objects are constructed from global options of the corresponding name, or from the default constructor (e.g., `SnowParam()`) if no option is specified. The user can set customizations during start-up (e.g., in an `.Rprofile` file) with, for instance, `options(MulticoreParam=quote(MulticoreParam))`.

The act of “registering” a back-end modifies the existing `BiocParallelParam` in the list; only one param of each type can be present in the registry. When `default=TRUE`, the newly registered param is moved to the top of the list thereby making it the default. When `default=FALSE`, the param is modified ‘in place’ vs being moved to the top.

`bpparam()`, invoked with no arguments, returns the default `BiocParallelParam` instance from the registry. When called with the text name of a `bpparamClass`, the global options are consulted first, e.g., `options(MulticoreParam=MulticoreParam())` and then the value of `registered(bpparamClass)`.

## Value

`register` returns, invisibly, a list of registered back-ends.

`registered` returns the back-end of type `bpparamClass` or, if `bpparamClass` is missing, a list of all registered back-ends.

`bpparam` returns the back-end of type `bpparamClass` or,

**Author(s)**

Martin Morgan <mailto:mtmorgan@fhcrc.org>.

**See Also**

[BiocParallelParam](#) for possible values of BPPARAM.

**Examples**

```
## -----
## The registry
## -----

## The default registry.
default <- registered()
default

## When default = TRUE the last param registered becomes the new default.
snowparam <- SnowParam(workers = 3, type = "SOCK")
register(snowparam, default = TRUE)
registered()

## Retrieve the default back-end,
bpparam()

## or a specific BiocParallelParam.
bpparam("SnowParam")

## restore original registry -- push the defaults in reverse order
for (param in rev(default))
  register(param)

## -----
## Specifying a back-end for evaluation
## -----

## The back-end of choice is given as the BPPARAM argument to
## the BiocParallel functions. None, one, or multiple back-ends can be
## used.

bplapply(1:6, sqrt, BPPARAM = MulticoreParam(3))

## When not specified, the default from the registry is used.
bplapply(1:6, sqrt)
```

---

SerialParam-class

*Enable serial evaluation*

---

**Description**

This class is used to parameterize serial evaluation, primarily to facilitate easy transition from parallel to serial code.



**Usage**

```
SerialParam(catch.errors = TRUE, stop.on.error = TRUE, log = FALSE,
            threshold = "INFO", logdir= NA_character_)
```

**Arguments**

catch.errors	DEPRECATED; see <a href="#">SnowParam</a> .
stop.on.error	A logical determining behavior on error; see <a href="#">SnowParam</a> .
log	logical(1) Enable logging; see <a href="#">SnowParam</a> .
threshold	character(1) Logging threshold; see <a href="#">SnowParam</a> .
logdir	character(1) Log files directory. When not provided, log messages are returned to stdout.

**Constructor**

```
SerialParam(catch.errors = FALSE, log = FALSE, threshold = "INFO"):
```

Return an object to be used for serial evaluation of otherwise parallel functions such as [bplapply](#), [bpvec](#).

**Methods**

The following generics are implemented and perform as documented on the corresponding help page (e.g., `?bpworkers`): [bpworkers](#), [bpisup](#), [bpstart](#), [bpstop](#), are implemented, but do not have any side-effects.

**Author(s)**

Martin Morgan <mailto:mtmorgan@fhcrc.org>

**See Also**

`getClass("BiocParallelParam")` for additional parameter classes.

`register` for registering parameter classes for use in parallel evaluation.

**Examples**

```
p <- SerialParam()
simplify2array(bplapply(1:10, sqrt, BPPARAM=p))
bpvec(1:10, sqrt, BPPARAM=p)

## Not run:
register(SerialParam(), default=TRUE)

## End(Not run)
```

---

SnowParam-class	<i>Enable simple network of workstations (SNOW)-style parallel evaluation</i>
-----------------	---

---

## Description

This class is used to parameterize simple network of workstations (SNOW) parallel evaluation on one or several physical computers. `snowWorkers()` chooses the number of workers based on global user preference (`options(mc.cores=...)`), or the minimum of 8 and the number of detected cores (`detectCores()`).

## Usage

```
## constructor
## -----

SnowParam(workers = snowWorkers(), type=c("SOCK", "MPI", "FORK"),
           tasks = 0L, catch.errors=TRUE, stop.on.error = TRUE,
           progressbar = FALSE, RNGseed = NULL,
           timeout = 30L * 24L * 60L * 60L,
           log = FALSE, threshold = "INFO", logdir = NA_character_,
           resultdir = NA_character_, jobname = "BPJOB", ...)

## coercion
## -----

## as(SOCKcluster, SnowParam)
## as(spawnedMPIcluster, SnowParam)

## detect workers
## -----

snowWorkers()
```

## Arguments

workers	integer(1) Number of workers. Defaults to all cores available as determined by <code>detectCores</code> . For a SOCK cluster workers can be a <code>character()</code> vector of host names.
type	character(1) Type of cluster to use. Possible values are SOCK (default) and MPI. Instead of <code>type=FORK</code> use <code>MulticoreParam</code> .
tasks	integer(1). The number of tasks per job. value must be a scalar integer $\geq 0$ L.  In this documentation a job is defined as a single call to a function, such as <code>bplapply</code> , <code>bpmapply</code> etc. A task is the division of the X argument into chunks. When <code>tasks == 0</code> (default), X is divided as evenly as possible over the number of workers.  A tasks value of $> 0$ specifies the exact number of tasks. Values can range from 1 (all of X to a single worker) to the length of X (each element of X to a different worker).

	When the length of X is less than the number of workers each element of X is sent to a worker and tasks is ignored.
catch.errors	DEPRECATED. logical(1) Enable the catching of errors and warnings.
stop.on.error	logical(1) Enable stop on error.
progressbar	logical(1) Enable progress bar (based on plyr::progress_text).
RNGseed	integer(1) Seed for random number generation. When not NULL, this value is passed to parallel::clusterSetRNGStream to generate random number streams on each worker.
timeout	numeric(1) Time (in seconds) allowed for worker to complete a task. This value is passed to base::setTimeLimit() as both the cpu and elapsed arguments. If the computation exceeds timeout an error is thrown with message 'reached elapsed time limit'.
log	logical(1) Enable logging.
threshold	character(1) Logging threshold as defined in futile.logger.
logdir	character(1) Log files directory. When not provided, log messages are returned to stdout.
resultdir	character(1) Job results directory. When not provided, results are returned as an R object (list) to the workspace.
jobname	character(1) Job name that is prepended to log and result files. Default is "BPJOB".
...	Additional arguments passed to <a href="#">makeCluster</a>

## Details

SnowParam is used for distributed memory computing and supports 2 cluster types: 'SOCK' (default) and 'MPI'. The SnowParam builds on infrastructure in the snow and parallel packages and provides the additional features of error handling, logging and writing out results. When not specified, the default number of workers is determined by snowWorkers() which is parallel::detectCores() - 2. Machines with 3 or less cores are assigned a single worker.

**error handling:** The catch.errors field has been deprecated.

By default all computations are attempted and partial results are returned with any error messages.

- catch.errors (DEPRECATED) determines whether errors are caught and returned with other results. When TRUE, all computations are attempted and output contains both errors and successfully completed results. When FALSE, the job is terminated as soon as the first error is hit and only the error message is returned (no results); this is the default behavior of the parent packages, e.g., parallel, snow, foreach.
- stop.on.error A logical. Stops all jobs as soon as one job fails or wait for all jobs to terminate. When FALSE, the return value is a list of successful results along with error messages as 'conditions'.
- The bpok(x) function returns a logical() vector that is FALSE for any jobs that threw an error. The input x is a list output from a bp\*apply function such as bplapply or bpmapply.

**logging:** When log = TRUE the futile.logger package is loaded on the workers. All log messages written in the futile.logger format are captured by the logging mechanism and returned real-time (i.e., as each task completes) instead of after all jobs have finished.

Messages sent to stdout and stderr are returned to the workspace by default. When log = TRUE these are diverted to the log output. Those familiar with the outfile argument to makeCluster

can think of `log = FALSE` as equivalent to `outfile = NULL`; providing a `logdir` is the same as providing a name for `outfile` except that `BiocParallel` writes a log file for each task.

The log output includes additional statistics such as memory use and task runtime. Memory use is computed by calling `gc(reset=TRUE)` before code evaluation and `gc()` (no reset) after. The output of the second `gc()` call is sent to the log file. There are many ways to track memory use - this particular approach was taken because it is consistent with how the `BatchJobs` package reports memory on the workers.

**log and result files:** Results and logs can be written to a file instead of returned to the workspace. Writing to files is done from the master as each task completes. Options can be set with the `logdir` and `resultdir` fields in the constructor or with the accessors, `bplogdir` and `bpresultdir`.

**random number generation:** `MulticoreParam` and `SnowParam` use the random number generation support from the parallel package. These params are snow-derived clusters so the arguments for multicore-derived functions such as `mc.set.seed` and `mc.reset.stream` do not apply.

Random number generation is controlled through the `param` argument, `RNGseed` which is passed to `parallel::clusterSetRNGStream`. `clusterSetRNGStream` uses the L'Ecuyer-CMRG random number generator and distributes streams to the members of a cluster. If `RNGseed` is not `NULL` it serves as the seed to the streams, otherwise the streams are set from the current seed of the master process after selecting the L'Ecuyer generator. See `?clusterSetRNGStream` for more details.

NOTE: The `PSOCK` cluster from the `parallel` package does not support cluster options `scriptdir` and `userScript`. `PSOCK` is not supported because these options are needed to re-direct to an alternate worker script located in `BiocParallel`.

## Constructor

```
SnowParam(workers = snowWorkers(), type=c("SOCK", "MPI"), tasks = 0L, catch.error = FALSE)
```

Return an object representing a SNOW cluster. The cluster is not created until `bpstart` is called. Named arguments in ... are passed to `makeCluster`.

## Accessors: Logging and results

In the following code, `x` is a `SnowParam` object.

`bpprogressbar(x)`, `bpprogressbar(x) <- value`: Get or set the value to enable text progress bar. value must be a `logical(1)`.

`bpjobname(x)`, `bpjobname(x) <- value`: Get or set the job name.

`bpRNGseed(x)`, `bpRNGseed(x) <- value`: Get or set the seed for random number generation. value must be a `numeric(1)`.

`bplog(x)`, `bplog(x) <- value`: Get or set the value to enable logging. value must be a `logical(1)`.

`bpthreshold(x)`, `bpthreshold(x) <- value`: Get or set the logging threshold. value must be a `character(1)` string of one of the levels defined in the `futile.logger` package: "TRACE", "DEBUG", "INFO", "WARN", "ERROR", or "FATAL".

`bplogdir(x)`, `bplogdir(x) <- value`: Get or set the directory for the log file. value must be a `character(1)` path, not a file name. The file is written out as `BPLOG.out`. If no `logdir` is provided and `bplog=TRUE` log messages are sent to `stdout`.

`bpresultdir(x)`, `bpresultdir(x) <- value`: Get or set the directory for the result files. value must be a `character(1)` path, not a file name. Separate files are written for each job with the prefix `TASK` (e.g., `TASK1`, `TASK2`, etc.). When no `resultdir` is provided the results are returned to the session as `list`.

**Accessors: Back-end control**

In the code below `x` is a `SnowParam` object. See the `?BiocParallelParam` man page for details on these accessors.

```
bpworkers(x), bpworkers(x) <- value, bpnworkers(x)
bptasks(x), bptasks(x) <- value
bpstart(x)
bpstop(x)
bpisup(x)
bpbackend(x), bpbackend(x) <- value
```

**Accessors: Error Handling**

In the code below `x` is a `SnowParam` object. See the `?BiocParallelParam` man page for details on these accessors.

```
bpcatchErrors(x), bpcatchErrors(x) <- value
bpstopOnError(x), bpstopOnError(x) <- value
```

**Methods: Evaluation**

In the code below `BPPARAM` is a `SnowParam` object. Full documentation for these functions are on separate man pages: see `?bpmapply`, `?bplapply`, `?bpvec`, `?bpiterate` and `?bpaggregate`.

```
bpmapply(FUN, ..., MoreArgs=NULL, SIMPLIFY=TRUE, USE.NAMES=TRUE, BPPARAM=bpparam)
bplapply(X, FUN, ..., BPPARAM=bpparam())
bpvec(X, FUN, ..., AGGREGATE=c, BPPARAM=bpparam())
bpiterate(ITER, FUN, ..., BPPARAM=bpparam())
bpaggregate(x, data, FUN, ..., BPPARAM=bpparam())
```

**Methods: Other**

In the code below `x` is a `SnowParam` object.

`show(x)`: Displays the `SnowParam` object.

`bpok(x)`: Returns a `logical()` vector: `FALSE` for any jobs that resulted in an error. `x` is the result list output by a `BiocParallel` function such as `bplapply` or `bpmapply`.

**Coercion**

`as(from, "SnowParam")`: Creates a `SnowParam` object from a `SOCKcluster` or `spawnedMPIcluster` object. Instances created in this way cannot be started or stopped.

**Author(s)**

Martin Morgan and Valerie Obenchain.

**See Also**

- register for registering parameter classes for use in parallel evaluation.
- [MulticoreParam](#) for computing in shared memory
- [BatchJobsParam](#) for computing with cluster schedulers
- [DoparParam](#) for computing with foreach
- [SerialParam](#) for non-parallel evaluation

**Examples**

```
## -----
## Job configuration:
## -----

## SnowParam supports distributed memory computing. The object fields
## control the division of tasks, error handling, logging and result
## format.
bpparam <- SnowParam()
bpparam

## Fields are modified with accessors of the same name:
bplog(bpparam) <- TRUE
bpresultdir(bpparam) <- "/myResults/"
bpparam

## -----
## Logging:
## -----

## When 'log == TRUE' the workers use a custom script (in BiocParallel)
## that enables logging and access to other job statistics. Log messages
## are returned as each job completes rather than waiting for all to
## finish.

## In 'fun', a value of 'x = 1' will throw a warning, 'x = 2' is ok
## and 'x = 3' throws an error. Because 'x = 1' sleeps, the warning
## should return after the error.

X <- 1:3
fun <- function(x) {
  if (x == 1) {
    Sys.sleep(2)
    if (TRUE & c(TRUE, TRUE)) ## warning
      x
  } else if (x == 2) {
    x ## ok
  } else if (x == 3) {
    sqrt("FOO") ## error
  }
}

## By default logging is off. Turn it on with the bplog()<- setter
## or by specifying 'log = TRUE' in the constructor.
bpparam <- SnowParam(3, log = TRUE, stop.on.error = FALSE)
tryCatch({
```

```

      bplapply(X, fun, BPPARAM = bpparam)
    }, error=identity)

## When a 'logdir' location is given the messages are redirected to a
## file:
## Not run:
bplogdir(bpparam) <- tempdir()
bplapply(X, fun, BPPARAM = bpparam)
list.files(bplogdir(bpparam))

## End(Not run)

## -----
## Managing results:
## -----

## By default results are returned as a list. When 'resultdir' is given
## files are saved in the directory specified by job, e.g., 'TASK1.Rda',
## 'TASK2.Rda', etc.
## Not run:
bpparam <- SnowParam(2, resultdir = tempdir())
bplapply(X, fun, BPPARAM = bpparam)
list.files(bpresultdir(bpparam))

## End(Not run)

## -----
## Error handling:
## -----

## When 'stop.on.error' is TRUE the process returns as soon as an error
## is thrown.

## When 'stop.on.error' is FALSE all computations are attempted. Partial
## results are returned along with errors. Use bpttry() to see the
## partial results
bpparam <- SnowParam(2, stop.on.error = FALSE)
res <- bpttry(bplapply(list(1, "two", 3, 4), sqrt, BPPARAM = bpparam))
res

## Calling bpok() on the result list returns TRUE for elements with no
## error.
bpok(res)

## -----
## Random number generation:
## -----

## Random number generation is controlled with the 'RNGseed' field.
## This seed is passed to parallel::clusterSetRNGStream
## which uses the L'Ecuyer-CMRG random number generator and distributes
## streams to members of the cluster.

bpparam <- SnowParam(3, RNGseed = 7739465)
bplapply(seq_len(bpnworkers(bpparam)), function(i) rnorm(1),
         BPPARAM = bpparam)

```

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