

# Package ‘spray’

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**Type** Package

**Title** Sparse Arrays and Multivariate Polynomials

**Version** 1.0-26

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**Description** Sparse arrays interpreted as multivariate polynomials.  
Uses 'disordR' discipline (Hankin, 2022, <[doi:10.48550/ARXIV.2210.03856](https://doi.org/10.48550/ARXIV.2210.03856)>). To cite the package in publications please use Hankin (2022) <[doi:10.48550/ARXIV.2210.10848](https://doi.org/10.48550/ARXIV.2210.10848)>.

**License** GPL (>= 2)

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**LinkingTo** Rcpp

**URL** <https://github.com/RobinHankin/spray>,  
<https://robinhankin.github.io/spray/>

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spray-package	<i>Sparse arrays and multivariate polynomials</i>
---------------	---

---

## Description

Functionality for sparse arrays, with emphasis on their interpretation as multivariate polynomials.

## Details

Base R has the capability of dealing with arbitrary dimensioned numerical arrays, with the array class.

A *sparse array* is a type of array in which nonzero elements are stored along with an index vector describing their coordinates. This allows for efficient storage and manipulation as base arrays often require the storing of many zero elements which consume computational and memory resources.

In the package, sparse arrays are represented as objects of class `spray`. They use the C++ standard template library (STL) map class, with keys being (unsigned) integer vectors, and values floats.

One natural application of sparse arrays, for which the package was written, is multivariate polynomials and the package vignette presents an extended discussion. Note that other interpretations exist: the **stokes** and **weyl** packages interpret `spray` objects as differential forms and elements of a Weyl algebra respectively.

## Author(s)

Robin K. S. Hankin

**Examples**

```
# define a spray using a matrix of indices and a vector of values:
M <- matrix(sample(0:3,21,replace=TRUE),ncol=3)
a <- spray(M,sample(7))

# there are many pre-defined simple sprays:
b <- homog(3,4)

# arithmetic operators work:
a + 2*b
a - a*b^2/4
a+b

# we can sum over particular dimensions:
asum(a+b,1)

# differentiation is supported:
deriv(a^6,2)

# extraction and replacement work as expected:

b[1,2,1]
b[1,2,1,drop=TRUE]

b[diag(3)] <- 3
```

---

arity

*The arity of a spray object*

---

**Description**

The arity of a spray object: the number of indices needed to retrieve an entry, or the number of columns in the index matrix.

**Usage**

```
arity(S)
```

**Arguments**

S                    a spray object

**Value**

Returns an integer

**Author(s)**

Robin K. S. Hankin

**Examples**

```
(a <- rspray())
arity(a)
```

---

as.array

*Coerce spray objects to arrays*


---

**Description**

Coerces spray objects to arrays. Includes off-by-one functionality via option of fbyone.

**Usage**

```
## S3 method for class 'spray'
as.array(x, offbyone=FALSE, compact=FALSE, ...)
## S3 method for class 'spray'
dim(x)
```

**Arguments**

x	spray object
offbyone	Boolean with default FALSE meaning to interpret the index entries as positions in their dimension, and TRUE meaning to add one to index values so that zero entries appear in the first place
compact	Boolean with default FALSE meaning to translate the spray as is, and TRUE meaning to add constants to each column of the index matrix so that the resulting array is as small as possible
...	Further arguments, currently ignored

**Details**

Argument of fbyone defaults to FALSE; but if it is set to TRUE, it effectively adds one from the index matrix, so a zero entry in the index matrix means the first position in that dimension.

After the subtraction, if performed, the function will not operate if any index is less than 1.

**Value**

Returns an array of dimension  $\text{dim}(S)$ . The “meat” of the function is

```
out <- array(0, dS)
out[ind] <- coeffs(S)
```

**Author(s)**

Robin K. S. Hankin

**Examples**

```
(M <- matrix(sample(0:4,28,replace=TRUE),ncol=4))
(S <- spray(M,sample(7),addrepeats=TRUE))
as.array(S,offbyone=TRUE)      # a large object!  sprays are terse

S <- spray(matrix(sample(1:4,28,replace=TRUE),ncol=4),sample(7))
A <- as.array(S)  # S has no zero indices [if it did, we would need to use offbyone=TRUE]

stopifnot(all(S[index(S),drop=TRUE] == A[index(S)]))
```

---

as.character	<i>Coerce spray objects to character</i>
--------------	--

---

**Description**

Coerces spray objects to a character string or disord character vector.

**Usage**

```
## S3 method for class 'spray'
as.character(x, ..., split=FALSE)
```

**Arguments**

x	spray object
...	Further arguments, currently ignored
split	Boolean with default FALSE meaning to return a length-one character vector, and TRUE meaning to return a disord object with elements being terms, coerced to character

**Details**

The method uses `print_spray_polyform()` and as such is sensitive to option `sprayvars`, but not `polyform`.

**Author(s)**

Robin K. S. Hankin

**Examples**

```
as.character(rspray())
as.character(rspray(),split=TRUE)
```

as.function.spray      *Coerce a spray object to a function*

---

### Description

Coerce a spray object to a function

### Usage

```
## S3 method for class 'spray'  
as.function(x,...)
```

### Arguments

x                      spray object, interpreted as a multivariate polynomial  
...                     Further arguments, currently ignored

### Value

Returns a function; this function returns a numeric vector.

### Note

Coercion is possible even if some indices are zero or negative. The function is not vectorized in the arity of its argument.

### Author(s)

Robin K. S. Hankin

### Examples

```
(S <- spray(matrix(1:6,3,2),1:3))  
(f <- as.function(S))  
f(2:3) == 3*2^3*3^6 + 2*2^2*3^5 + 1*2^1*3^4 # should be TRUE
```

```
S1 <- spray(matrix(sample(-2:2,replace=TRUE,21),ncol=3),rnorm(7),addrepeats=TRUE)  
S2 <- spray(matrix(sample(-2:2,replace=TRUE,15),ncol=3),rnorm(5),addrepeats=TRUE)
```

```
f1 <- as.function(S1)  
f2 <- as.function(S2)
```

```
f3 <- as.function(S1*S2)
```

```
x <- 4:6
```

```
f1(x)*f2(x)-f3(x) # should be zero
```

```
# coercion is vectorized:  
f1(matrix(1:33,ncol=3))
```

---

**asum***Sum over dimension margins*

---

## Description

Sum over specified dimension margins.

## Usage

```
## S3 method for class 'spray'  
asum(S, dims, drop=TRUE, ...)  
asum_inverted(S, dims)  
process_dimensions(S,dims)
```

## Arguments

S	spray object
dims	Vector of strictly positive integers corresponding to dimensions to be summed over
drop	Boolean, with default TRUE meaning to drop the summed dimensions, and FALSE meaning to retain them.
...	Further arguments, currently ignored

## Details

Function `asum.spray()` is the method for `asum()`. This takes a spray, and a vector of integers corresponding to dimensions to be summed over.

Function `asum_inverted()` is the same, but takes a vector of integers corresponding to dimensions not to sum over. This function is here because there is nice C++ idiom for it.

Function `process_dimensions()` ensures that the `dims` argument is consistent with the spray `S` and returns a cleaned version thereof.

## Value

Returns a spray object.

## Author(s)

Robin K. S. Hankin

**Examples**

```

S <- spray(matrix(sample(0:2,60,replace=TRUE),ncol=3),addrepeats=TRUE)
S

asum(S,1)
asum(S,1:2)

asum(S,1:2,drop=FALSE)

asum(S,c(1,3)) == asum_inverted(S,2)

```

---

constant

*Get or set the constant term of a spray object*


---

**Description**

The constant term of a spray object is the coefficient corresponding to an index of all zeros. These functions get or set the constant of a spray object.

**Usage**

```

is.constant(x)
constant(x,drop=FALSE)
constant(x) <- value
drop(x)

```

**Arguments**

x	Object of class spray
value	Numeric value to set the constant coefficient to
drop	Boolean, with default FALSE meaning to return a spray object and TRUE meaning to return a numeric value

**Value**

In function `constant()`, return the coefficient, or a constant multivariate polynomial, depending on the value of `drop`.

**Note**

The behaviour of the `drop` argument (sort of) matches that of the spray extractor method. Function `drop()` returns the elements of the coefficients.

Function `constant()` ensures that zero spray objects retain the argument's arity.

It might have been better to call `is.constant()` `is.scalar()`, for consistency with the `stokes` and `clifford` packages. But this is not clear.



**Author(s)**

Robin K. S. Hankin

**See Also**[Extract](#)**Examples**

```
(S <- spray(partitions::blockparts(rep(2,3),3,TRUE))
constant(S)
constant(S) <- 33
S
drop(constant(S,drop=FALSE))
```

deriv

*Partial differentiation of spray objects***Description**

Partial differentiation of spray objects interpreted as multivariate polynomials

**Usage**

```
## S3 method for class 'spray'
deriv(expr, i , derivative = 1, ...)
aderiv(S,orders)
```

**Arguments**

expr	A spray object, interpreted as a multivariate polynomial
i	Dimension to differentiate with respect to
derivative	How many times to differentiate
...	Further arguments, currently ignored
S	spray object
orders	The orders of the differentials

**Details**

Function `deriv.spray()` is the method for generic `spray()`; if `S` is a spray object, then `spray(S, i, n)` returns  $\partial^n S / \partial x_i^n = S^{(x_i, \dots, x_i)}$ .

Function `aderiv()` is the generalized derivative; if `S` is a spray of arity 3, then `aderiv(S, c(i, j, k))` returns  $\frac{\partial^{i+j+k} S}{\partial x_1^i \partial x_2^j \partial x_3^k}$ .

**Value**

Both functions return a spray object.

**Author(s)**

Robin K. S. Hankin

**See Also**

[asum](#)

**Examples**

```
(S <- spray(matrix(sample(-2:2,15,replace=TRUE),ncol=3),addrepeats=TRUE))

deriv(S,1)
deriv(S,2,2)

# differentiation is invariant under order:
aderiv(S,1:3) == deriv(deriv(deriv(S,1,1),2,2),3,3)

# Leibniz's rule:
S1 <- spray(matrix(sample(0:3,replace=TRUE,21),ncol=3),sample(7),addrepeats=TRUE)
S2 <- spray(matrix(sample(0:3,replace=TRUE,15),ncol=3),sample(5),addrepeats=TRUE)

S1*deriv(S2,1) + deriv(S1,1)*S2 == deriv(S1*S2,1)

# Generalized Leibniz:
aderiv(S1*S2,c(1,1,0)) == (
  aderiv(S1,c(0,0,0))*aderiv(S2,c(1,1,0)) +
  aderiv(S1,c(0,1,0))*aderiv(S2,c(1,0,0)) +
  aderiv(S1,c(1,0,0))*aderiv(S2,c(0,1,0)) +
  aderiv(S1,c(1,1,0))*aderiv(S2,c(0,0,0))
)
```

---

Extract.spray

*Extract or Replace Parts of a spray*

---

**Description**

Extract or replace subsets of sprays.

**Usage**

```
## S3 method for class 'spray'
S[... , drop=FALSE]
## S3 replacement method for class 'spray'
S[index, ...] <- value
```

**Arguments**

S	A spray object
index	elements to extract or replace
value	replacement value
...	Further arguments
drop	Boolean, with default FALSE meaning to return a spray object and TRUE meaning to drop the spray structure and return a numeric vector

**Details**

These methods should work as expected, although the off-by-one issue might be a gotcha. **disordR** discipline is enforced where appropriate.

In `S[index, ...]`, argument `drop` is `FALSE` by default, in which case a spray object is returned. If `drop` is `TRUE` a numeric vector is returned, with elements corresponding to the rows of `index`. Compare `coeffs(S)`, which returns a `disord` object; in `S[index, drop=TRUE]`, the rows of `index` specify a unique order for the return value.

If `a <- spray(diag(3))`, for example, then idiom such as `a[c(1, 2, 3)]` cannot work, because one would like `a[1, 2, 3]` and `a[1:3, 2, 3]` to work.

If `p <- 1:3`, then one might expect idiom such as `S[1, , p, 1:3]` to work but this is problematic and a discussion is given in `inst/missing_accessor.txt`.

Functions `spray_extract_disord()` and `spray_replace_disord()` are low-level helper functions which implement idiom such as `a[coeffs(a) < 3]` and `anda[coeffs(a) < 3] <- 99`.

**Examples**

```
(a <- spray(diag(5)))
a[rbind(rep(1,5))] <- 5
a

a[3,4,5,3,1] # the NULL polynomial

a[0,1,0,0,0]
a[0,1,0,0,0,drop=TRUE]

a[2,3:5,4,3,3] <- 9
a

options(polyform = TRUE) # print as a multivariate polynomial
a
```

```

options(polyform = FALSE) # print in sparse array form
a

(S1 <- spray(diag(5),1:5))
(S2 <- spray(1-diag(5),11:15))
(S3 <- spray(rbind(c(1,0,0,0,0),c(1,2,1,1,1))))

S1[] <- 3
S1[] <- S2

S1[S3] <- 99
S1

S <- rspray()
S[coeffs(S) > 4]
S[coeffs(S) < 6] <- 99
S

```

---

homog

*Various functions to create simple spray objects*


---

### Description

Various functions to create simple spray objects such as single-term, homogeneous, and constant multivariate polynomials.

### Usage

```

product(power)
homog(d, power=1)
linear(x, power=1)
lone(n, d=n)
one(d)
as.id(S)
xyz(d)

```

### Arguments

d	An integer; generally, the dimension or arity of the resulting spray object
power	Integer vector of powers
x	Numeric vector of coefficients
S	A spray object
n	In function lone(), the term to raise to power 1

**Value**

All functions documented here return a spray object

**Note**

The functions here are related to their equivalents in the **multipol** package, but are not exactly the same.

Function `zero()` is documented at `zero.Rd`, but is listed below for convenience.

**Author(s)**

Robin K. S. Hankin

**See Also**

[constant](#), [zero](#)

**Examples**

```
product(1:3)      # x * y^2 * z^3
homog(3)          # x + y + z
homog(3,2)       # x^2 + xy + xz + y^2 + yz + z^2
linear(1:3)      # 1*x + 2*y + 3*z
linear(1:3,2)    # 1*x^2 + 2*y^2 + 3*z^2
lone(3)          # z
lone(2,3)        # y
one(3)           # 1
zero(3)          # 0
xyz(3)           # xyz
```

---

knight

*Generating function for a chess knight and king*


---

**Description**

Generating function for a chess knight and king on an arbitrarily-dimensional chessboard

**Usage**

```
knight(d=2)
king(d=2)
```

**Arguments**

`d` Dimensionality of the board, defaulting to 2

**Value**

Returns the generating function of the piece in question.

**Note**

The pieces are forced to move; if they have the option of not moving, add 1 to the returned spray. The vignette contains a short discussion.

**Author(s)**

Robin K. S. Hankin

**Examples**

```
knight() # default 2D chess board
king()   # ditto

knight()^2 # generating function for two knight's moves

## How many ways can a knight return to its starting square in 6 moves?
constant(knight()^6)

## How many in 6 or fewer?
constant((1+knight())^6)

## Where does a randomly-moving knight end up?
d <- xyz(2)
kt <- (1+knight())*d^2/9
persp(1:25,1:25,as.array(d*kt^6))

## what is the probability that a 4D king is a knight's move from
## (0,0,0,0) after 6 moves?

sum(coeffs(((king(4)/80)^4)[knight(4)]))
```

---

nterms

*Number of nonzero terms in a spray object*


---

**Description**

Number of nonzero terms in a spray object

**Usage**

```
nterms(x)
## S3 method for class 'spray'
length(x)
```

**Arguments**

x                    Object of class spray

**Details**

Number of nonzero terms in a spray object. Function `length()` is defined so that `seq_along()` works as expected

**Author(s)**

Robin K. S. Hankin

**Examples**

```
(a <- rspray())  
nterms(a)
```

```
seq_along(a)
```

---

oom

*One-over-one-minus for spray objects*

---

**Description**

One-over-one-minus for spray objects; the nearest to ‘division’ that we can get.

**Usage**

```
oom(S, n)
```

**Arguments**

S	object of class spray
n	Order of the approximation

**Details**

Returns the Taylor expansion to order  $n$  of  $1/(1 - S)$ , that is,  $1 + S + S^2 + S^3 + \dots + S^n$ .

**Value**

Returns a spray object of the same arity as S.

**Note**

Uses Horner’s method for efficiency

**Author(s)**

Robin K. S. Hankin

**Examples**

```
(x <- spray(matrix(1)))
oom(x,5) # 1 + x + x^2 + x^3 + x^4 + x^5

(a <- homog(4,2))
d <- (1-a)*oom(a,3)

constant(d) # should be 1
rowSums(index(d)) # a single 0 and lots of 8s.
```

---

Ops.spray

*Arithmetic Ops Group Methods for sprays*


---

**Description**

Allows arithmetic operators to be used for spray calculations, such as addition, multiplication, division, integer powers, etc. Objects of class spray are interpreted as sparse multivariate polynomials.

**Usage**

```
## S3 method for class 'spray'
Ops(e1, e2 = NULL)
spray_negative(S)
spray_times_spray(S1,S2)
spray_times_scalar(S,x)
spray_plus_spray(S1,S2)
spray_plus_scalar(S,x)
spray_power_scalar(S,n)
spray_power_scalar_stla(S,n)
spray_eq_spray(S1,S2)
spray_eq_numeric(S1,x)
```

**Arguments**

e1, e2, S, S1, S2	Objects of class spray, here interpreted as sparse multivariate polynomials
x	Real valued scalar
n	Non-negative integer

**Details**

The function Ops.spray() passes unary and binary arithmetic operators (“+”, “-”, “\*”, “/”, “==”, and “^”) to the appropriate specialist function.

The most interesting operators are “\*” and “+” which execute multivariate polynomial multiplication and addition respectively.

Testing for equality uses spray\_eq\_spray(). Note that spray\_eq\_spray(S1,S2) is algebraically equivalent to is.zero(S1-S2), but faster (FALSE is returned as soon as a mismatch is found).



Function `spray_power_scalar()` is the functional representation for powers: `spray_power_scalar(X,n)` is the same as  $X^n$ . Function `spray_power_scalar_stla()` is an experimental replacement for `spray_power_scalar()` that may offer speed advantages.

### Value

The functions all return spray objects except “==”, which returns a logical.

### Author(s)

Robin K. S. Hankin

### See Also

[oom](#)

### Examples

```
M <- matrix(sample(0:3,21,replace=TRUE),ncol=3)
a <- spray(M,sample(7))
b <- homog(3,4)

# arithmetic operators mostly work as expected:
a + 2*b
a - a*b^2/4
a+b

S1 <- spray(partitions::compositions(4,3))
S2 <- spray(diag(3)) # S2 = x+y+z

stopifnot( (S1+S2)^3 == S1^3 + 3*S1^2*S2 + 3*S1*S2^2 + S2^3 )
```

### Description

Parallel (pairwise) maxima and minima for sprays.

**Usage**

```

maxpair_spray(S1,S2)
minpair_spray(S1,S2)
## S3 method for class 'spray'
pmax(x, ...)
## S3 method for class 'spray'
pmin(x, ...)

```

**Arguments**

x, S1, S2	Spray objects
...	spray objects to be compared

**Details**

Function `maxpair_spray()` finds the pairwise maximum for two sprays. Specifically, if `S3 <- maxpair_spray(S1, S2)`, then `S3[v] == max(S1[v], S2[v])` for every index vector `v`.

Function `pmax.spray()` is the method for the generic `pmax()`, which takes any number of arguments. If `S3 <- maxpair_spray(S1, S2, ...)`, then `S3[v] == max(S1[v], S2[v], ...)` for every index vector `v`.

Function `pmax.spray()` operates right-associatively:

`pmax(S1, S2, S3, S4) == f(S1, f(S2, f(S3, S4)))` where `f()` is short for `maxpair_spray()`. So if performance is important, put the smallest spray (in terms of number of nonzero entries) last.

In these functions, a scalar is interpreted as a sort of global maximum. Thus if `S3 <- pmax(S, x)` we have `S3[v] == max(S[v], x)` for every index `v`. Observe that this operation is not defined if `x > 0`, for then there would be an infinity of `v` for which `S3[v] != 0`, an impossibility (or at least counter to the principles of a sparse array). The **frab** package discusses this issue in vignette `inst/wittgenstein.Rmd`. Note also that `x` cannot have length `> 1` as the elements of a spray object are stored in an arbitrary order, following `disordR` discipline.

Functions `minpair_spray()` and `pmin.spray()` are analogous. Note that `minpair_spray(S1, S2)` is algebraically equivalent to `-pmax_spray(-S1, -S2)`; see the examples.

The value of `pmax(S)` is problematic. Suppose `all(coeffs(S) < 0)`; the current implementation returns `pmax(S) == S` but there is a case for returning the null polynomial.

**Value**

Returns a spray object

**Author(s)**

Robin K. S. Hankin

**Examples**

```

S1 <- rspray(100, vals=sample(100)-50)
S2 <- rspray(100, vals=sample(100)-50)
S3 <- rspray(100, vals=sample(100)-50)

```

```

# following comparisons should all be TRUE:

jj <- pmax(S1,S2,S3)
jj == maxpair_spray(S1,maxpair_spray(S2,S3))
jj == maxpair_spray(maxpair_spray(S1,S2),S3)

pmax(S1,S2,S3) == -pmin(-S1,-S2,-S3)
pmin(S1,S2,S3) == -pmax(-S1,-S2,-S3)

pmax(S1,-Inf) == S1
pmin(S1, Inf) == S2

pmax(S1,-3)

## Not run:
pmax(S1,3) # not defined

## End(Not run)

```

---

print.spray

*Print methods for spray objects*


---

### Description

Print methods for spray objects with options for printing in matrix form or multivariate polynomial form

### Usage

```

## S3 method for class 'spray'
print(x, ...)
print_spray_matrixform(S)
print_spray_polyform(S,give=FALSE)
printedvalue(v)

```

### Arguments

x, S	spray object
give	Boolean, with default FALSE meaning to print the value of S, and TRUE meaning to return a string (without nice formatting); used in <code>as.character.spray()</code>
v	Numeric vector
...	Further arguments (currently ignored)

**Details**

The `print` method, `print.spray()`, dispatches to helper functions `print_spray_matrixform()` and `print_spray_polyform()` depending on the value of option `polyform`; see the examples section.

Option `sprayvars` is a character vector with entries corresponding to the variable names for printing. The `sprayvars` option has no algebraic significance: all it does is affect the print method.

Function `printedvalue()` is a low-level helper function that takes a numeric argument and returns the value as printed (thus respecting options `scipen` and `digits`).

Note that printing a `spray` object (in either matrix form or polynomial form) generally takes much longer than calculating it.

**Value**

Returns its argument invisibly.

**Note**

There are a couple of hard-wired symbols for multiplication and equality which are defined near the top of the helper functions.

There are no checks for option `sprayvars` being sensible. For example, repeated entries, or entries with zero length, are acceptable but the output might be confusing or uninformative.

**Author(s)**

Robin K. S. Hankin

**Examples**

```
(a <- spray(diag(3)))

options(polyform = FALSE)
a^3

options(polyform = TRUE)
a^3

options(sprayvars=letters)
a <- diag(26)
spray(a)

## Following example from mpoly:
a[1 + cbind(0:25, 1:26) %% 26] <- 2
spray(a)
```

---

rspray	<i>Random spray objects</i>
--------	-----------------------------

---

**Description**

Creates random spray objects as quick-and-dirty examples of multivariate polynomials

**Usage**

```
rspray(n=9 , vals = seq_len(n), arity = 3, powers = 0:2)
rsprayy(n=30, vals = seq_len(n), arity = 7, powers = 0:8)
```

**Arguments**

n	Number of distinct rows (maximum); repeated rows are merged (argument <code>addrepeats</code> is TRUE)
vals	Values to use for coefficients
arity	Arity of the spray; the number of columns in the index matrix
powers	Set from which to sample the entries of the index matrix

**Value**

Returns a spray object

**Note**

If the index matrix contains repeated rows, the returned spray object will contain fewer than `n` entries

**Author(s)**

Robin K. S. Hankin

**See Also**

[spray](#)

**Examples**

```
rspray()
rspray(4)*rspray(3,rnorm(3))
rspray(3,arity=7,powers=-2:2)^3
rspray(1000,vals=rnorm(1000))
```

---

spray	<i>Sparse arrays: spray objects</i>
-------	-------------------------------------

---

## Description

Create, coerce, and test for sparse array objects

## Usage

```
spray(M, x, addrepeats=FALSE)
spraymaker(L, addrepeats=FALSE, arity=ncol(L[[1]]))
is.spray(S)
as.spray(arg1, arg2, addrepeats=FALSE, offbyone=FALSE)
index(S)
coeffs(S)
coeffs(S) <- value
is_valid_spray(L)
```

## Arguments

M	Integer matrix with rows corresponding to index positions
x	Numeric value with elements corresponding to spray entries
S	Object to be tested for being a spray
L	A list, nominally of two elements (index matrix and value) which is to be tested for acceptability to be coerce to class spray
arg1, arg2	Various arguments to be coerced to a spray
addrepeats	Boolean, with default FALSE meaning to check for repeated index rows and, if any are found, return an error
value	In the assignment operator <code>coeffs&lt;-( )</code> , a disord object (or a length-one numeric vector), so that <code>coeffs(S) &lt;- x</code> works as expected
offbyone	In function <code>as.spray()</code> , when converting from an array. Argument <code>offbyone</code> is Boolean with default FALSE meaning to insert array elements in positions corresponding to index elements, and TRUE meaning to add one
arity	In function <code>spraymaker()</code> , integer specifying the arity (number of columns of the index matrix <code>L[[1]]</code> ); ignored if L is non-empty. See details

## Details

Spray objects are sparse arrays interpreted as multivariate polynomials. They can be added and subtracted; “\*” is interpreted as polynomial multiplication.

To create a spray object the user should use `spray()`, if a matrix of indices and vector of values is available, or `as.spray()` which tries hard to do the Right Thing (tm).

Function `spraymaker()` is the formal creator function, and it is written to take the output of the C++ routines and return a spray object. The reason this needs an `arity` argument is that C++

sometimes returns NULL (in lieu of a zero-row matrix, which it cannot deal with). In this case, we need some way to tell R the arity of the corresponding spray object.

Rownames and colnames of the index matrix are removed by `spraymaker()` [C++ routine `spray_maker()` discards the `dimnames` attribute of matrix M], but the print method might add colnames to printed output, via option `sprayvars`.

Functions `index()` and `coeffs()` are accessor methods. Function `index()` returns an integer-valued matrix with rows corresponding to variable powers.

There is an extensive vignette available; type `vignette("spray")` at the command line.

### Note

Function `coeffs()` was formerly known as `value()`.

Technically, `index()` breaks `disordR` discipline.

### Author(s)

Robin K. S. Hankin

### See Also

[Ops,spray-package](#)

### Examples

```
S <- spray(diag(5)) # missing second argument interpreted as '1'.
as.array(S,offbyone=TRUE) # zero indices interpreted as ones.

M <- matrix(1:5,6,5) # note first row matches the sixth row

## Not run: spray(M,1:6) # will not work because addrepeats is not TRUE

spray(M,1:6,addrepeats=TRUE) # 7=1:6

S <- spray(matrix(1:7,5,7))
a <- as.array(S) # will not work if any(M<1)
S1 <- as.spray(a)
stopifnot(S==S1)

a <- rspray(20)
coeffs(a)[coeffs(a) %% 2 == 1] <- 99 # every odd coefficient -> 99
```

---

spray-class	<i>Class “spray”</i>
-------------	----------------------

---

**Description**

The formal S4 class for sprays.

**Objects from the Class**

Objects *can* be created by calls of the form `new("spray", ...)` but this is not encouraged. Use functions `spray()` or `as.spray()` instead.

**Slots**

`index`: Index matrix  
`value`: Numeric vector holding coefficients

**Author(s)**

Robin K. S. Hankin

**See Also**

[spray](#)

---

spraycross	<i>Cross product for spray objects</i>
------------	--

---

**Description**

Provides a natural cross product for spray objects, useful for tensors and  $k$ -forms

**Usage**

```
spraycross(S, ...)
spraycross2(S1, S2)
```

**Arguments**

`S, S1, S2, ...` spray objects

**Details**

Tensor products for sprays. This is *not* an algebraic product of sprays interpreted as multivariate polynomials. The function is used in the **stokes** package.

Function `spraycross2()` is a helper function that takes exactly two arguments. Function `spraycross()` is a more general function that takes any number of arguments.



**Value**

Returns a spray object

**Author(s)**

Robin K. S. Hankin

**Examples**

```
a <- spray(matrix(1:4,2,2),c(2,5))
b <- spray(matrix(c(10,11,12,13),2,2),c(7,11))
a
b
spraycross2(a,b)
spraycross2(b,a)

spraycross(a,b,b)
```

---

 spray\_cpp

*Low-level functions that call C++ source code*


---

**Description**

Low-level functions that call C++ source code, as detailed in the automatically generated `RcppExports.R` file.

**Usage**

```
spray_maker(M, d)
spray_add(M1, d1, M2, d2)
spray_mult(M1, d1, M2, d2)
spray_overwrite(M1, d1, M2, d2)
spray_accessor(M, d, Mindex)
spray_setter(M1, d1, M2, d2)
spray_equality(M1, d1, M2, d2)
spray_asum_include(M,d,n)
spray_asum_exclude(M,d,n)
spray_deriv(M,d,n)
spray_pmax(M1,d1,M2,d2)
spray_pmin(M1,d1,M2,d2)
spray_power(M,d,pow)
spray_spray_accessor()
spray_spray_add()
spray_spray_asum_exclude()
spray_spray_asum_include()
spray_spray_deriv()
spray_spray_equality()
```

```
spray_spray_maker()  
spray_spray_mult()  
spray_spray_overwrite()  
spray_spray_pmax()  
spray_spray_pmin()  
spray_spray_setter()  
spray_spray_power()
```

### Arguments

M, M1, M2, Mindex	Integer valued matrices with rows corresponding to array indices
d, d1, d2	Vector of values corresponding to nonzero array entries
n	Integer vector corresponding to dimensions to sum over for the sum functions
pow	Nonnegative integer for spray_power()

### Value

These functions return a two-element list which is coerced to an object of class `spray` by function `spraymaker()`.

### Note

These functions aren't really designed for the end-user.

Function `spray_equality()` cannot simply check for equality of `$value` because the order of the index rows is not specified in a `spray` object. Function `spray_crush()` has been removed as it is redundant.

### Author(s)

Robin K. S. Hankin

### See Also

[spraymaker](#), [spray](#)

---

spray\_missing\_accessor

*Discussion document*

---

### Description

Discussion about the difficulties of implementing idiom like `S[1, , 5, , ]` in the package

### Usage

```
spray_missing_accessor(S, dots)
```

**Arguments**

S	Object of class spray
dots	further arguments

**Details**

File `inst/missing_accessor.txt` presents an extended discussion of the difficulties of implementing idiom like `S[1, , 5, , ]` in the package.

**Author(s)**

Robin K. S. Hankin

---

subs	<i>Substitute values into a spray object</i>
------	--

---

**Description**

Substitute values into a spray object, interpreted as a multivariate polynomial

**Usage**

```
subs(S, dims, x, drop=TRUE)
```

**Arguments**

S	spray object
dims	Integer or logical vector with entries corresponding to the dimensions to be substituted
x	Numeric vector of values to be substituted
drop	Boolean, with default TRUE meaning to return the <code>drop()</code> of the result, and FALSE meaning to return a spray object consistently

**Note**

It is much easier if argument `dims` is sorted into increasing order. If not, caveat emptor!

**Author(s)**

Robin K. S. Hankin

**See Also**

[process\\_dimensions](#)

**Examples**

```
(S <- spray(matrix(sample(0:3,60,replace=TRUE),nrow=12)))

subs(S,c(2,5),1:2)

P <- homog(3,3)
subs(P,1,2)
```

---

summary.spray

*Summaries of spray objects*


---

**Description**

A summary method for spray objects, and a print method for summaries.

**Usage**

```
## S3 method for class 'spray'
summary(object, ...)
## S3 method for class 'summary.spray'
print(x, ...)
```

**Arguments**

object, x	Object of class spray
...	Further arguments, passed to head()

**Details**

A summary.spray object is summary of a spray object x: a list with first element being a summary() of the coefficients (which is a disord object), and the second being a spray object comprising a few selected index-coefficient pairs. The selection is done by head().

**Note**

The “representative selection” is implementation-specific, as it uses disordR::elements() to extract rows of the index matrix and coefficients.

**Author(s)**

Robin K. S. Hankin

**Examples**

```
a <- rspray()^2
a
summary(a)
summary(a,2)

options(polyform=TRUE)
summary(a^4,3)
options(polyform=FALSE) # restore default
```

---

zap

*Zap small values in a spray object*


---

**Description**

Generic version of zapsmall()

**Usage**

```
zap(x, digits = getOption("digits"))
## S4 method for signature 'spray'
zapsmall(x, digits = getOption("digits"))
```

**Arguments**

x	spray object
digits	number of digits to retain

**Details**

Given a spray object, coefficients close to zero are ‘zapped’, i.e., replaced by ‘0’, using `base::zapsmall()`. Function `zap()` is an easily-typed alias; `zapsmall()` is the S4 generic.

Note, `zap()` actually changes the numeric value, it is not just a print method.

**Author(s)**

Robin K. S. Hankin

**Examples**

```
(S <- spray(matrix(sample(1:50),ncol=2),10^-(1:25)))
zap(S)

S-zap(S) # print method will probably print zeros...
coeffs(S-zap(S)) # ...but they are nevertheless nonzero
```

zero

*The zero polynomial***Description**

Test for the zero, or empty, polynomial

**Usage**

```
zero(d)
is.zero(x)
is.empty(L)
```

**Arguments**

L, x	A two-element list of indices and values, possibly a spray object or numeric vector
d	Integer specifying dimensionality of the spray (the arity)

**Details**

Functions `is.empty()` and `is.zero()` are synonyms. If spray objects are interpreted as multivariate polynomials, “`is.zero()`” is more intuitive, if sprays are interpreted as sparse arrays, “`is.empty()`” is better (for me).

Passing a zero-row index matrix can have unexpected effects:

```
> dput(spray(matrix(0,0,5),9))
structure(list(structure(numeric(0), .Dim = c(0L, 5L)), numeric(0)), class = "spray")
```

Above, the index matrix has zero rows (and no elements) but the fact that it has five columns is retained. Arguably `spray()` should return an error here, as the number of rows of the index matrix should match the length of the coefficient vector and they do not: the index has zero rows and the coefficient vector has length 1 (although they match in the returned value). The returned spray object has no coefficients [specifically, `numeric(0)`]; this is consistent with the index matrix having zero rows.

Zero coefficients are discarded by the back end:

```
> spray(matrix(1,1,5),0)
empty sparse array with 5 columns
> dput(spray(matrix(1,1,5),0))
structure(list(structure(numeric(0), dim = c(0L, 5L)), numeric(0)), class = "spray")
```

Above, the index matrix given to `spray()` has one row but the coefficient is a length-one vector with element zero. The resulting spray object has a NULL index matrix [because rows with zero coefficients are removed] and a NULL coefficient. It is also permissible to pass a zero-row matrix:

```
spray(matrix(0,0,5),0)
empty sparse array with 5 columns
```

```
dput(spray(matrix(0,0,5),0))
structure(list(structure(numeric(0), dim = c(0L, 5L)), numeric(0)), class = "spray")
```

In previous versions of the package, the index matrix in the returned spray object could be NULL under some circumstances. If so, the arity of the spray object is lost. It is probably worth noting that `spray()`, given a zero-row index matrix, loses a length one coefficients vector, but complains about a length-two coefficient vector:

```
> dput(spray(matrix(0,0,5),0))
structure(list(structure(numeric(0), dim = c(0L, 5L)), numeric(0)), class = "spray")
> dput(spray(matrix(0,0,5),3))
structure(list(structure(numeric(0), dim = c(0L, 5L)), numeric(0)), class = "spray")
> dput(spray(matrix(0,0,5),1:2))
Error in is_valid_spray(L) : nrow(L[[1]]) == length(L[[2]]) is not TRUE
>
> identical(spray(matrix(0,0,5),0),spray(matrix(0,0,5),3))
[1] TRUE
```

### Examples

```
(a <- lone(1,3))

is.zero(a-a) # should be TRUE

is.zero(zero(6))

x <- spray(t(0:1))
y <- spray(t(1:0))

is.zero((x+y)*(x-y)-(x^2-y^2)) # TRUE
```

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