Package ‘onion’

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Title Octonions and Quaternions
LazyData TRUE
Description Quaternions and Octonions are four- and eight- dimensional extensions of the complex numbers. They are normed division algebras over the real numbers and find applications in spatial rotations (quaternions), and string theory and relativity (octonions). The quaternions are noncommutative and the octonions nonassociative. See the package vignette for more details.
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Description

Quaternions and Octonions are four- and eight- dimensional extensions of the complex numbers. They are normed division algebras over the real numbers and find applications in spatial rotations (quaternions), and string theory and relativity (octonions). The quaternions are noncommutative and the octonions nonassociative. See the package vignette for more details.

Details

Package: onion
Version: 1.5-0
Title: Octonions and Quaternions
LazyData: TRUE
Authors@R: person(given=c("Robin", "K. S."), family="Hankin", role = c("aut","cre"), email="hankin.robin@gmail.com")
Description: Quaternions and Octonions are four- and eight- dimensional extensions of the complex numbers. They are normed division algebras over the real numbers and find applications in spatial rotations (quaternions), and string theory and relativity (octonions). The quaternions are noncommutative and the octonions nonassociative. See the package vignette for more details.
Maintainer: Robin K. S. Hankin <hankin.robin@gmail.com>
There are precisely four normed division algebras over the reals: the reals themselves, the complex numbers, the quaternions, and the octonions. The R system is well equipped to deal with the first two: the onion package provides some functionality for the third and fourth.
Author(s)

NA

Maintainer: Robin K. S. Hankin <hankin.robin@gmail.com>

References


Examples

```r
rquat(10)  # random quaternions

Ok + (Oi + Ojl)/(Oj-Oil)  # basic octonions

x <- roct(10)
y <- roct(10)
z <- roct(10)

x*(y*z) - (x*y)*z  # nonassociative!
```

---

**Arith**

Methods for Function Arith in package Onion

Description

Methods for Arithmetic functions for onions: +, -, *, /, ^

Usage

```r
onion_negative(z)
onion_inverse(z)
onion_arith_onion(e1,e2)
onion_arith_numeric(e1,e2)
numeric_arith_onion(e1,e2)
harmonize_oo(a,b)
harmonize_on(a,b)
onion_plus_onion(a,b)
onion_plus_numeric(a,b)
onion_prod_onion(e1,e2)
octonion_prod_octonion(o1,o2)
quaternion_prod_quaternion(q1,q2)
onion_prod_numeric(a,b)
onion_power_singleinteger(o,n)
onion_power_numeric(o,p)
```
Arith

Arguments

z,e1,e2,a,b,o,o1,o2,n,q1,q2,p

onions or numeric vectors

Details

The package implements the Arith group of S4 generics so that idiom like A + B*C works as expected with onions.

Functions like onion_inverse() and onion_plus_onion() are low-level helper functions. The only really interesting operation is multiplication; functions octonion_prod_octonion() and quaternion_prod_quaternion() dispatch to C.

Names are implemented and the rules are inherited (via harmonize_oo() and harmonize_on()) from rbind().

Value

generally return an onion

Note

Previous versions of the package included the option to use native R rather than the faster compiled C code used here. But this was very slow and is now discontinued.

Author(s)

Robin K. S. Hankin

Examples

a <- rquat()
b <- rquat()a
Re(a)
j(a) <- 0.2a*b
b*a # quaternions are noncommutative

x <- as.octonion(matrix(rnorm(40),nrow=8))y <- roct()z <- roct()x*(y*z) - (x*y)*z # octonions are nonassociative [use associator()]
biggest  

*Returns the biggest type of a set of onions*

**Description**

Returns the biggest type of a set of onions; useful for “promoting” a set of onions to the most general type.

**Usage**

```
biggest(...)  
```

**Arguments**

...  

Onionic vectors

**Details**

If any argument passed to `biggest()` is an octonion, then return the string “octonion”. Failing that, if any argument is a quaternion, return the string “quaternion”, and failing that, return “scalar”.

**Value**

Character string representing the type

**Author(s)**

Robin K. S. Hankin

**Examples**

```
biggest(O1,rquat(100),1:4)  
```

---

bind  

*Binding of onionmats*

**Description**

Methods for `rbind()` and `cbind()` of onionmats. These are implemented by specifying methods for `rbind2()` and `cbind2()`.

**Usage**

```
bind_onion(x,bind,...)
bind_onion_onion(x,y,bind,...)
bind_onion_onionmat(x,y,bind,...)
bind_onionmat_onion(x,y,bind,...)
```
The Stanford Bunny

A set of 3D points in the shape of a rabbit (the Stanford Bunny)

Usage

data(bunny)

Format

A three column matrix with 35947 rows. Each row is the Cartesian coordinates of a point on the surface of the bunny.

Value

as for format

Source

https://graphics.stanford.edu/data/3Dscanrep/
Examples

    data(bunny)
p3d(rotate(bunny,Hk))

---

**Concatenation**

**Description**

Combines its arguments to form a single onion.

**Usage**

```r
c_onionpair(x,y)
## S4 method for signature 'onion'
c(x,...)
```

**Arguments**

`x, y, ...` onions

**Details**

Returns an onion of the same type as its arguments. Names are inherited from the behaviour of `cbind()`, not `c()`.

**Value**

An onion

**Note**

The method is not perfect; it will not, for example, coerce its arguments to the `biggest()` type, so `c(rquat(), roct())` will fail. You will have to coerce the arguments by hand.

Dispatch is based on the class of the first argument, so `c(1, rquat())` will return a list (not an onion), and `c(rquat(), 1)` will fail.

**Author(s)**

Robin K. S. Hankin

**Examples**

```r
a <- roct(3)
b <- seq_onion(from=Oil, to=Oj, len=6)
c(a, b)
c(rquat(3), H1, H0, Him)
```
Compare-methods

Methods for compare S4 group

Description

Methods for comparison (equal to, greater than, etc) of onions. Only equality makes sense.

Value

Return a boolean

Examples

# roct() > 0 # meaningless and returns an error

x <- as.octonion(matrix(sample(0:1,800,TRUE,p=c(9,1)),nrow=8))
y <- as.octonion(matrix(sample(0:1,800,TRUE,p=c(9,1)),nrow=8))
x==y

matrix(as.quaternion(100+1:12),3,4) == 102

Complex

Complex functionality for onions

Description

Functionality in the Complex group.

The norm Norm(O) of onion O is the product of O with its conjugate: |O| = OO* but a more efficient numerical method is used (see dotprod()).

The Mod Mod(O) of onion O is the square root of its norm.

The sign of onion O is the onion with the same direction as O but with unit Norm: sign(O)=O/Mod(O).

Function Im() sets the real component of its argument to zero, and Conj() flips the sign of its argument’s non-real components.
Usage

## S4 method for signature 'onion'
Re(z)

## S4 method for signature 'onion'
Im(z)

Re(z) <- value
Im(x) <- value

## S4 method for signature 'onion'
Conj(z)

## S4 method for signature 'onion'
Mod(z)

onion_abs(x)
onion_conjugate(z)

## S4 method for signature 'onion'
sign(x)

Arguments

x, z Object of class onion or glub
value replacement value

Value

All functions documented here return a numeric vector or matrix of the same dimensions as their argument, apart from functions Im() and Conj(), which return an object of the same class as its argument.

Note

If x is a numeric vector and y an onion, one might expect typing x[1] <- y to result in x being a onion. This is impossible, according to John Chambers.

Extract and set methods for components such as i, j, k are documented at Extract.Rd

Author(s)

Robin K. S. Hankin

See Also

Extract

Examples

a <- rquat()
Re(a)
Re(a) <- j(a)
Im(a)
condense

b <- romat()
A <- romat()
Im(A) <- Im(A)*10

condense

Condense an onionic vector into a short form

Description

Condense an onion into a string vector showing whether the elements are positive, zero or negative.

Usage

condense(x, as.vector=FALSE)

Arguments

x
An onionic vector

as.vector
Boolean, indicating whether to return a vector or matrix

Value

If as.vector is TRUE, return a string vector of the same length as x whose elements are length 4 or 8 strings for quaternions or octonions respectively. If FALSE, return a matrix with these columns.

The characters are “+” for a positive, “-” for a negative, and “∅” for a zero, element.

Author(s)

Robin K. S. Hankin

Examples

condense(roct(3))
condense(roct(3), as.vector=TRUE)


**cumsum**

*Cumulative sums and products of onions*

**Description**

Cumulative sums and products of onions

**Usage**

onion_cumsum(x)
onion_cumprod(x)

**Arguments**

x          onion

**Value**

An onion

**Note**

The octonions are nonassociative but `cumprod()` operates left-associatively, as in \(((a[1]*a[2])*a[3])*a[4]\) etc.

**Author(s)**

Robin K. S. Hankin

**Examples**

```r
cumsum(as.quaternion(matrix(runif(20),4,5)))
cumsum(roct(5))
cumprod(rquat(7))
```
Description

Methods for "[" and "[<-", i.e., extraction or subsetting of onions.

Usage

```r
## S4 method for signature 'onion'
i(z)
## S4 method for signature 'onion'
j(z)
## S4 method for signature 'onion'
k(z)
## S4 method for signature 'octonion'
l(z)
## S4 method for signature 'octonion'
il(z)
## S4 method for signature 'octonion'
jl(z)
## S4 method for signature 'octonion'
k1(z)
## S4 method for signature 'onionmat'
i(z)
## S4 method for signature 'onionmat'
j(z)
## S4 method for signature 'onionmat'
k(z)
## S4 method for signature 'onionmat'
il(z)
## S4 method for signature 'onionmat'
jl(z)
## S4 method for signature 'onionmat'
k1(z)
```

```r
i(x) <- value
j(x) <- value
k(x) <- value
l(x) <- value
il(x) <- value
jl(x) <- value
k1(x) <- value
```

Arguments

- `x, z` Object of class onion
- `value` replacement value
Value

Extraction and methods return an onion or onionmat. Replacement methods return an object of the same class as x.

Note

If x is a numeric vector and y a onion, one might expect typing x[1] <- y to result in x being a onion. This is impossible, according to John Chambers.

Author(s)

Robin K. S. Hankin

Examples

```r
a <- roct(9)
il(a)
Re(a) <- 1:9

j(a) <- 1(a)
a
```

---

**length**

*Length of an octonionic vector*

Description

Get or set the length of onions

Usage

```r
## S4 method for signature 'onion'
length(x)
```

Arguments

x An onion

Details

Operates on the columns of the matrix as expected.

Value

integer
Author(s)

Robin K. S. Hankin

Examples

```r
a <- roct(5)
length(a)
```

---

Logical operations on onions

Description

Logical operations on onions are not supported

Usage

```r
onion_logic(e1, e2)
```

Arguments

```r
e1, e2  onions
```

Value

```
none
```

Note

Carrying out logical operations in this group will report an error. Negation, “!” is not part of this group.

Author(s)

Robin K. S. Hankin

Examples

```r
# roct() & roct()  # reports an error
```
Description

Various elementary functions for onions

Usage

```
onion_log(x, base=exp(1))
onion_exp(x)
onion_sign(x)
onion_sqrt(x)
onion_cosh(x)
onion_sinh(x)
onion_acos(x)
onion_acosh(x)
onion_asin(x)
onion_asinh(x)
onion_atan(x)
onion_atanh(x)
onion_cos(x)
onion_sin(x)
onion_tan(x)
onion_tanh(x)
onion_cos(x)
onion_sin(x)
onion_tan(x)
onion_tanh(x)
```

Arguments

- **x**: Object of class onion
- **base**: In function log(), the base of the logarithm

Details

Standard math stuff. I am not convinced that the trig functions (sin() etc) have any value.

Author(s)

Robin K. S. Hankin
Examples

```r
x <- roct()
exp(x+x) - exp(x)*exp(x) # zero to numerical precision

jj <- exp(log(x)/2)  # use sqrt() here
jj*jj-x # also small

y <- roct()
exp(x+y) - exp(x)*exp(y) # some rules do not operate for onions

max(Mod(c(sin(asin(x))-x,asin(sin(x))-x))) # zero to numerical precision
```

---

names  

Names of an onionic vector

Description

Functions to get or set the names of an onion

Usage

```r
## S4 method for signature 'onion'
names(x)
## S4 method for signature 'onionmat'
rownames(x)
## S4 method for signature 'onionmat'
colnames(x)
## S4 method for signature 'onionmat'
dimnames(x)
## S4 method for signature 'onionmat'
dim(x)
```

Arguments

- `x` onion

Details

Names attributes refers to colnames of the internal matrix, which are retrieved or set using colnames() or colnames<-().
Author(s)

Robin K. S. Hankin

Examples

```r
a <- roct(5)
names(a) <- letters[1:5]

b <- romat()
dimnames(b) <- list(month = month.abb[1:5], location=names(islands)[1:6])
```

---

**Unit onions**

**Description**

Each of the eight unit quaternions and octonions

**Usage**

- H1
- Hi
- Hj
- Hk
- H0
- Him
- Hall
- O1
- Oi
- Oj
- Ok
- O1
- Oil
- Ojl
- O0
- Oim
- Oall

**Format**

Each one is an onionic vector of length one.
Details

Try \texttt{Hi (=quaternion(i=1))} to get the pattern for the first four. The next ones are the zero quaternion, the pure imaginary quaternion with all components 1, and the quaternion with all components 1. The ones beginning with “O” follow a similar pattern.

These are just variables that may be overwritten and thus resemble \texttt{T} and \texttt{F} whose value may be changed.

Value

A length-one onion, either a quaternion or an octonion

Examples

\begin{verbatim}
Oall
seq_onion(from=O1,to=O11,len=6)

stopifnot(Hj*Hk == Hi)
stopifnot(Okl*O1l == -Oj )  # See tests/test_aaa.R for the full set
\end{verbatim}

Basic onion functions

Description

Construct, coerce to, test for, and print onions

Usage

\begin{verbatim}
octonion(length.out = NULL, Re = 0, i = 0, j = 0, k = 0, l = 0, il = 0, jl = 0, kl = 0)
as.octonion(x, single = FALSE)
is.octonion(x)
quaternion(length.out = NULL, Re = 0, i = 0, j = 0, k = 0)
as.quaternion(x, single = FALSE)
is.quaternion(x)
is.onion(x)
as.onion(x, type, single=FALSE)
quaternion_to_octonion(from)
octonion_to_quaternion(from)
## S4 method for signature 'onion'
as.matrix(x)
## S4 method for signature 'onion'
as.numeric(x)
\end{verbatim}
Arguments

length.out  In functions quaternion() and octonion(), the length of the onionic vector returned
Re              The real part of the onionic vector returned
i,j,k           In functions quaternion() and octonion(), component i, j, k respectively of the returned onionic
l,il,jl,kl      In function octonion(), component l, il, jl, kl respectively of the returned onionic
x,from          Onion to be tested or printed
single          In functions as.octonion() and as.quaternion(), Boolean with default FALSE meaning to interpret x as a vector of reals to be coerced into an onionic with zero imaginary part; and TRUE meaning to interpret x as a length 4 (or length 8) vector and return the corresponding single onionic.
type            In function as.onion() a string either “quaternion” or “octonion” denoting the algebra to be forced into

Details

Functions quaternion() and octonion() use standard recycling where possible; rbind() is used.
Functions as.quaternion() and as.octonion() coerce to quaternions and onions respectively.
If given a complex vector, the real and imaginary components are interpreted as Re and i respectively.
The output of type() is accepted as the type argument of function as.onion(); thus as.onion(out, type=type(x)) works as expected.

Value

Generally return onions

Note

An onion is any algebra (over the reals) created by an iterated Cayley-Dickson process. Examples include quaternions, octonions, and sedenions. There does not appear to be a standard generic term for such objects (I have seen n-ion, anion and others. But “onion” is pronounceable and a bona fide English word).
Creating further onions—such as the sedenions—is intended to be straightforward.
There is a nice example of the onion package in use in the permutations package, under cayley.Rd. This also shows the quaternion group Q8, but from a different perspective.

Author(s)

Robin K. S. Hankin
Examples

```r
x <- octonion(Re=1,il=1:3)
x
kl(x) <- 100
x

as.quaternion(diag(4))
```

# Cayley table for the quaternion group Q8:
a <- c(H1,-H1,Hi,-Hi,Hj,-Hj,Hk,-Hk)
names(a) <- c("+1","-1","+i","-i","+j","-j","+k","-k")

f <- Vectorize(function(x,y){names(a)[a==a[x]*a[y]]})
X <- noquote(outer(1:8,1:8, f))
rownames(X) <- names(a)
colnames(X) <- names(a)
X
```

---

**onion-class**

*Class* "onion"

---

**Description**

The formal S4 class for onion and onionmat objects

**Objects from the Class**

Class *onion* is a virtual S4 class extending classes *quaternion* and *octonion*. In package documentation, “*onion*” means an R object that behaves as a vector of quaternions or octonions, stored as a four- or eight-row numeric matrix.

Class *onionmat* is the S4 class for matrices whose elements are quaternions or octonions. An onionmat is stored as a two-element list, the first being an onion and the second an integer matrix which holds structural matrix attributes such as dimensions and dimnames. Most standard arithmetic R idiom for matrices should work for onionmats.

Class *index* is taken from the excellent *Matrix* package and is a setClassUnion() of classes numeric, logical, and character, which mean that it is an arity-one matrix index.

**Author(s)**

Robin K. S. Hankin
**Examples**

```r
as.octonion(1:8, single=TRUE)
as.quaternion(matrix(runif(20), nrow=4))

H <- matrix(rquat(21), 3, 7)
dimnames(H) <- list(foo=letters[1:3], bar=state.abb[1:7])
i(H) <- 0.1

I <- matrix(rquat(14), 7, 2)
dimnames(I) <- list(foo=state.abb[1:7], baz=LETTERS[1:2])
H %*% I
```

---

**Description**

Simple functionality for quaternionic and octonionic matrices, intended for use in the `jordan` package. Use idiom like `matrix(H, im, 4, 5)` or `matrix(roct(6), 2, 3)` to create an `onionmat` object, a matrix of onions.

The package is intended to match base R’s matrix functionality in the sense that standard R idiom just goes through for onionic matrices. Determinants are not well-defined for quaternionic or octonionic matrices, and matrix inverses are not implemented.

**Usage**

```r
newonionmat(d, M)
onionmat(data = NA, nrow = 1, ncol = 1, byrow = FALSE, dimnames = NULL)
as.onionmat(x)
is.onionmat(x)
onionmat_negative(e1)
onionmat_inverse(e1)
onionmat_prod_onionmat(e1, e2)
onionmat_power_onionmat(...)
onionmat_prod_single(x, y)
onionmat_power_single(e1, e2)
onionmat_plus_onionmat(e1, e2)
matrix_arith_onion(e1, e2)
onion_arith_matrix(e1, e2)
matrix_plus_onion(e1, e2)
matrix_prod_onion(e1, e2)
drop(x)
```

### S4 method for signature 'onionmat, onionmat'

```r
cprod(x, y)
```
## S4 method for signature 'onionmat,missing'
cprod(x,y)
## S4 method for signature 'onionmat,ANY'
cprod(x,y)
## S4 method for signature 'ANY,ANY'
cprod(x,y)
## S4 method for signature 'onion,missing'
cprod(x,y)
## S4 method for signature 'onion,onion'
cprod(x,y)
## S4 method for signature 'onion, onionmat'
cprod(x,y)
## S4 method for signature 'onionmat, onion'
cprod(x,y)
## S4 method for signature 'onionmat, onionmat'
tcprod(x,y)
## S4 method for signature 'onionmat, missing'
tcprod(x,y)
## S4 method for signature 'onionmat, ANY'
tcprod(x,y)
## S4 method for signature 'ANY, ANY'
tcprod(x,y)
## S4 method for signature 'onion, missing'
cprod(x,y)
## S4 method for signature 'onion, onion'
cprod(x,y)
## S4 method for signature 'onion, onionmat'
cprod(x,y)
## S4 method for signature 'onionmat, onion'
cprod(x,y)
## S4 method for signature 'onionmat'
t(x)
## S4 method for signature 'onion'
t(x)
## S4 method for signature 'onionmat'
ht(x)
## S4 method for signature 'onion'
ht(x)
nrow(x)
ncol(x)
herm_onion_mat(real_diagonal, onions)
onionmat_complex(z)
onionmat_conjugate(z)
onionmat_imag(z)
onionmat_re(z)
onionmat_mod(z)
onionmat_matrixprod_onionmat(x,y)
onion_matrixprod_onionmat(x,y)
onionmat_matrixprod_numeric(x,y)
onionmat_matrixprod_onion(x,y)

Arguments

d,M data and matrix index
x,y,z,e1,e2 Objects of class onionmat
data,nrow,ncol,byrow,dimnames
   In function onionmat(), as for matrix()
... Further arguments (currently ignored)
real_diagonal, onions
   In function herm_onion_mat(), on- and off- diagonal elements of an Hermitian
   matrix

Details

An object of class onionmat is a two-element list, the first of which is an onion, and the second an
integer matrix used for tracking attributes such as dimensions and dimnames. This device makes
the extraction and replacement methods easy.

The S4 method for matrix() simply dispatches to onionmat(), which is a drop-in replacement for
matrix().

Function newonionmat() is lower-level: it also creates onionmat objects, but takes two arguments:
an onion and a matrix; the matrix argument can be used to specify additional attributes via attr(),
but this ability is not currently used in the package.

Functions such as onionmat_plus_onionmat() are low-level helper functions, not really designed
for the end-user.

Vignette onionmat shows some use-cases.

Author(s)

Robin K. S. Hankin

Examples

matrix(rquat(28),4,7)
M <- onionmat(rquat(10),2,5)
cprod(M)
Re(M)
Re(M) <- 0.3

romat() %*% rquat(6)
**Description**

Convert a quaternion to and from an equivalent orthogonal matrix

**Usage**

```
matrix2quaternion(M)
as.orthogonal(Q)
```

**Arguments**

- `M` A three-by-three orthogonal matrix
- `Q` A vector of quaternions

**Value**

Function `matrix2quaternion()` returns a quaternion.
Function `as.orthogonal()` returns either a $3 \times 3$ matrix or a $3 \times 3 \times n$ array of orthogonal matrices

**Note**

Function `matrix2quaternion()` is low-level; use `as.quaternion()` to convert arrays.

**Author(s)**

Robin K. S. Hankin

**See Also**

`rotate`

**Examples**

```
as.orthogonal(rquat(1))

o <- function(w){diag(3)-2*outer(w,w)/sum(w^2)} # Householder
matrix2quaternion(o(1:3)) # Booorrrriinnnggg
matrix2quaternion(o(1:3) %*% o(3:1))

Q <- rquat(7)
Q <- Q/abs(Q)
as.quaternion(as.orthogonal(Q)) # +/- Q
```
A <- replicate(7, o(rnorm(3)) %*% o(rnorm(3)))
max(abs(as.orthogonal(as.quaternion(A)) - A))

p3d

Three dimensional plotting

Description

Three dimensional plotting of points. Produces a nice-looking 3D scatterplot with greying out of further points giving a visual depth cue.

Usage

p3d(x, y, z, xlim = NULL, ylim = NULL, zlim = NULL, d0 = 0.2, h = 1, ...)

Arguments

x, y, z vector of x, y, z coordinates to be plotted. If x is a matrix, interpret the rows as 3D Cartesian coordinates
xlim, ylim, zlim Limits of plot in the x, y, z directions, with default NULL meaning to use range()
d0 E-folding distance for graying out (depths are standardized to be between 0 and 1)
h The hue for the points, with default value of 1 corresponding to red. If NULL, produce black points greying to white
...
Further arguments passed to persp() and points()

Value

Value returned is that given by function trans3d().

Author(s)

Robin K. S. Hankin

See Also

bunny

data(bunny)
p3d(bunny, theta=3, phi=104, box=FALSE)
Description

Plotting method for onionic vectors

Usage

## S4 method for signature 'onion'
plot(x,y, ...)

Arguments

x, y  Onions
...

Further arguments passed to plot.default()

Details

The function is plot(Re(x), Mod(Im(x)), ...), and thus behaves similarly to plot() when called with a complex vector.

Value

Called for its side-effect of plotting a diagram

Author(s)

Robin K. S. Hankin

Examples

plot(roct(30))

Description

Returns various inner and outer products of two onionic vectors.
Usage

x %<*>% y
x %>*<% y
x %<.>% y
x %>.<% y
x %.% y
onion_g_even(x,y)
onion_g_odd (x,y)
onion_e_even(x,y)
onion_e_odd (x,y)
dotprod(x,y)

Arguments

x, y onions

Details

This page documents an attempt at a consistent notation for onionic products. The default product for onions (viz “*”) is sometimes known as the “Grassman product”. There is another product known as the Euclidean product defined by $E(p, q) = p'q$ where $x'$ is the conjugate of $x$.

Each of these products separates into an “even” and an “odd” part, here denoted by functions $g_{\text{even}}()$ and $g_{\text{odd}}()$ for the Grassman product, and $e_{\text{even}}()$ and $e_{\text{odd}}()$ for the Euclidean product. These are defined as follows:

- $g_{\text{even}}(x,y) = (xy+yx)/2$
- $g_{\text{odd}}(x,y) = (xy-yx)/2$
- $e_{\text{even}}(x,y) = (x'y+y'x)/2$
- $e_{\text{odd}}(x,y) = (x'y-y'x)/2$

These functions have an equivalent binary operator.

The Grassman operators have a “*”; they are “%<*>%” for the even Grassman product and “%>*<%” for the odd product.

The Euclidean operators have a “.”; they are “%<.>%” for the even Euclidean product and “%>.<%” for the odd product.

Function dotprod() returns the Euclidean even product of two onionic vectors. That is, if $x$ and $y$ are eight-element vectors of the components of two onions, return $\text{sum}(x*y)$.

Note that the returned value is a numeric vector (compare %<.>%, e.even(), which return onionic vectors with zero imaginary part).

There is no binary operator for the ordinary Euclidean product (it seems to be rarely needed in practice). For $\text{Conj}(x)*x$, $\text{Norm}(x)$ is much more efficient and accurate.

Function prod() is documented at Summary.Rd.

Note

Frankly if you find yourself using these operators you might be better off using the clifford package, which has an extensive and consistent suite of product operators.
Author(s)

Robin K. S. Hankin

Examples

0j %<.>% 0all

rep

Replicate elements of onionic vectors

Description

Replicate elements of onionic vectors

Usage

```r
## S4 method for signature 'onion'
rep(x, ...)
```

Arguments

- `x`: Onionic vector
- `...`: Further arguments passed to `seq.default()`

Author(s)

Robin K. S. Hankin

Examples

```r
a <- roct(3)
rep(a,2) + a[1]
rep(a,each=2)
rep(a,length.out=5)
```
Description

Random quaternion or octonion vectors and matrices

Usage

rquat(n=5)
roct(n=5)
romat(type="quaternion", nrow=5, ncol=6, ...)

Arguments

n Length of random vector returned
nrow,ncol,... Further arguments specifying properties of the returned matrix
type string specifying type of elements

Details

Function rquat() returns a quaternionic vector, roct() returns an octonionic vector, and romat() a quaternionic matrix.

Functions rquat() and roct() give a quick “get you going” random onion to play with. Function romat() gives a simple onionmat, although arguably matrix(roct(4),2,2) is as convenient.

Author(s)

Robin K. S. Hankin

References


Examples

rquat(3)
roct(3)
plot(roct(30))
romat()
**rotate**

Rotates 3D vectors using quaternions

**Description**
Rotates a three-column matrix whose rows are vectors in 3D space, using quaternions

**Usage**

```r
rotate(x, H)
```

**Arguments**

- `x`: A matrix of three columns whose rows are points in 3D space
- `H`: A quaternion. Does not need to have unit modulus

**Value**
Returns a matrix of the same size as `x`

**Author(s)**
Robin K. S. Hankin

**See Also**

- `orthogonal`

**Examples**

```r
data(bunny)
par(mfrow=c(2,2))
par(mai=rep(0,4))
p3d(rotate(bunny,H1),box=FALSE)
p3d(rotate(bunny,H1-H1+Hj),box=FALSE)
p3d(rotate(bunny,Hk),box=FALSE)
p3d(rotate(bunny,Hall),box=FALSE)

o <- function(w){diag(3)-2*outer(w,w)/sum(w^2)} # Householder
O <- o(1:3) %*% o(3:1)
rotate(bunny,as.quaternion(O))
bunny %*% t(O) # should be the same; note transpose
```
seq

Description
Rough equivalent of seq() for onions.

Usage
seq_onion(from=1, to=1, by=((to-from)/(length.out-1)), length.out=NULL, slerp=FALSE, ...)

Arguments
- from: Onion for start of sequence
- to: Onion for end of sequence
- by: Onion for interval
- length.out: Length of vector returned
- slerp: Boolean, with default FALSE meaning to use linear interpolation and TRUE meaning to use spherical linear interpolation (useful for animating 3D rotation)
- ...: Further arguments (currently ignored)

Author(s)
Robin K. S. Hankin

Examples
seq(from=O1, to=Oil, length.out=6)
seq(from=H1, to=(Hi+Hj)/2, len=10, slerp=TRUE)

show

Description
Show methods for onions

Usage
## S4 method for signature 'onion'
show(object)
onion_show(x, h=getOption("show_onions_horizontally"))
Arguments

x, object

h

Onions

Boolean, with default FALSE meaning to print horizontally and TRUE meaning to print by columns.

Details

If options("horiz") is TRUE, then print by rows rather than columns (provided that the default value of argument h is not overridden). The default behaviour is to print by columns; do this by setting horiz to anything other than TRUE, including leaving it unset.

Note

Print method for onionmat objects is also sensitive to this option.

Author(s)

Robin K. S. Hankin

Examples

roct(4)

sum

Various summary statistics for onions

Description

Various summary statistics for onions

Usage

onion_allsum(x)

## S4 method for signature 'onion'

sum(x)

## S4 method for signature 'quaternion'

prod(x)

## S4 method for signature 'octonion'

sum(x)

## S4 method for signature 'onionmat'

sum(x)

## S4 method for signature 'octonion'

prod(x)

## S4 method for signature 'onion'

str(object, ...)

str_onion(object, vec.len = 4, ...)

onion_allsum(x)

onionmat_allsum(x)

quaternion_allprod(x)
Arguments
x, object,...
vec.len

Details
For a onion object, return the sum or product accordingly

Value
Return an onion

Note
Function str() uses functionality from condense().

Author(s)
Robin K. S. Hankin

Examples
sum(roct())
str(roct())

---

threeform Various non-field diagnostics

Description
Diagnostics of non-field behaviour: threeform, associator, commutator

Usage
threeform(x1, x2, x3)
associator(x1, x2, x3)
commutator(x1, x2)

Arguments
x1, x2, x3

Details
The threeform is defined as Re(x1 * (Conj(x2) * x3) - x3 * (Conj(x2) * x1))/2;
the associator is (x1 * x2) * x3 - x1 * (x2 * x3);
the commutator is x1 * x2 - x2 * x1.
Value

Returns an octonionic vector.

Author(s)

Robin K. S. Hankin

Examples

```r
x <- roct(7) ; y <- roct(7) ; z <- roct(7)
associator(x,y,z)
```

Description

Zapping small components to zero

Usage

```r
## S4 method for signature 'onion'
zapsmall(x,digits=getOption("digits"))
## S4 method for signature 'onionmat'
zapsmall(x,digits=getOption("digits"))
```

Arguments

- `x` An onion or onionmat
- `digits` integer indicating the precision to be used as in base::zapsmall()

Details

Uses base::zapsmall() to zap small elements to zero.

Value

An onion

Author(s)

Robin K. S. Hankin
Examples

zapsmall(as.octonion(0.01^(1:8), single=TRUE))

a <- roct(7)
x <- a^1/a
x
zapsmall(x)
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