

Package ‘Directional’

July 5, 2024

Type Package

Title A Collection of Functions for Directional Data Analysis

Version 6.7

Date 2024-07-05

Author

Michail Tsagris, Giorgos Athineou, Christos Adam, Anamul Sajib, Eli Amson, Micah J. Waldstein

Maintainer Michail Tsagris <mtsagris@uoc.gr>

Description A collection of functions for directional data (including massive data, with millions of observations) analysis. Hypothesis testing, discriminant and regression analysis, MLE of distributions and more are included. The standard textbook for such data is the “Directional Statistics” by Mardia, K. V. and Jupp, P. E. (2000). Other references include a) Phillip J. Paine, Simon P. Preston Michail Tsagris and Andrew T. A. Wood (2018). “An elliptically symmetric angular Gaussian distribution”. *Statistics and Computing* 28(3): 689-697. <doi:10.1007/s11222-017-9756-4>. b) Tsagris M. and Alenazi A. (2019). “Comparison of discriminant analysis methods on the sphere”. *Communications in Statistics: Case Studies, Data Analysis and Applications* 5(4):467--491. <doi:10.1080/23737484.2019.1684854>. c) P. J. Paine, S. P. Preston, M. Tsagris and Andrew T. A. Wood (2020). “Spherical regression models with general covariates and anisotropic errors”. *Statistics and Computing* 30(1): 153--165. <doi:10.1007/s11222-019-09872-2>. d) Tsagris M. and Alenazi A. (2024). “An investigation of hypothesis testing procedures for circular and spherical mean vectors”. *Communications in Statistics-Simulation and Computation*, 53(3): 1387--1408. <doi:10.1080/03610918.2022.2045499>. e) Tsagris M. and Alzeley O. (2023). “Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling”. <doi:10.48550/arXiv.2302.02468>.

License GPL (>= 2)

Imports bigstatsr, doParallel, foreach, ggplot2, grDevices, magrittr, parallel, Rfast, Rfast2, Rnanoflann, rgl, rnaturalearth, sf

Suggests bigreadr

RoxygenNote 6.1.1

NeedsCompilation no

Repository CRAN

Date/Publication 2024-07-05 10:50:02 UTC

Contents

Directional-package	4
A test for testing the equality of the concentration parameters for circular data	6
Angular central Gaussian random values simulation	7
Anova for (hyper-)spherical data	8
Anova for circular data	10
BIC for the model based clustering using mixtures of von Mises-Fisher distributions	11
Bootstrap 2-sample mean test for (hyper-)spherical data	12
Bootstrap 2-sample mean test for circular data	14
Bootstrap ANOVA for (hyper-)spherical data	15
Bootstrap ANOVA for circular data	17
Check visually whether matrix Fisher samples is correctly generated or not	18
Circular correlations between one and many circular variables	19
Circular correlations between two circular variables	20
Circular distance correlation between two circular variables	21
Circular or angular regression	22
Circular-linear correlation	24
Column-wise MLE of the angular Gaussian and the von Mises Fisher distributions	25
Column-wise uniformity Watson test for circular data	27
Contour plot (on the plane) of the ESAG and Kent distributions without any data	28
Contour plot (on the sphere) of a mixture of von Mises-Fisher distributions	29
Contour plot (on the sphere) of some spherical rotationally symmetric distributions	30
Contour plot (on the sphere) of the ESAG and Kent distributions	32
Contour plot (on the sphere) of the SESPC distribution	34
Contour plot of a mixture of von Mises-Fisher distributions model	35
Contour plot of spherical data using a von Mises-Fisher kernel density estimate	36
Contour plots of some rotationally symmetric distributions	38
Conversion of cosines to azimuth and plunge	39
Converting a rotation matrix on $SO(3)$ to an unsigned unit quaternion	40
Converting an unsigned unit quaternion to rotation matrix on $SO(3)$	41
Cross validation for estimating the classification rate	42
Cross validation in von Mises-Fisher discriminant analysis	44
Cross validation with ESAG discriminant analysis	45
Cross validation with Purkayastha discriminant analysis	47
Cumulative distribution function of circular distributions	48
Density of a mixture of von Mises-Fisher distributions	50
Density of some (hyper-)spherical distributions	51
Density of some circular distributions	52
Density of the SESPC distribution	54
Density of the spherical ESAG and Kent distributions	56
Density of the Wood bimodal distribution on the sphere	57
Euclidean transformation	58
Euler angles from a rotation matrix on $SO(3)$	59
Forward Backward Early Dropping selection for circular data using the SPML regression	60
Generate random folds for cross-validation	62
Generation of unit vector(s) with a given angle	63
Goodness of fit test for grouped data	64

Habeck's rotation matrix generation	65
Haversine distance matrix	66
Hypothesis test for IAG distribution over the ESAG distribution	67
Hypothesis test for SIPC distribution over the SESPC distribution	68
Hypothesis test for von Mises-Fisher distribution over Kent distribution	69
Interactive 3D plot of spherical data	71
Inverse of Lambert's equal area projection	72
Inverse of the Euclidean transformation	73
k-NN algorithm using the arc cosinus distance	74
k-NN regression	75
Lambert's equal area projection	77
Logarithm of the Kent distribution normalizing constant	78
Many simple circular or angular regressions	79
Maps of the world and the continents	80
Mixtures of Von Mises-Fisher distributions	81
MLE of (hyper-)spherical rotationally symmetric distributions	82
MLE of some circular distributions	85
MLE of some circular distributions with multiple samples	88
MLE of the ESAG distribution	89
MLE of the Kent distribution	90
MLE of the Matrix Fisher distribution on $SO(3)$	92
MLE of the Purkayashta distribution	93
MLE of the SESPC distribution	94
MLE of the Wood bimodal distribution on the sphere	95
Naive Bayes classifiers for circular data	96
Normalised spatial median for directional data	98
Permutation based 2-sample mean test for (hyper-)spherical data	99
Permutation based 2-sample mean test for circular data	100
Prediction in discriminant analysis based on ESAG distribution	102
Prediction in discriminant analysis based on Purkayastha distribution	103
Prediction in discriminant analysis based on von Mises-Fisher distribution	104
Prediction with some naive Bayes classifiers for circular data	105
Projections based test of uniformity	106
Random sample of matrices in $SO(p)$	107
Rayleigh's test of uniformity	108
Read a file as a Filebacked Big Matrix	110
Rotation axis and angle of rotation given a rotation matrix	111
Rotation matrix from a rotation axis and angle of rotation	112
Rotation matrix on $SO(3)$ from three Euler angles	113
Rotation matrix to rotate a spherical vector along the direction of another	114
Saddlepoint approximations of the Fisher-Bingham distributions	116
Simulation from a Bingham distribution using any symmetric matrix A	117
Simulation from a Matrix Fisher distribution on $SO(3)$	118
Simulation of random values from a Bingham distribution	119
Simulation of random values from a mixture of von Mises-Fisher distributions	120
Simulation of random values from a spherical Fisher-Bingham distribution	122
Simulation of random values from a spherical Kent distribution	123
Simulation of random values from rotationally symmetric distributions	124

Simulation of random values from some circular distributions	126
Simulation of random values from the ESAG distribution	128
Simulation of random values from the SESPC distribution	129
Spherical and hyper-spherical distance correlation	130
Spherical and hyperspherical median	131
Spherical regression using rotationally symmetric distributions	132
Spherical regression using the ESAG distribution	134
Spherical regression using the SESPC distribution	135
Spherical-spherical correlation	137
Spherical-spherical regression	138
Summary statistics for circular data	139
Summary statistics for grouped circular data	140
Test for a given mean direction	142
Test for equality of concentration parameters for spherical data	143
Test of equality of the concentration parameters for circular data	144
The k-nearest neighbours using the cosinus distance	145
Transform unit vectors to angular data	146
Tuning of the bandwidth parameter in the von Mises kernel	147
Tuning of the bandwidth parameter in the von Mises-Fisher kernel	148
Tuning of the k-NN algorithm using the arc cosinus distance	150
Tuning of the k-NN regression	151
Uniformity test for circular data	153
von Mises kernel density estimation	154
von Mises-Fisher kernel density estimation for (hyper-)spherical data	156

Index	158
--------------	------------

Directional-package	<i>This is an R package that provides methods for the statistical analysis of directional data, including massive (very large scale) directional data.</i>
---------------------	--

Description

Circular-linear regression, spherical-spherical regression, spherical regression, discriminant analysis, ANOVA for circular and (hyper-)spherical data, tests for equality of concentration parameters, maximum likelihood estimation of the parameters of many distributions, random values generation from various distributions, contour plots and many more functions are included.

Details

Package:	Directional
Type:	Package
Version:	6.7
Date:	2024-07-05
License:	GPL-2

Maintainers

Michail Tsagris <mtsagris@uoc.gr>.

Note**Acknowledgments:**

Professor Andy Wood and Dr Simon Preston from the university of Nottingham are highly appreciated for being my supervisors during my post-doc in directional data analysis.

Dr Georgios Pappas (former postDoc at the university of Nottingham) helped me construct the contour plots of the von Mises-Fisher and the Kent distribution.

Dr Christopher Fallaize and Dr Theo Kypraios from the university of Nottingham have provided a function for simulating from the Bingham distribution using rejection sampling. So any questions regarding this function should be addressed to them.

Dr Kwang-Rae Kim (post-doc at the university of Nottingham) answered some of my questions.

Giorgos Borboudakis (PhD student at the university of Crete) pointed out to me a not so clear message in the algorithm of generating random values from the von Mises-Fisher distribution.

Panagiotis (pronounced Panayiotis) Tzirakis (master student at the department of computer science in Heraklion during the 2013-2015 seasons) showed me how to perform parallel computing in R and he is greatly acknowledged and appreciated not only from me but from all the readers of this document. He also helped me with the vectorization of some contour plot functions.

Professor John Kent from the university of Leeds is acknowledged for clarifying one thing with the ovalness parameter in his distribution.

Phillip Paine (postdoc at the university of Nottingham) spotted that the function `rfb` is rather slow and he suggested me to change it. The function has changed now and this is also due to Joshua Davis (from Carleton College, Northfield, MN) who spotted that mistakes could occur, due a vector not being a matrix.

Professor Kurt Hornik from the Vienna university of economics and business is greatly acknowledged for his patience and constant help with this (and not only) R package.

Manos Papadakis is also acknowledged for his programming tips and for his assistance with the "htest" class object.

Dr Mojgan Golzy spotted a mistake in the function `desag` and Michail is very happy for that.

Lisette de Jonge-Hoekstra from the University of Groningen found a wrong sentence in the help file of function `spml.reg` which is now deleted.

Peter Harremoes from the Copenhagen Business College spotted a mistake in the confidence interval of the function `circ.summary` which has now been corrected.

Dr Gregory Emvalomatis from the University of Crete helped me understand better the EM algorithm for mixture models and I fixed a bug in the function `mixvmf.mle`.

Kinley Russell, PhD student at the Johns Hopkins University School of Medicine, suggested that I include bootstrap ANOVA functions.

Sia Ahmadi found a mistake in the function `conc.test` which has now been corrected.

If you want more information on many of these algorithms see Chapters 9 and 10 in the following document. https://www.researchgate.net/publication/324363311_Multivariate_data_analysis_in_R

Author(s)

Michail Tsagris <mtsagris@uoc.gr>, Giorgos Athineou <gioathineou@gmail.com>, Christos Adam <pada4m4@gmail.com>, Anamul Sajib <sajibstat@du.ac.bd>, Eli Amson <eli.amson1988@gmail.com> and Micah J. Waldstein <micah@waldste.in>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley and Sons.

A test for testing the equality of the concentration parameters for circular data

A test for testing the equality of the concentration parameter among g samples, where $g \geq 2$ for circular data

Description

A test for testing the equality of the concentration parameter among g samples, where $g \geq 2$ for circular data. It is a tangential approach.

Usage

```
tang.conc(u, ina, rads = FALSE)
```

Arguments

u	A numeric vector containing the values of all samples.
ina	A numerical variable or factor indicating the groups of each value.
rads	If the data are in radians this should be TRUE and FALSE otherwise.

Details

This test works for circular data.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test.
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chicester: John Wiley & Sons. Fisher, N. I. (1995). Statistical analysis of circular data. Cambridge University Press.

See Also

[embed.circaov](#), [hcf.circaov](#), [lr.circaov](#), [het.circaov](#), [conc.test](#)

Examples

```
x <- rvonmises(100, 2.4, 15)
ina <- rep(1:4,each = 25)
tang.conc(x, ina, rads = TRUE)
```

Angular central Gaussian random values simulation

Angular central Gaussian random values simulation

Description

Angular central Gaussian random values simulation.

Usage

```
racg(n, sigma)
```

Arguments

n	The sample size, a numerical value.
sigma	The covariance matrix in R^d .

Details

The algorithm uses univariate normal random values and transforms them to multivariate via a spectral decomposition. The vectors are then scaled to have unit length.

Value

A matrix with the simulated data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tyler D. E. (1987). Statistical analysis for the angular central Gaussian distribution on the sphere. *Biometrika* 74(3): 579–589.

See Also

[acg.mle](#), [rvmf](#), [rvonmises](#)

Examples

```
s <- cov( iris[, 1:4] )
x <- racg(100, s)
Directional::acg.mle(x)
Directional::vmf.mle(x)
## the concentration parameter, kappa, is very low, close to zero, as expected.
```

Anova for (hyper-)spherical data

Analysis of variance for (hyper-)spherical data

Description

Analysis of variance for (hyper-)spherical data.

Usage

```
hcf.aov(x, ina, fc = TRUE)
hclr.aov(x, ina)
lr.aov(x, ina)
embed.aov(x, ina)
het.aov(x, ina)
```

Arguments

x	A matrix with the data in Euclidean coordinates, i.e. unit vectors.
ina	A numerical variable or a factor indicating the group of each vector.
fc	A boolean that indicates whether a corrected F test should be used or not.

Details

The high concentration (`hcf.aov`), high concentration log-likelihood ratio (`hclr.aov`), log-likelihood ratio (`lr.aov`), embedding approach (`embed.aov`) or the non equal concentration parameters approach (`het.aov`) is used.

Value

This is an "hstest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degree(s) of freedom of the test.
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. Australian & New Zealand Journal of Statistics, 59(1): 119–135.

Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. Communications in Statistics-Simulation and Computation, 53(3): 1387–1408.

See Also

[hcf.boot](#), [hcfboot](#), [hclr.circaov](#),

Examples

```
x <- rvmf(60, rnorm(3), 15)
ina <- rep(1:3, each = 20)
hcf.aov(x, ina)
hcf.aov(x, ina, fc = FALSE)
lr.aov(x, ina)
embed.aov(x, ina)
het.aov(x, ina)
```

Anova for circular data

Analysis of variance for circular data

Description

Analysis of variance for circular data.

Usage

```
hcf.circaov(u, ina, rads = FALSE)
hclr.circaov(u, ina, rads = FALSE)
lr.circaov(u, ina, rads = FALSE)
het.circaov(u, ina, rads = FALSE)
embed.circaov(u, ina, rads = FALSE)
```

Arguments

u	A numeric vector containing the data.
ina	A numerical or factor variable indicating the group of each value.
rads	If the data are in radians, this should be TRUE and FALSE otherwise.

Details

The high concentration (`hcf.circaov`), high concentration likelihood ratio (`hclr.aov`), log-likelihood ratio (`lr.circaov`), embedding approach (`embed.circaov`) or the non equal concentration parameters approach (`het.circaov`) is used.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degree(s) of freedom of the test.
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

- Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
- Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. Australian & New Zealand Journal of Statistics, 59(1): 119–135.
- Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. Communications in Statistics-Simulation and Computation, 53(3): 1387–1408.

See Also

[hclr.aov](#), [hcfcirc.boot](#), [hcfcircboot](#)

Examples

```
x <- rvonmises(100, 2.4, 15)
ina <- rep(1:4,each = 25)
hcf.circaov(x, ina, rads = TRUE)
lr.circaov(x, ina, rads = TRUE)
het.circaov(x, ina, rads = TRUE)
embed.circaov(x, ina, rads = TRUE)
hclr.circaov(x, ina, rads = TRUE)
```

BIC for the model based clustering using mixtures of von Mises-Fisher distributions

BIC to choose the number of components in a model based clustering using mixtures of von Mises-Fisher distributions

Description

BIC to choose the number of components in a model based clustering using mixtures of von Mises-Fisher distributions

Usage

```
bic.mixvmf(x, G = 5, n.start = 20)
```

Arguments

- | | |
|---------|--|
| x | A matrix containing directional data. |
| G | The maximum number of clusters to be tested. Default value is 5. |
| n.start | The number of random starts to try. See also R's built-in function kmeans for more information about this. |

Details

If the data are not unit vectors, they are transformed into unit vectors.

Value

A plot of the BIC values and a list including:

BIC	The BIC values for all the models tested.
runtime	The run time of the algorithm. A numeric vector. The first element is the user time, the second element is the system time and the third element is the elapsed time.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Hornik, K. and Grun, B. (2014). movMF: An R package for fitting mixtures of von Mises-Fisher distributions. *Journal of Statistical Software*, 58(10):1–31.

See Also

[mixvmf.mle](#), [rmixvmf](#), [mixvmf.contour](#)

Examples

```
x <- as.matrix( iris[, 1:4] )
x <- x / sqrt( rowSums(x^2) )
bic.mixvmf(x)
```

Bootstrap 2-sample mean test for (hyper-)spherical data

Bootstrap 2-sample mean test for (hyper-)spherical data

Description

Bootstrap 2-sample mean test for (hyper-)spherical data.

Usage

```
hcf.boot(x1, x2, fc = TRUE, B = 999)
lr.boot(x1, x2, B = 999)
hclr.boot(x1, x2, B = 999)
embed.boot(x1, x2, B = 999)
het.boot(x1, x2, B = 999)
```

Arguments

x1	A matrix with the data in Euclidean coordinates, i.e. unit vectors.
x2	A matrix with the data in Euclidean coordinates, i.e. unit vectors.
fc	A boolean that indicates whether a corrected F test should be used or not.
B	The number of bootstraps to perform.

Details

The high concentration (`hcf.boot`), log-likelihood ratio (`lr.boot`), high concentration log-likelihood ratio (`hclr.boot`), embedding approach (`embed.boot`) or the non equal concentration parameters approach (`het.boot`) is used.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. Since these are bootstrap based tests this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
- Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. *Australian & New Zealand Journal of Statistics*, 59(1): 119–135.
- Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. *Communications in Statistics-Simulation and Computation*, 53(3): 1387–1408.

See Also

[hcf.aov](#), [hcf.perm](#), [hcfboot](#)

Examples

```
x <- rvmf(60, rnorm(3), 15)
ina <- rep(1:2, each = 30)
x1 <- x[ina == 1, ]
x2 <- x[ina == 2, ]
hcf.boot(x1, x2)
lr.boot(x1, x2)
het.boot(x1, x2)
```

Bootstrap 2-sample mean test for circular data

Bootstrap 2-sample mean test for circular data

Description

Bootstrap 2-sample mean test for circular data.

Usage

```
hcfcirc.boot(u1, u2, rads = TRUE, B = 999)
lrcirc.boot(u1, u2, rads = TRUE, B = 999)
hclrcirc.boot(u1, u2, rads = TRUE, B = 999)
embedcirc.boot(u1, u2, rads = TRUE, B = 999)
hetcirc.boot(u1, u2, rads = TRUE, B = 999)
```

Arguments

u1	A numeric vector containing the data of the first sample.
u2	A numeric vector containing the data of the first sample.
rads	If the data are in radians, this should be TRUE and FALSE otherwise.
B	The number of bootstraps to perform.

Details

The high concentration (`hcfcirc.boot`), the log-likelihood ratio test (`lrcirc.boot`), high concentration log-likelihood ratio (`hclrcirc.boot`), embedding approach (`embedcirc.boot`), or the non equal concentration parameters approach (`hetcirc.boot`) is used.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. Since these are bootstrap based tests this is "NA".
p.value	The p-value of the test.

alternative A character with the alternative hypothesis.
method A character with the test used.
data.name A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.

Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. Australian & New Zealand Journal of Statistics, 59(1): 119–135.

Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. Communications in Statistics-Simulation and Computation, 53(3): 1387–1408.

See Also

[hcf.circaov](#), [hcfcircboot](#), [het.aov](#)

Examples

```
u1 <- rvonmises(20, 2.4, 5)
u2 <- rvonmises(20, 2.4, 10)
hcfcirc.boot(u1, u2)
```

Bootstrap ANOVA for (hyper-)spherical data

Bootstrap ANOVA for (hyper-)spherical data

Description

Bootstrap ANOVA for (hyper-)spherical data.

Usage

```
hcfboot(x, ina, B = 999)
hetboot(x, ina, B = 999)
```

Arguments

<code>x</code>	A matrix with the combined data (from all groups) in Euclidean coordinates, i.e. unit vectors.
<code>ina</code>	The grouping variables. A factor or a numerical vector specifying the groups to which each observation belongs to.
<code>B</code>	The number of bootstraps to perform.

Details

The high concentration (`hcfboot`), or the non equal concentration parameters approach (`hetboot`) is used.

Value

This is an "htest" class object. Thus it returns a list including:

<code>statistic</code>	The test statistic value.
<code>parameter</code>	The degrees of freedom of the test. Since these are bootstrap based tests this is "NA".
<code>p.value</code>	The p-value of the test.
<code>alternative</code>	A character with the alternative hypothesis.
<code>method</code>	A character with the test used.
<code>data.name</code>	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. Australian & New Zealand Journal of Statistics, 59(1): 119–135.

Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. Communications in Statistics-Simulation and Computation, 53(3): 1387–1408.

See Also

[hcf.boot](#), [hcf.aov](#)

Examples

```
x <- rvmf(60, rnorm(3), 10)
ina <- rep(1:3, each = 20)
hcfboot(x, ina)
```

Bootstrap ANOVA for circular data

Bootstrap ANOVA for circular data

Description

Bootstrap ANOVA for circular data.

Usage

```
hfcircboot(u, ina, rads = TRUE, B = 999)
hetcircboot(u, ina, rads = TRUE, B = 999)
```

Arguments

u	A numeric vector containing the data of all groups.
ina	The grouping variables. A factor or a numerical vector specifying the groups to which each observation belongs to.
rads	If the data are in radians, this should be TRUE and FALSE otherwise.
B	The number of bootstraps to perform.

Details

The high concentration (hfcircboot), or the non equal concentration parameters approach (hetcircboot) is used.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. Since these are bootstrap based tests this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.
- Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. Australian & New Zealand Journal of Statistics, 59(1): 119–135.
- Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. Communications in Statistics-Simulation and Computation, 53(3): 1387–1408.

See Also

[hcf.circaov](#), [het.aov](#)

Examples

```
u1 <- rvonmises(20, 2.4, 5)
u2 <- rvonmises(20, 2.4, 10)
hcfcirc.boot(u1, u2)
```

Check visually whether matrix Fisher samples is correctly generated or not

Check visually whether matrix Fisher samples is correctly generated or not.

Description

It plots the log probability trace of matrix Fisher distribution which should close to the maximum value of the logarithm of matrix Fisher distribution, if samples are correctly generated.

Usage

```
visual.check(x, Fa)
```

Arguments

x	The simulated data. An array with at least 2 3x3 matrices.
Fa	An arbitrary 3x3 matrix represents the parameter matrix of this distribution.

Details

For a given parameter matrix Fa, maximum value of the logarithm of matrix Fisher distribution is calculated via the form of singular value decomposition of $Fa = U\Lambda V^T$ which is $tr(\Lambda)$. Multiply the last column of U by -1 and replace small eigenvalue, say, λ_3 by $-\lambda_3$ if $|UV^T| = -1$.

Value

A plot which shows log probability trace of matrix Fisher distribution. The values are also returned.

Author(s)

Anamul Sajib.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd>.

References

Habeck M. (2009). Generation of three-dimensional random rotations in fitting and matching problems. *Computational Statistics*, 24(4):719–731.

Examples

```
Fa <- matrix( c(85, 11, 41, 78, 39, 60, 43, 64, 48), ncol = 3) / 10
x <- rmatrixfisher(1000, Fa)
a <- visual.check(x, Fa)
```

Circular correlations between one and many circular variables
Circular correlations between two circular variables

Description

Circular correlations between two circular variables.

Usage

```
circ.cors1(theta, phi, rads = FALSE)
circ.cors2(theta, phi, rads = FALSE)
```

Arguments

theta	The first circular variable expressed in radians, not degrees.
phi	The other circular variable. In the case of "circ.cors1" this is a matrix with many circular variables. In either case, the values must be in radians, not degrees.
rads	If the data are expressed in rads, then this should be TRUE. If the data are in degrees, then this is FALSE.

Details

Correlation for circular variables using the cosine and sine formula of Jammaladaka and Sen-Gupta (1988).

Value

A matrix with two columns, the correlations and the p-values.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Jammalamadaka, R. S. and Sengupta, A. (2001). Topics in circular statistics. World Scientific.

Jammalamadaka, S. R. and Sarma, Y. R. (1988). A correlation coefficient for angular variables. *Statistical Theory and Data Analysis*, 2:349–364.

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[spml.reg](#)

Examples

```
y <- runif(50, 0, 2 * pi)
x <- matrix(runif(50 * 10, 0, 2 * pi), ncol = 10)
circ.cors1(y, x, rads = TRUE)
```

Circular correlations between two circular variables

Circular correlations between two circular variables

Description

Circular correlations between two circular variables.

Usage

```
circ.cor1(theta, phi, rads = FALSE)
```

```
circ.cor2(theta, phi, rads = FALSE)
```

Arguments

theta	The first circular variable.
phi	The other circular variable.
rads	If the data are expressed in rads, then this should be TRUE. If the data are in degrees, then this is FALSE.

Details

circ.cor1: Correlation for circular variables using the cosinus and sinus formula of Jammalamadaka and SenGupta (1988).

circ.cor2: Correlation for circular variables using the cosinus and sinus formula of Mardia and Jupp (2000).

Value

A vector including:

rho The value of the correlation coefficient.
p-value The p-value of the zero correlation hypothesis testing.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Jammalamadaka, R. S. and Sengupta, A. (2001). Topics in circular statistics. World Scientific.
Jammalamadaka, S. R. and Sarma, Y. R. (1988) . A correlation coefficient for angular variables. Statistical Theory and Data Analysis, 2:349–364.
Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[circlin.cor](#), [circ.cor2](#), [spml.reg](#)

Examples

```
y <- runif(50, 0, 2 * pi)
x <- runif(50, 0, 2 * pi)
circ.cor1(x, y, rads = TRUE)
circ.cor2(x, y, rads = TRUE)
```

Circular distance correlation between two circular variables
Circular distance correlation between two circular variables

Description

Circular distance correlation between two circular variables.

Usage

```
circ.dcor(theta, phi, rads = FALSE)
```

Arguments

theta The first circular variable.
phi The other circular variable.
rads If the data are expressed in rads, then this should be TRUE. If the data are in degrees, then this is FALSE.

Details

The angular data are transformed to their Euclidean coordinates and then the distance correlation is computed.

Value

A list including:

dcov	The distance covariance.
dvarX	The distance variance of x.
dvarY	The distance variance of Y.
dcor	The distance correlation.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

G.J. Szekely, M.L. Rizzo and N. K. Bakirov (2007). Measuring and Testing Independence by Correlation of Distances. *Annals of Statistics*, 35(6):2769-2794.

See Also

[circlin.cor](#), [circ.cor2](#), [spher.dcor](#)

Examples

```
y <- runif(50, 0, 2 * pi)
x <- runif(50, 0, 2 * pi)
circ.dcor(x, y, rads = TRUE)
```

Circular or angular regression

Circular or angular regression

Description

Regression with circular dependent variable and Euclidean or categorical independent variables.

Usage

```
spml.reg(y, x, rads = TRUE, xnew = NULL, seb = FALSE, tol = 1e-07)
circpurka.reg(y, x, rads = TRUE, xnew = NULL)
cipc.reg(y, x, rads = TRUE, xnew = NULL, tol = 1e-06)
gpcpc.reg(y, x, rads = TRUE, reps = 20, xnew = NULL)
```

Arguments

y	The dependent variable, a numerical vector, it can be in radians or degrees.
x	The independent variable(s). Can be Euclidean or categorical (factor variables).
rads	If the dependent variable is expressed in rads, this should be TRUE and FALSE otherwise.
reps	How many starting values shall the algorithm use? By default it uses 20 different starting values.
xnew	The new values of some independent variable(s) whose circular values you want to predict. Can be Euclidean or categorical. If they are categorical, the user must provide them as dummy variables. It does not accept factor variables. If you have no new x values, leave it NULL (default).
seb	a boolean variable. If TRUE, the standard error of the coefficients will be returned. Set to FALSE in case of simulation studies or in other cases such as a forward regression setting for example. In these cases, it can save some time.
tol	The tolerance value to terminate the Newton-Raphson algorithm.

Details

For the `spml.reg()`, the Newton-Raphson algorithm is fitted in this regression as described in Presnell et al. (1998). For the `cipc.reg()`, the Newton-Raphson algorithm is fitted in this regression as described in Tsagris and Alenazy (2023). Note that the `cipc.reg()` is the same as the wrapped Cauchy regression. For the `circpurka.reg()` the `optim()` function is employed. For the `gcpc.reg()` the `optim()` and the `optimise()` functions are being used.

Value

A list including:

runtime	The runtime of the procedure.
iters	The number of iterations required until convergence of the Newton-Raphson algorithm.
beta	The regression coefficients.
seb	The standard errors of the coefficients.
loglik	The value of the maximised log-likelihood.
est	The fitted values expressed in radians if the observed data are in radians and in degrees otherwise. If <code>xnew</code> is not NULL, i.e. if you have new x values, then the predicted values of y will be returned.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Presnell Brett, Morrison Scott P. and Littell Ramon C. (1998). Projected multivariate linear models for directional data. *Journal of the American Statistical Association*, 93(443): 1068-1077.
- Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70-83
- Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

See Also

[circlin.cor](#), [circ.cor1](#), [circ.cor2](#), [spher.cor](#), [spher.reg](#)

Examples

```
x <- rnorm(100)
z <- cbind(3 + 2 * x, 1 - 3 * x)
y <- cbind( rnorm(100,z[,1], 1), rnorm(100, z[,2], 1) )
y <- y / sqrt( rowSums(y^2) )
y <- ( atan( y[, 2] / y[, 1] ) + pi * I(y[, 1] < 0) ) %% (2 * pi)
a <- spml.reg(y, x, rads = TRUE, xnew = x)
b <- cipc.reg(y, x, rads = TRUE, xnew = x)
```

Circular-linear correlation

Circular-linear correlation

Description

It calculates the squared correlation between a circular and one or more linear variables.

Usage

```
circlin.cor(theta, x, rads = FALSE)
```

Arguments

theta	The circular variable.
x	The linear variable or a matrix containing many linear variables.
rads	If the circular variable is in rads, this should be TRUE and FALSE otherwise.

Details

The squared correlation between a circular and one or more linear variables is calculated.

Value

A matrix with as many rows as linear variables including:

R-squared	The value of the squared correlation.
p-value	The p-value of the zero correlation hypothesis testing.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[circ.cor1](#), [circ.cor2](#), [spml.reg](#)

Examples

```
phi <- rvonmises(50, 2, 20, rads = TRUE)
x <- 2 * phi + rnorm(50)
y <- matrix(rnorm(50 * 5), ncol = 5)
circlin.cor(phi, x, rads = TRUE)
circlin.cor(phi, y, rads = TRUE)
```

Column-wise MLE of the angular Gaussian and the von Mises Fisher distributions

Column-wise MLE of the angular Gaussian and the von Mises Fisher distributions

Description

Column-wise MLE of the angular Gaussian and the von Mises Fisher distributions.

Usage

```
colspml.mle(x, tol = 1e-07, maxiters = 100, parallel = FALSE)
colvm.mle(x, tol = 1e-07)
```

Arguments

<code>x</code>	A numerical matrix with data. Each column refers to a different vector of observations of the same distribution. The values of for Lognormal must be greater than zero, for the logitnormal they must be percentages, excluding 0 and 1, whereas for the Borel distribution the <code>x</code> must contain integer values greater than 1.
<code>tol</code>	The tolerance value to terminate the Newton-Raphson algorithm.
<code>maxiters</code>	The maximum number of iterations that can take place in each regression.
<code>parallel</code>	Do you want this to be executed in parallel or not. The parallel takes place in C++, and the number of threads is defined by each system's available cores.

Details

For each column, `spml.mle` function is applied that fits the angular Gaussian distribution estimates its parameters and computes the maximum log-likelihood.

Value

A matrix with four columns. The first two are the mean vector, then the γ parameter, and the fourth column contains maximum log-likelihood.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Presnell Brett, Morrison Scott P. and Littell Ramon C. (1998). Projected multivariate linear models for directional data. *Journal of the American Statistical Association*, 93(443): 1068–1077.

See Also

[spml.mle](#), [spml.reg](#), [vmf.mle](#)

Examples

```
x <- matrix( runif(100 * 10), ncol = 10)
a <- colspml.mle(x)
b <- colvm.mle(x)
x <- NULL
```

Column-wise uniformity Watson test for circular data
Column-wise uniformity tests for circular data

Description

Column-wise uniformity tests for circular data.

Usage

```
colwatsons(u, rads = FALSE)
```

Arguments

u	A numeric matrix containing the circular data which are expressed in radians. Each column is a different sample.
rads	A boolean variable. If the data are in radians, put this TRUE. If the data are expressed in degrees make this FALSE.

Details

These tests are used to test the hypothesis that the data come from a circular uniform distribution.

Value

A matrix with two columns, the value of the test statistic and its associated p-value.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Jammalamadaka S. Rao and SenGupta A. (2001). Topics in Circular Statistics, pg. 156–157.

See Also

[watson](#), [kuiper](#), [fishkent](#)

Examples

```
x <- matrix( rvonmises(n = 50 * 10, m = 2, k = 0), ncol = 10 )
res<-colwatsons(x)
x <- NULL
```

Contour plot (on the plane) of the ESAG and Kent distributions
without any data

Contour plot (on the plane) of the ESAG and Kent and ESAG distributions without any data

Description

The contour plot (on the plane) of the spherical ESAG and Kent distributions is produced.

Usage

```
esag.contour(mu, gam, lat, long)
kent.contour(k, b)
```

Arguments

k	The concentration parameter.
b	The ovalness parameter. It has to be less than $k/2$ in order for the distribution to be unimodal. Otherwise it is bimodal.
mu	The mean vector the ESAG distribution, a vector in R^3 .
gam	The two gamma parameters of the ESAG distribution.
lat	A positive number determining the range of degrees to move left and right from the latitude center. See the example to better understand this argument.
long	A positive number determining the range of degrees to move up and down from the longitude center. See the example to better understand this argument.

Details

The goal of this function is for the user to see how the Kent or the SAG distribution looks like.

Value

A plot containing the contours of the distribution.

Author(s)

Michail Tsagris and Christos Adam.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Christos Adam <pada4m4@gmail.com>.

References

Kent John (1982). The Fisher-Bingham distribution on the sphere. *Journal of the Royal Statistical Society, Series B*, 44(1): 71–80.

Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3):689–697.

See Also

[vmf.contour](#), [vmf.kerncontour](#), [spher.esag.contour](#)

Examples

```
kent.contour(10, 4)

mu <- colMeans( as.matrix( iris[,1:3] ) )
gam <- c(1,0.5)
esag.contour(mu, gam, 50, 50)
esag.contour(mu, gam, 30, 40)
```

Contour plot (on the sphere) of a mixture of von Mises-Fisher distributions

Contour plot (on the sphere) of a mixture of von Mises-Fisher distributions

Description

The contour plot (on the sphere) of a mixture of von Mises-Fisher distributions is produced.

Usage

```
spher.mixvmf.contour(probs, mu, k, bgcol = "snow", dat = NULL, col = NULL,
  lat = 50, long = 50)
```

Arguments

probs	This is a vector with the mixing probability of each group.
mu	A matrix with the mean direction of each group.
k	A vector with the concentration parameter of each group.
bgcol	The color of the surface of the sphere.
dat	If you have you want to plot supply them here. This has to be a numerical matrix with three columns, i.e. unit vectors.
col	If you supplied data then choose the color of the points. If you did not choose a color, the points will appear in red.
lat	A positive number determining the range of degrees to move left and right from the latitude center. See the example to better understand this argument.
long	A positive number determining the range of degrees to move up and down from the longitude center. See the example to better understand this argument.

Details

The goal of this function is for the user to see how the mixtures of von Mises-Fisher look like.

Value

A plot containing the contours of the mixture distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Kurt Hornik and Bettina Grün (2014). movMF: An R Package for Fitting Mixtures of von Mises-Fisher Distributions <http://cran.r-project.org/web/packages/movMF/vignettes/movMF.pdf>

Mardia K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

Sra S. (2012). A short note on parameter approximation for von Mises-Fisher distributions: and a fast implementation of $I_s(x)$. Computational Statistics, 27(1): 177–190.

See Also

[spher.esag.contour](#), [spher.vmf.contour](#), [mixvmf.mle](#)

Examples

```
k <- runif(3, 4, 20)
probs <- c(0.2, 0.5, 0.3)
mu <- matrix(rnorm(9, 0, 0.5), ncol = 3)
mu <- mu / sqrt( rowSums(mu^2) )
## the lat and long are decreased to 10. Increase them back to 50 to
## see the difference
spher.mixvmf.contour(probs, mu, k, lat = 10, long = 10)
```

Contour plot (on the sphere) of some spherical rotationally symmetric distributions

Contour plot (on the sphere) of some spherical rotationally symmetric distributions

Description

The contour plot (on the sphere) of some spherical rotationally symmetric distributions is produced.

Usage

```
spher.vmf.contour(mu, k, bgcol = "snow", dat = NULL, col = NULL,  
  lat = 50, long = 50)  
spher.purka.contour(theta, a, bgcol = "snow", dat = NULL, col = NULL,  
  lat = 50, long = 50)  
spher.spcauchy.contour(mu, rho, bgcol = "snow", dat = NULL, col = NULL,  
  lat = 50, long = 50)  
spher.pkbd.contour(mu, rho, bgcol = "snow", dat = NULL, col = NULL,  
  lat = 50, long = 50)
```

Arguments

mu	The mean or the median direction, depending on the distribution, a unit vector.
theta	The mean direction (unit vector) of the Purkayastha distribution.
k	The concentration parameter (κ) of the von Mises-Fisher distribution.
a	The concentration parameter (α) of the Purkayastha distribution.
rho	The concentration parameter (ρ) of the spherical Cauchy distribution.
bgcol	The color of the surface of the sphere.
dat	If you have you want to plot supply them here. This has to be a numerical matrix with three columns, i.e. unit vectors.
col	If you supplied data then choose the color of the points. If you did not choose a color, the points will appear in red.
lat	A positive number determining the range of degrees to move left and right from the latitude center. See the example to better understand this argument.
long	A positive number determining the range of degrees to move up and down from the longitude center. See the example to better understand this argument.

Details

The goal of this function is for the user to see how the von Mises-Fisher, the Purkayastha, the spherical Cauchy or the Poisson kernel based distribution looks like.

Value

A plot containing the contours of the distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
- Sra S. (2012). A short note on parameter approximation for von Mises-Fisher distributions: and a fast implementation of $I_s(x)$. Computational Statistics, 27(1): 177–190.
- Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. The Indian Journal of Statistics, Series A, 53(1): 70–83.
- Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. Communications in Statistics-Theory and Methods, 19(6): 1973–1986.
- Kato S. and McCullagh P. (2020). Some properties of a Cauchy family on the sphere derived from the Mobius transformations. Bernoulli, 26(4): 3224–3248. <https://arxiv.org/pdf/1510.07679.pdf>
- Golzy M. and Markatou M. (2020). Poisson kernel-based clustering on the sphere: convergence properties, identifiability, and a method of sampling. Journal of Computational and Graphical Statistics, 29(4): 758–770.
- Sablica L., Hornik K. and Leydold J. (2023). Efficient sampling from the PKBD distribution. Electronic Journal of Statistics, 17(2): 2180–2209.

See Also

[spher.esag.contour](#), [spher.mixvmf.contour](#), [kent.contour](#)

Examples

```
mu <- colMeans( as.matrix( iris[, 1:3] ) )
mu <- mu / sqrt( sum(mu^2) )
## the lat and long are decreased to 30. Increase them back to 50 to
## see the difference
spher.spcauchy.contour(mu, 0.7, lat = 30, long = 30)
```

Contour plot (on the sphere) of the ESAG and Kent distributions

Contour plot (on the sphere) of the ESAG and Kent distributions

Description

The contour plot (on the sphere) of the ESAG and Kent distributions is produced.

Usage

```
spher.esag.contour(mu, gam, bgcol = "snow", dat = NULL, col = NULL,
  lat = 50, long = 50)
spher.kent.contour(G, param, bgcol = "snow", dat = NULL, col = NULL,
  lat = 50, long = 50)
```

Arguments

mu	The mean vector the ESAG distribution, a vector in R^3 .
gam	The two gamma parameters of the ESAG distribution.
G	For the Kent distribution, a 3 x 3 matrix whose first column is the mean direction. The second and third columns are the major and minor axes respectively.
param	For the Kent distribution a vector with the concentration κ and ovalness β parameters. The angle ψ has been absorbed inside the matrix G.
bgcol	The color of the surface of the sphere.
dat	If you have you want to plot supply them here. This has to be a numerical matrix with three columns, i.e. unit vectors.
col	If you supplied data then choose the color of the points. If you did not choose a color, the points will appear in red.
lat	A positive number determining the range of degrees to move left and right from the latitude center. See the example to better understand this argument.
long	A positive number determining the range of degrees to move up and down from the longitude center. See the example to better understand this argument.

Details

The goal of this function is for the user to see how the ESAG or the Kent distribution looks like.

Value

A plot containing the contours of the distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Kent John (1982). The Fisher-Bingham distribution on the sphere. *Journal of the Royal Statistical Society, Series B*, 44(1): 71–80.

Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3):689–697.

See Also

[esag.contour](#), [spher.purka.contour](#), [kent.contour](#)

Examples

```
mu <- colMeans( as.matrix( iris[, 1:3] ) )
gam <- c(1 ,0.5)
## the lat and long are decreased to 30. Increase them back to 50 to
## see the difference
spher.esag.contour(mu, gam, lat = 30, long = 30)
```

Contour plot (on the sphere) of the SESPC distribution

Contour plot (on the sphere) of the SESPC distribution

Description

The contour plot (on the sphere) of the SESPC distribution is produced.

Usage

```
spher.sespc.contour(mu, theta, bgcol = "snow", dat = NULL, col = NULL,
  lat = 50, long = 50)
```

Arguments

mu	The mean vector the SESPC distribution, a vector in R^3 .
theta	The two θ parameters of the SESPC distribution.
bgcol	The color of the surface of the sphere.
dat	If you have you want to plot supply them here. This has to be a numerical matrix with three columns, i.e. unit vectors.
col	If you supplied data then choose the color of the points. If you did not choose a color, the points will appear in red.
lat	A positive number determining the range of degrees to move left and right from the latitude center. See the example to better understand this argument.
long	A positive number determining the range of degrees to move up and down from the longitude center. See the example to better understand this argument.

Details

The goal of this function is for the user to see how the SESPC distribution looks like.

Value

A plot containing the contours of the distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

See Also

[spher.esag.contour](#), [spher.spscauchy.contour](#)

Examples

```
mu <- colMeans( as.matrix( iris[, 1:3] ) )
theta <- c(1 ,0.5)
## the lat and long are decreased to 30. Increase them back to 50 to
## see the difference
spher.sespc.contour(mu, theta, lat = 30, long = 30)
```

Contour plot of a mixture of von Mises-Fisher distributions model

Contour plot of a mixture of von Mises-Fisher distributions model for spherical data only.

Description

Contour lines are produced of mixture model for spherical data only.

Usage

```
mixvmf.contour(u, mod)
```

Arguments

u	A two column matrix. The first column is the longitude and the second is the latitude.
mod	This is mix.vmf object, actually it is a list. Run a mixture model and save it as mod for example, mod = mix.vmf(x, 3).

Details

The contour plot is displayed with latitude and longitude in the axes. No Lambert projection is used here. This works for spherical data only which are given as longitude and latitude.

Value

A plot including: The points and the contour lines.

Author(s)

Michail Tsagris and Christos Adam.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Christos Adam <pada4m4@gmail.com>.

References

Kurt Hornik and Bettina Grün (2014). movMF: An R Package for Fitting Mixtures of von Mises-Fisher Distributions <http://cran.r-project.org/web/packages/movMF/vignettes/movMF.pdf>

See Also

[vmf.kerncontour](#), [vmf.contour](#), [mixvmf.mle](#)

Examples

```
k <- runif(2, 4, 20)
prob <- c(0.4, 0.6)
mu <- matrix( rnorm(6), ncol = 3 )
mu <- mu / sqrt( rowSums(mu^2) )
x <- rmixvmf(200, prob, mu, k)$x
mod <- mixvmf.mle(x, 2)
y <- euclid.inv(x)
mixvmf.contour(y, mod)
```

Contour plot of spherical data using a von Mises-Fisher kernel density estimate

Contour plot of spherical data using a von Mises-Fisher kernel density estimate

Description

Contour plot of spherical data using a von Mises-Fisher kernel density estimate.

Usage

```
vmf.kerncontour(u, thumb = "none", den.ret = FALSE, full = FALSE, ngrid = 100)
```

Arguments

u	A two column matrix. The first column is the latitude and the second is the longitude.
thumb	This is either 'none' (default), or 'rot' for the rule of thumb suggested by Garcia-Portugues (2013). If it is "none" it is estimated via cross validation, with the fast function vmfkde.tune .

<code>den.ret</code>	If FALSE (default), plots the contours of the density along with the individual points. If TRUE, will instead return a list with the Longitudes, Latitudes and Densities. Look at the 'value' section for details.
<code>full</code>	If FALSE (default), uses the range of positions from 'u' to calculate and optionally plot densities. If TRUE, calculates densities covering the entire sphere.
<code>ngrid</code>	Sets the resolution of the density calculation.

Details

It calculates the contour plot using a von Mises-Fisher kernel for spherical data only.

Value

The contour lines of the data. If "den.ret" was set to TRUE a list including:

<code>lat</code>	The latitude values.
<code>long</code>	The longitude values.
<code>h</code>	The optimal bandwidth.
<code>den</code>	The kernel density estimate contour points.

Author(s)

Michail Tsagris, Micah J. Waldstein and Christos Adam.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>, Micah J. Waldstein <micah@waldste.in> and Christos Adam <pada4m4@gmail.com>.

References

Garcia Portugues, E. (2013). Exact risk improvement of bandwidth selectors for kernel density estimation with directional data. *Electronic Journal of Statistics*, 7, 1655–1685.

See Also

[vmf.kde](#), [vmfkde.tune](#), [vmf.contour](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
x <- euclid.inv(x)

vmf.kerncontour(x, "rot")
```

Contour plots of some rotationally symmetric distributions

Contour plots of some rotationally symmetric distributions

Description

Contour plots of some rotationally symmetric distributions.

Usage

```
vmf.contour(k)
spcauchy.contour(mu, rho, lat = 50, long = 50)
purka.contour(theta, a, lat = 50, long = 50)
pkbd.contour(mu, rho, lat = 50, long = 50)
```

Arguments

k	The concentration parameter.
mu	The mean direction (unit vector) of the von Mises-Fisher, the IAG, the spherical Cauchy distribution, or the Poisson kernel based distribution.
rho	The ρ parameter of the spherical Cauchy distribution, or the Poisson kernel based distribution.
theta	The median direction for the Purkayastha distribution, a unit vector.
a	The concentration parameter of the Purkayastha distribution.
lat	A positive number determining the range of degrees to move left and right from the latitude center. See the example to better understand this argument.
long	A positive number determining the range of degrees to move up and down from the longitude center. See the example to better understand this argument.

Details

The user specifies the concentration parameter only and not the mean direction or data. This is for illustration purposes only. The graph of the von Mises-Fisher distribution will always contain circles, as this distribution is the analogue of a bivariate normal in two dimensions with a zero covariance.

Value

A contour plot of the distribution.

Author(s)

Michail Tsagris and Christos Adam.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Christos Adam <pada4m4@gmail.com>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
- Kato S. and McCullagh P. (2020). Some properties of a Cauchy family on the sphere derived from the Mobius transformations. *Bernoulli*, 26(4): 3224–3248. <https://arxiv.org/pdf/1510.07679.pdf>
- Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70–83
- Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. *Communications in Statistics-Theory and Methods*, 19(6): 1973–1986.
- Golzy M. and Markatou M. (2020). Poisson kernel-based clustering on the sphere: convergence properties, identifiability, and a method of sampling. *Journal of Computational and Graphical Statistics*, 29(4): 758–770.
- Sablica L., Hornik K. and Leydold J. (2023). Efficient sampling from the PKBD distribution. *Electronic Journal of Statistics*, 17(2): 2180–2209.

See Also

[rvmf](#), [vmf.mle](#), [vmf.kerncontour](#), [kent.contour](#), [sphereplot](#)

Examples

```
vmf.contour(5)
mu <- colMeans( as.matrix( iris[,1:3] ) )
mu <- mu / sqrt( sum(mu^2) )
spcauchy.contour(mu, 0.7, 30, 30)
spcauchy.contour(mu, 0.7, 60, 60)
```

Conversion of cosines to azimuth and plunge
Conversion of cosines to azimuth and plunge

Description

Conversion of cosines to azimuth and plunge.

Usage

```
cosap(x,y,z)
```

Arguments

x	x component of cosine.
y	y component of cosine.
z	z component of cosine.

Details

Orientation: $x > 0$ is 'eastward', $y > 0$ is 'southward', and $z > 0$ is 'downward'.

Value

A list including:

A	The azimuth
P	The plunge

Author(s)

Eli Amson.

R implementation and documentation: Eli Amson <eli.amson1988@gmail.com>.

References

Amson E, Arnold P, Van Heteren AH, Cannoville A, Nyakatura JA. Trabecular architecture in the forelimb epiphyses of extant xenarthrans (Mammalia). *Frontiers in Zoology*.

See Also

[euclid](#), [euclid.inv](#), [eul2rot](#)

Examples

```
cosap(-0.505, 0.510, -0.696)
```

Converting a rotation matrix on $SO(3)$ to an unsigned unit quaternion
Converting a rotation matrix on $SO(3)$ to an unsigned unit quaternion

Description

It returns an unsigned unit quaternion in S^3 (the four-dimensional sphere) from a 3×3 rotation matrix on $SO(3)$.

Usage

```
rot2quat(X)
```

Arguments

X	A rotation matrix in $SO(3)$.
---	--------------------------------

Details

Firstly construct a system of linear equations by equating the corresponding components of the theoretical rotation matrix proposed by Prentice (1986), and given a rotation matrix. Finally, the system of linear equations are solved by following the tricks mentioned in second reference here in order to achieve numerical accuracy to get quaternion values.

Value

A unsigned unite quaternion.

Author(s)

Anamul Sajib.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd>.

References

Prentice, M. J. (1986). Orientation statistics without parametric assumptions. *Journal of the Royal Statistical Society. Series B: Methodological* 48(2). //http://www.euclideanspace.com/maths/geometry/rotations/conversions

See Also

[quat2rot](#), [rotation](#), [Arotation](#) \ link{rot.matrix}

Examples

```
x <- rnorm(4)
x <- x/sqrt( sum(x^2) ) ## an unit quaternion in R4 ##
R <- quat2rot(x)
R
x
rot2quat(R) ## sign is not exact as you can see
```

Converting an unsigned unit quaternion to rotation matrix on $SO(3)$

Converting an unsigned unit quaternion to rotation matrix on $SO(3)$

Description

It forms a (3 x 3) rotation matrix on $SO(3)$ from an unsigned unite quaternion in S^3 (the four-dimensional sphere).

Usage

```
quat2rot(x)
```

Arguments

x An unsigned unit quaternion in S^3 .

Details

Given an unsigned unit quaternion in S^3 it forms a rotation matrix on $SO(3)$, according to the transformation proposed by Prentice (1986).

Value

A rotation matrix.

Author(s)

Anamul Sajib.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd>.

References

Prentice, M. J. (1986). Orientation statistics without parametric assumptions. *Journal of the Royal Statistical Society. Series B: Methodological* 48(2).

See Also

[rot2quat](#), [rotation](#), [Arotation rot.matrix](#)

Examples

```
x <- rnorm(4)
x <- x/sqrt( sum(x^2) )
x                    ## an unit quaternion in R4 ##
quat2rot(x)
```

Cross validation for estimating the classification rate

Cross validation for estimating the classification rate

Description

Cross validation for estimating the classification rate.

Usage

```
dirda.cv(x, ina, folds = NULL, nfolds = 10, k = 2:10, stratified = FALSE,
         type = c("vmf", "iag", "esag", "kent", "knn"),
         seed = NULL, B = 1000, parallel = FALSE)
```

Arguments

<code>x</code>	A matrix with the data in Eulclidean coordinates, i.e. unit vectors. The matrix must have three columns, only spherical data are currently supported.
<code>ina</code>	A variable indicating the groupings.
<code>fold</code> s	Do you already have a list with the folds? If not, leave this NULL.
<code>nfolds</code>	How many folds to create?
<code>k</code>	If you choose to use k-NN, what will be the k values?
<code>stratified</code>	Should the folds be created in a stratified way? i.e. keeping the distribution of the groups similar through all folds?
<code>seed</code>	If seed is TRUE, the results will always be the same.
<code>type</code>	The type of classifier to use. The available options are "vmf" (von Mises-Fisher distribution), "esag" (ESAG distribution), "kent" (Kent distribution), "knn" (k-NN algorithm). You can choose any of them or all of them. Note that "esag" and "kent" work only with spherical data.
<code>B</code>	If you used k-NN, should a bootstrap correction of the bias be applied? If yes, 1000 is a good value.
<code>parallel</code>	If you want the standard -NN algorithm to take place in parallel set this equal to TRUE.

Details

Cross-validation for the estimation of the performance of a classifier.

The estimated performance of the best classifier is overestimated. After the cross-validation procedure, the predicted values produced by all classifiers are collected, from all folds, in an $n \times M$ matrix, where n is the number of samples and M the number of all classifiers used. We sample rows (predictions) with replacement from P and denote them as the in-sample values. The non re-sampled rows are denoted as out-of-sample values. The performance of each classifier in the in-sample rows is calculated and the classifier with the optimal performance is selected, followed by the calculation of performance in the out-of-sample values. This process is repeated B times and the average performance is returned. The only computational overhead is with the repetitive resampling and calculation of the performance, i.e. no model or classifier is fitted nor trained. For more information see Tsamardinos et al. (2018). This procedure though takes place only for the k-NN algorithm.

The good thing with the function is that you can run any method you want by supplying the folds yourselves using the command `makefolds`. Then suppose you want to run another method. By supplying the same folds you will be able to have comparative results for all methods.

Value

A list including:

<code>perf</code>	A vector with the estimated performance of each classifier.
<code>best</code>	The classifier with the optimal performance.
<code>boot.perf</code>	The bootstrap bias corrected performance.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4), 467–491.

Mardia, K. V. and Jupp, P. E. (2000). *Directional statistics*. Chichester: John Wiley & Sons.

Paine P.J., Preston S.P. and Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3):689–697.

Morris J. E. and Laycock P. J. (1974). Discriminant analysis of directional data. *Biometrika*, 61(2): 335–341.

Tsamardinos I., Greasidou E. and Borboudakis G. (2018). *Machince Learning*, 107(12): 1895–1922.

See Also

[esag.da](#), [vmfda.pred](#), [dirknn](#), [knn.reg](#)

Examples

```
x <- rvmf(300, rnorm(3), 10)
ina <- sample.int(4, 300, replace = TRUE)
dirda.cv(x, ina, B = 1000)
```

Cross validation in von Mises-Fisher discriminant analysis

Cross validation for estimating the classification rate of a discriminant analysis for directional data assuming a von Mises-Fisher distribution

Description

Cross validation for estimating the classification rate of a discriminant analysis for directional data assuming a von Mises-Fisher distribution.

Usage

```
vmf.da(x, ina, fraction = 0.2, R = 200, seed = NULL)
```

Arguments

x	A matrix with the data in Eulclidean coordinates, i.e. unit vectors.
ina	A variable indicating the groupings.
fraction	The fraction of data to be used as test set.
R	The number of repetitions.
seed	If seed is TRUE, the results will always be the same.

Details

A repeated cross validation procedure is performed to estimate the rate of correct classification.

Value

A list including:

- | | |
|---------|---|
| percent | The estimated percent of correct classification and two estimated standard deviations. The one is the standard deviation of the rates and the other is assuming a binomial distribution. |
| ci | Three types of confidence intervals, the standard one, another one based on the binomial distribution and the third one is the empirical one, which calculates the upper and lower 2.5% of the rates. |

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4): 467–491.

Morris J. E. and Laycock P. J. (1974). Discriminant analysis of directional data. *Biometrika*, 61(2): 335–341.

See Also

[vmfda.pred](#), [mixvmf.mle](#), [vmf.mle](#), [dirknn](#)

Examples

```
x <- rvmf(100, rnorm(4), 15)
ina <- rep(1:2, each = 50)
vmf.da(x, ina, fraction = 0.2, R = 200)
```

Cross validation with ESAG discriminant analysis

Cross validation for estimating the classification rate of a discriminant analysis for directional data assuming an ESAG distribution

Description

Cross validation for estimating the classification rate of a discriminant analysis for directional data assuming an ESAG distribution.

Usage

```
esag.da(y, ina, fraction = 0.2, R = 100, seed = NULL)
```

Arguments

<code>y</code>	A matrix with the data in Euclidean coordinates, i.e. unit vectors. The matrix must have three columns, only spherical data are currently supported.
<code>ina</code>	A variable indicating the groupings.
<code>fraction</code>	The fraction of data to be used as test set.
<code>R</code>	The number of repetitions.
<code>seed</code>	You can specify your own seed number here or leave it NULL.

Details

A repeated cross validation procedure is performed to estimate the rate of correct classification.

Value

A list including:

<code>percent</code>	The estimated percent of correct classification and two estimated standard deviations. The one is the standard deviation of the rates and the other is assuming a binomial distribution.
<code>ci</code>	Three types of confidence intervals, the standard one, another one based on the binomial distribution and the third one is the empirical one, which calculates the upper and lower 2.5% of the rates.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4), 467–491.
- Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3):689–697.
- Mardia, K. V. and Jupp, P. E. (2000). *Directional statistics*. Chichester: John Wiley & Sons.

See Also

[vmf.da](#), [vmfda.pred](#), [dirknn](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
ina <- rep(1:2, each = 50)
esag.da(x, ina, fraction = 0.2, R = 50)
```

Cross validation with Purkayastha discriminant analysis

Cross validation for estimating the classification rate of a discriminant analysis for directional data assuming a Purkayastha distribution

Description

Cross validation for estimating the classification rate of a discriminant analysis for directional data assuming a Purkayastha distribution.

Usage

```
purka.da(y, ina, fraction = 0.2, R = 100, seed = NULL)
```

Arguments

y	A numerical vector with data expressed in radians, or a matrix with two columns (cos and sin) for circular data. Or a matrix with 3 columns (unit vectors) for spherical data.
ina	A variable indicating the groupings.
fraction	The fraction of data to be used as test set.
R	The number of repetitions.
seed	You can specify your own seed number here or leave it NULL.

Details

A repeated cross validation procedure is performed to estimate the rate of correct classification.

Value

A list including:

percent	The estimated percent of correct classification and two estimated standard deviations. The one is the standard deviation of the rates and the other is assuming a binomial distribution.
ci	Three types of confidence intervals, the standard one, another one based on the binomial distribution and the third one is the empirical one, which calculates the upper and lower 2.5% of the rates.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70-83

Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. *Communications in Statistics-Theory and Methods*, 19(6): 1973-1986.

See Also

[vmf.da](#), [vmfda.pred](#), [dirknn](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
ina <- rep(1:2, each = 50)
purka.da(x, ina, fraction = 0.2, R = 50)
```

Cumulative distribution function of circular distributions
Cumulative distribution function of circular distributions

Description

Cumulative probability distribution of circular distributions.

Usage

```
pvm(u, m, k, rads = FALSE)
pspml(u, mu, rads = FALSE)
pwrapcauchy(u, m, rho, rads = FALSE)
pcircpurka(u, m, a, rads = FALSE)
pcircbeta(u, m, a, b, rads = FALSE)
pcardio(u, m, rho, rads = FALSE)
pcircexp(u, lambda, rads = FALSE)
pcipc(u, omega, g, rads = FALSE)
pgcpc(u, omega, g, rho, rads = FALSE)
pmmvm(u, m, k, N, rads = FALSE)
```

Arguments

u	A numerical value, either in radians or in degrees.
m	The mean direction of the von Mises and the multi-modal von Mises distribution in radians or in degrees.
mu	The mean vector, a vector with two values for the "pspml".
omega	The location parameter of the CIPC and GCPC distributions.
g	The norm of the mean vector for the CIPC and GCPC distributions.
k	The concentration parameter, κ .
lambda	The λ parameter of the circular exponential distribution. This must be positive.
a	The α parameter of the circular Purkayastha distribution or the α parameter of the circular Beta distribution.
b	The β parameter of the circular beta distribution.
rho	The ρ parameter of the Cardioid, wrapped Cauchy and GCPC distributions.
N	The number of modes to consider in the multi-modal von Mises distribution.
rads	If the data are in radians, this should be TRUE and FALSE otherwise.

Details

This value calculates the probability of u being less than some value θ .

Value

The probability that of u being less than θ , where u follows a circular distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Arthur Pewsey, Markus Neuhauser, and Graeme D. Ruxton (2013). Circular Statistics in R.
- Barnett M. J. and Kingston R. L. (2024). A note on the Hendrickson-Lattman phase probability distribution and its equivalence to the generalized von Mises distribution. *Journal of Applied Crystallography*, 57(2).
- Jammalamadaka S. R. and Kozubowski T. J. (2003). A new family of circular models: The wrapped Laplace distributions. *Advances and Applications in Statistics*, 3(1): 77–103.
- Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70–83
- Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. *Communications in Statistics—Theory and Methods*, 19(6): 1973–1986.
- Paula F. V., Nascimento A. D., Amaral G. J. and Cordeiro G. M. (2021). Generalized Cardioid distributions for circular data analysis. *Stats*, 4(3): 634–649.
- Zheng Sun (2009). Comparing measures of fit for circular distributions. MSc Thesis, University of Victoria. file:///C:/Users/mtsag/Downloads/zhengsun_master_thesis.pdf

See Also

[group.gof](#), [dvm](#), [dcircexp](#), [purka.mle](#), [dcircpurka](#), [dmmvm](#)

Examples

```
pvm(1, 2, 10, rads = TRUE)
pmmvm(1, 2, 10, 3, rads = TRUE)
pcircexp(c(1, 2), 2, rads = TRUE)
pcircpurka(2, 3, 0.3)
```

Density of a mixture of von Mises-Fisher distributions

Density of a mixture of von Mises-Fisher distributions

Description

Density of a mixture of von Mises-Fisher distributions.

Usage

```
dmixvmf(y, probs, mu, k, logden = FALSE)
```

Arguments

y	A matrix with unit vectors.
probs	This is a vector with the mixing probability of each group.
mu	A matrix with the mean direction of each group.
k	A vector with the concentration parameter of each group.
logden	If you the logarithm of the density values set this to TRUE.

Details

The function computes the density for a given mixture of von Mises-Fisher distributions.

Value

A vector with the (log) density values of y.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Kurt Hornik and Bettina Grün (2014). movMF: An R Package for Fitting Mixtures of von Mises-Fisher Distributions <http://cran.r-project.org/web/packages/movMF/vignettes/movMF.pdf>

See Also

[mixvmf.mle](#), [rvmf](#), [bic.mixvmf](#)

Examples

```
k <- runif(3, 4, 6)
probs <- c(0.2, 0.5, 0.3)
mu <- matrix(rnorm(9), ncol = 3)
mu <- mu / sqrt( rowSums(mu^2) )
x <- rmixvmf(200, probs, mu, k)$x
b <- dmixvmf(x, probs, mu, k)
```

Density of some (hyper-)spherical distributions

Density of some (hyper-)spherical distributions

Description

Density of some (hyper-)spherical distributions.

Usage

```
dvmf(y, mu, k, logden = FALSE )
iagd(y, mu, logden = FALSE)
dpurka(y, theta, a, logden = FALSE)
dspcauchy(y, mu, rho, logden = FALSE)
dpkbd(y, mu, rho, logden = FALSE)
```

Arguments

y	A matrix or a vector with the data expressed in Euclidean coordinates, i.e. unit vectors.
mu	The mean direction (unit vector) of the von Mises-Fisher, the IAG, the spherical Cauchy distribution, or of the Poisson kernel based distribution.
theta	The mean direction (unit vector) of the Purkayastha distribution.
k	The concentration parameter of the von Mises-Fisher distribution.
a	The concentration parameter of the Purkayastha distribution.
rho	The ρ parameter of the spherical Cauchy distribution, or of the Poisson kernel based distribution.
logden	If you the logarithm of the density values set this to TRUE.

Details

The density of the von Mises-Fisher, of the IAG, of the Purkayastha, of the spherical Cauchy distribution, or of the Poisson kernel based distribution is computed.

Value

A vector with the (log) density values of y .

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.
- Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70–83
- Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. *Communications in Statistics-Theory and Methods*, 19(6): 1973–1986.
- Kato S. and McCullagh P. (2020). Some properties of a Cauchy family on the sphere derived from the Mobius transformations. *Bernoulli*, 26(4): 3224–3248. <https://arxiv.org/pdf/1510.07679.pdf>
- Golzy M. and Markatou M. (2020). Poisson kernel-based clustering on the sphere: convergence properties, identifiability, and a method of sampling. *Journal of Computational and Graphical Statistics*, 29(4): 758–770.
- Sablica L., Hornik K. and Leydold J. (2023). Efficient sampling from the PKBD distribution. *Electronic Journal of Statistics*, 17(2): 2180–2209.

See Also

[kent.mle](#), [rkent](#), [esag.mle](#)

Examples

```
m <- colMeans( as.matrix( iris[,1:3] ) )
y <- rvmf(1000, m = m, k = 10)
dvmf(y, k=10, m)
```

Density of some circular distributions

Density of some circular distributions

Description

Density of some circular distributions.

Usage

```

dvm(x, m, k, rads = FALSE, logden = FALSE)
dspml(x, mu, rads = FALSE, logden = FALSE)
dwrapcauchy(x, m, rho, rads = FALSE, logden = FALSE)
dcircpurka(x, m, a, rads = FALSE, logden = FALSE)
dggvm(x, param, rads = FALSE, logden = FALSE)
dcircbeta(x, m, a, b, rads = FALSE, logden = FALSE)
dcardio(x, m, rho, rads = FALSE, logden = FALSE)
dcircexp(x, lambda, rads = FALSE, logden = FALSE)
dcipc(x, omega, g, rads = FALSE, logden = FALSE)
dgcpc(x, omega, g, rho, rads = FALSE, logden = FALSE)
dmmvm(x, m, k, N, rads = FALSE, logden = FALSE)

```

Arguments

x	A vector with circular data.
m	The mean value of the von Mises distribution and of the cardioid, a scalar. This is the median for the circular Purkayastha distribution.
mu	The mean vector, a vector with two values for the "spml" and the GCPC.
omega	The location parameter of the CIPC and GCPC distributions.
g	The norm of the mean vector for the CIPC and GCPC distributions.
k	The concentration parameter.
rho	For the wrapped Cauchy and Cardioid distributions, this is the ρ parameter. For the GCPC distribution this is the eigenvalue parameter, or covariance determinant.
a	The α parameter of the circular Purkayastha distribution or the α parameter of the circular Beta distribution.
b	The β parameter of the circular Beta distribution.
lambda	The λ parameter of the circular (or wrapped) exponential distribution. This must be positive.
param	The vector of parameters of the GGVM distribution as returned by the function ggvm.mle .
N	The number of modes to consider in the multi-modal von Mises distribution.
rads	If the data are in rads, then this should be TRUE, otherwise FALSE.
logden	If you the logarithm of the density values set this to TRUE.

Details

The density of the von Mises, bivariate projected normal, cardio, circular exponential, wrapped Cauchy, circular Purkayastha, CIPC or GCPC distributions is computed.

Value

A vector with the (log) density values of x.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.

Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

Presnell B., Morrison S. P. and Littell R. C. (1998). Projected multivariate linear models for directional data. *Journal of the American Statistical Association*, 93(443): 1068–1077.

Jammalamadaka S. R. and Kozubowski T. J. (2003). A new family of circular models: The wrapped Laplace distributions. *Advances and Applications in Statistics*, 3(1): 77–103.

Barnett M. J. and Kingston R. L. (2024). A note on the Hendrickson-Lattman phase probability distribution and its equivalence to the generalized von Mises distribution. *Journal of Applied Crystallography*, 57(2).

Paula F. V., Nascimento A. D., Amaral G. J. and Cordeiro G. M. (2021). Generalized Cardioid distributions for circular data analysis. *Stats*, 4(3): 634–649.

Zheng Sun (2009). Comparing measures of fit for circular distributions. MSc Thesis, University of Victoria. file:///C:/Users/mtsag/Downloads/zhengsun_master_thesis.pdf

See Also

[dkent](#), [rvonmises](#), [desag](#)

Examples

```
x <- rvonmises(500, m = 2.5, k = 10, rads = TRUE)
mod <- circ.summary(x, rads = TRUE, plot = FALSE)
den <- dvm(x, mod$mesos, mod$kappa, rads = TRUE, logden = TRUE )
mod$loglik
sum(den)
```

Density of the SESPC distribution

Density of the SESPC distribution

Description

Density of the SESPC distribution.

Usage

```
dsespc(y, mu, theta, logden = FALSE)
```

Arguments

y	A matrix or a vector with the data expressed in Euclidean coordinates, i.e. unit vectors.
mu	The mean vector the SESPC distribution, a vector in R^3 .
theta	The two θ parameters of the SESPC distribution.
logden	If you the logarithm of the density values set this to TRUE.

Details

The density of the SESPC distribution is computed.

Value

A vector with the (log) density values of y.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.

See Also

[desag](#), [sespc.mle](#)

Examples

```
m <- colMeans( as.matrix( iris[,1:3] ) )
y <- rsespc(1000, m, c(1, 1))
mod <- sespc.mle(y)
dsespc( y, mod$mu, mod$theta)
```

Density of the spherical ESAG and Kent distributions
Density of the spherical ESAG and Kent distributions

Description

Density of the spherical ESAG and Kent distributions.

Usage

```
desag(y, mu, gam, logden = FALSE)
dkent(y, G, param, logden = FALSE )
```

Arguments

y	A matrix or a vector with the data expressed in Euclidean coordinates, i.e. unit vectors.
mu	The mean vector the ESAG distribution, a vector in R^3 .
gam	The two γ parameters of the ESAG distribution.
G	For the Kent distribution only, a 3 x 3 matrix whose first column is the mean direction. The second and third columns are the major and minor axes respectively.
param	For the Kent distribution a vector with the concentration κ and ovalness β parameters. The ψ has been absorbed inside the matrix G.
logden	If you the logarithm of the density values set this to TRUE.

Details

The density of the spherical ESAG or Kent distribution is computed.

Value

A vector with the (log) density values of y.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.
- Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3):689–697.
- Kent John (1982). The Fisher-Bingham distribution on the sphere. *Journal of the Royal Statistical Society, Series B*, 44(1): 71–80.

See Also

[kent.mle](#), [rkent](#), [esag.mle](#)

Examples

```
m <- colMeans( as.matrix( iris[,1:3] ) )
y <- rkent(1000, k = 10, m = m, b = 4)
mod <- kent.mle(y)
dkent( y, G = mod$G, param = mod$param )
```

Density of the Wood bimodal distribution on the sphere

Density of the Wood bimodal distribution on the sphere

Description

Density of the Wood bimodal distribution on the sphere.

Usage

```
dwood(y, param, logden = FALSE)
```

Arguments

<code>y</code>	A matrix containing two columns. The first one is the latitude and the second is the longitude, both expressed in degrees.
<code>param</code>	A vector with the 5 parameters, in the order they are returned by the wood.mle function. That is, $(\gamma, \delta, \alpha, \beta, \kappa)$.
<code>logden</code>	If you the logarithm of the density values set this to TRUE.

Details

The density of the spherical Wood distribution is computed.

Value

A vector with the (log) density values of `y`.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Wood A.T.A. (1982). A bimodal distribution on the sphere. *Journal of the Royal Statistical Society, Series C*, 31(1): 52–58.

See Also

[dkent](#), [desag](#), [wood.mle](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
x <- euclid.inv(x)
mod <- wood.mle(x)
d <- dwood(x, mod$info[, 1])
```

Euclidean transformation

Euclidean transformation

Description

It transforms the data from the spherical coordinates to Euclidean coordinates.

Usage

```
euclid(u)
```

Arguments

u A two column matrix or even one single vector, where the first column (or element) is the latitude and the second is the longitude. The order is important.

Details

It takes the matrix of unit vectors of latitude and longitude and transforms it to unit vectors.

Value

A three column matrix:

U The Euclidean coordinates of the latitude and longitude.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

See Also

[euclid.inv](#), [Arotation](#), [lambert](#)

Examples

```
x <- rvmf(10, rnorm(3), 10)
u <- euclid.inv(x)
euclid(u)
x
```

Euler angles from a rotation matrix on $SO(3)$

Compute the Euler angles from a rotation matrix on $SO(3)$.

Description

It calculates three euler angles $(\theta_{12}, \theta_{13}, \theta_{23})$ from a (3×3) rotation matrix X , where X is defined as $X = R_z(\theta_{12}) \times R_y(\theta_{13}) \times R_x(\theta_{23})$. Here $R_x(\theta_{23})$ means a rotation of θ_{23} radians about the x axis.

Usage

```
rot2eul(X)
```

Arguments

X A rotation matrix which is defined as a product of three elementary rotations mentioned above. Here $\theta_{12}, \theta_{23} \in (-\pi, \pi)$ and $\theta_{13} \in (-\pi/2, \pi/2)$.

Details

Given a rotation matrix X , euler angles are computed by equating each element in X with the corresponding element in the matrix product defined above. This results in nine equations that can be used to find the euler angles.

Value

For a given rotation matrix, there are two equivalent sets of euler angles.

Author(s)

Anamul Sajib <sajibstat@du.ac.bd>.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd>.

References

Green, P. J. and Mardia, K. V. (2006). Bayesian alignment using hierarchical models, with applications in proteins bioinformatics. *Biometrika*, 93(2):235–254.

<http://www.staff.city.ac.uk/~sbbh653/publications/euler.pdf>

See Also[eul2rot](#)**Examples**

```
# three euler angles

theta.12 <- sample( seq(-3, 3, 0.3), 1 )
theta.23 <- sample( seq(-3, 3, 0.3), 1 )
theta.13 <- sample( seq(-1.4, 1.4, 0.3), 1 )

theta.12 ; theta.23 ; theta.13

X <- eul2rot(theta.12, theta.23, theta.13)
X ## A rotation matrix

e <- rot2eul(X)$v1

theta.12 <- e[3]
theta.23 <- e[2]
theta.13 <- e[1]

theta.12 ; theta.23 ; theta.13
```

Forward Backward Early Dropping selection for circular data using
the SPML regression

*Forward Backward Early Dropping selection for circular data using
the SPML regression*

Description

Forward Backward Early Dropping selection for circular data using the SPML regression.

Usage

```
spml.fbed(y, x, alpha = 0.05, K = 0, backward = FALSE,  
          parallel = FALSE, tol = 1e-07, maxiters = 100)
```

Arguments

y	The response variable, a numeric vector expressed in rads.
x	A matrix with continuous independent variables.
alpha	The significance threshold value for assessing p-values. Default value is 0.05.
K	How many times should the process be repeated? The default value is 0.

backward	After the Forward Early Dropping phase, the algorithm proceeds with the usual Backward Selection phase. The default value is set to TRUE. It is advised to perform this step as maybe some variables are false positives, they were wrongly selected. This is rather experimental now and there could be some mistakes in the indices of the selected variables. Do not use it for now.
parallel	If you want the algorithm to run in parallel set this TRUE.
tol	The tolerance value to terminate the Newton-Raphson algorithm.
maxiters	The maximum number of iterations Newton-Raphson will perform.

Details

The algorithm is a variation of the usual forward selection. At every step, the most significant variable enters the selected variables set. In addition, only the significant variables stay and are further examined. The non significant ones are dropped. This goes until no variable can enter the set. The user has the option to re-do this step 1 or more times (the argument K). In the end, a backward selection is performed to remove falsely selected variables. Note that you may have specified, for example, K=10, but the maximum value FBED used can be 4 for example.

Value

If K is a single number a list including: Note, that the "gam" argument must be the same though.

res	A matrix with the selected variables and their test statistic.
info	A matrix with the number of variables and the number of tests performed (or models fitted) at each round (value of K). This refers to the forward phase only.
runtime	The runtime required.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Borboudakis G. and Tsamardinos I. (2019). Forward-backward selection with early dropping. *Journal of Machine Learning Research*, 20(8): 1–39.

Tsagis M. (2018). Guide on performing feature selection with the R package MXM. <https://f1000research.com/articles/7-1505>

Presnell Brett, Morrison Scott P. and Littell Ramon C. (1998). Projected multivariate linear models for directional data. *Journal of the American Statistical Association*, 93(443): 1068–1077.

See Also

[spml.reg](#), [spml.regs](#), [spml.mle](#)

Examples

```
x <- matrix( runif(100 * 50, 1, 100), ncol = 50 )
y <- runif(100)
a <- spml.fbed(y, x)
```

```
Generate random folds for cross-validation
Generate random folds for cross-validation
```

Description

Random folds for use in a cross validation are generated. There is the option for stratified splitting as well.

Usage

```
makefolds(ina, nfolds = 10, stratified = TRUE, seed = NULL)
```

Arguments

<code>ina</code>	A variable indicating the groupings.
<code>nfolds</code>	The number of folds to produce.
<code>stratified</code>	A boolean variable specifying whether stratified random (TRUE) or simple random (FALSE) sampling is to be used when producing the folds.
<code>seed</code>	You can specify your own seed number here or leave it NULL.

Details

I was inspired by the command in the package **TunePareto** in order to do the stratified version.

Value

A list with `nfolds` elements where each element is a fold containing the indices of the data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

See Also

[dirda.cv](#)

Examples

```
a <- makefolds(iris[, 5], nfolds = 5, stratified = TRUE)
table(iris[a[[1]], 5]) ## 10 values from each group
```

Generation of unit vector(s) with a given angle
Generation of unit vector(s) with a given angle

Description

Generation of unit vector(s) with a given angle from a given unit vector.

Usage

```
vec(x, n = 1, deg = 90)
```

Arguments

x	A unit vector. If it is not a unit vector it becomes one.
n	The number of unit vectors to return.
deg	The angle between the given vector and the n vectors to be returned. This must be in degrees and it has to be between 0 and 180 degrees. If the angle is 0, the same unit vector will be returned. If the angle is 180, the same unit vector with the signs changed will be returned.

Details

The user provides a unit vector and the degrees. The function will return n unit vectors whose angle with the given unit vector equals the degrees given. For example, if you want 10 unit vectors perpendicular to the x put `vec(x, 10, 90)`.

Value

A list including:

runtime	The runtime of the procedure.
crit	The calculated angle between the given unit vector and each of the generated unit vectors.
mat	A matrix with the n unit vectors.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

See Also

[rvmf](#), [rbingham](#), [rfb](#)

Examples

```
x <- rnorm(10)
x <- x / sqrt( sum(x^2) )
a <- vec(x, 20, 90)
```

Goodness of fit test for grouped data

Goodness of fit test for grouped data

Description

Goodness of fit test for grouped data.

Usage

```
group.gof(g, ni, m, k, dist = "vm", rads = FALSE, R = 999, ncores = 1)
```

Arguments

<code>g</code>	A vector with the group points, either in radians or in degrees.
<code>ni</code>	The frequency of each or group class.
<code>m</code>	The mean direction in radians or in degrees.
<code>k</code>	The concentration parameter, κ .
<code>dist</code>	The distribution to be tested, it can be either "vm" or "uniform".
<code>rads</code>	If the data are in radians, this should be TRUE and FALSE otherwise.
<code>R</code>	The number of bootstrap simulations to perform, set to 999 by default.
<code>ncores</code>	The number of cores to use.

Details

When you have grouped data, you can test whether the data come from the von Mises-Fisher distribution or from a uniform distribution.

Value

This is an "hstest" class object. Thus it returns a list including:

<code>statistic</code>	The test statistic value.
<code>parameter</code>	Since this is a bootstrap based test, there are no degrees of freedom, hence this is "NA".
<code>p.value</code>	The p-value of the test.
<code>alternative</code>	A character with the alternative hypothesis.
<code>method</code>	A character with the test used.
<code>data.name</code>	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Arthur Pewsey, Markus Neuhauser, and Graeme D. Ruxton (2013). Circular Statistics in R.

See Also

[pvm](#), [circ.summary](#), [rvonmises](#)

Examples

```
x <- rvonmises(100, 2, 10)
g <- seq(min(x) - 0.1, max(x) + 0.1, length = 6)
ni <- as.vector( table( cut(x, g) ) )
group.gof(g, ni, 2, 10, dist = "vm", rads = TRUE, R = 299, ncores = 1)
group.gof(g, ni, 2, 5, dist = "vm", rads = TRUE, R = 299, ncores = 1)
```

Habeck's rotation matrix generation

Generation of three-dimensional random rotations using Habeck's algorithm.

Description

It generates random rotations in three-dimensional space that follow a probability distribution, matrix Fisher distribution, arising in fitting and matching problem.

Usage

```
habeck.rot(F)
```

Arguments

F An arbitrary 3 x 3 matrix represents the parameter matrix of this distribution.

Details

Firstly rotation matrices \mathbf{X} are chosen which are the closest to F, and then parameterized using euler angles. Then a Gibbs sampling algorithm is implemented to generate rotation matrices from the resulting distribution of the euler angles.

Value

A simulated rotation matrix.

Author(s)

Anamul Sajib.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd>.

References

Habeck M (2009). Generation of three-dimensional random rotations in fitting and matching problems. *Computational Statistics*, 24, 719–731.

Examples

```
F <- 10^(-1) * matrix( c(85, 11, 41, 78, 39, 60, 43, 64, 48), ncol = 3 ) ## Arbitrary F matrix
X <- habeck.rot(F)
det(X)
```

Haversine distance matrix

Havesine distance matrix

Description

Haversine distance matrix.

Usage

```
haversine.dist(x)
```

Arguments

x A a matrix of two columns. The first column is the latitude and the second the longitude.

Details

The function computes the haversine distance between all observations.

Value

A matrix with the haversine distances between all observations.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

https://en.wikipedia.org/wiki/Haversine_formula

See Also[cosnn](#), [dirknn](#)**Examples**

```
x <- rvmf(10, rnorm(3), 10)
x <- euclid.inv(x)
haversine.dist(x)
```

Hypothesis test for IAG distribution over the ESAG distribution

Hypothesis test for IAG distribution over the ESAG distribution

Description

The null hypothesis is whether an IAG distribution fits the data well, where the alternative is that ESAG distribution is more suitable.

Usage

```
iagesag(x, B = 1, tol = 1e-07)
```

Arguments

<code>x</code>	A numeric matrix with three columns containing the data as unit vectors in Euclidean coordinates.
<code>B</code>	The number of bootstrap re-samples. By default is set to 999. If it is equal to 1, no bootstrap is performed and the p-value is obtained through the asymptotic distribution.
<code>tol</code>	The tolerance to accept that the Newton-Raphson algorithm used in the IAG distribution has converged.

Details

Essentially it is a test of rotational symmetry, whether the two γ parameters are equal to zero. This works for spherical data only.

Value

This is an "hstest" class object. Thus it returns a list including:

<code>statistic</code>	The test statistic value.
<code>parameter</code>	The degrees of freedom of the test. If bootstrap was employed this is "NA".
<code>p.value</code>	The p-value of the test.
<code>alternative</code>	A character with the alternative hypothesis.
<code>method</code>	A character with the test used.
<code>data.name</code>	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3):689–697.

See Also

[fishkent](#), [iagesag](#), [pc.test](#), [esag.mle](#), [kent.mle](#),

Examples

```
x <- rvmf(100, rnorm(3), 15)
iagesag(x)
fishkent(x, B = 1)
```

Hypothesis test for SIPC distribution over the SESPC distribution

Hypothesis test for SIPC distribution over the SESPC distribution

Description

The null hypothesis is whether an SIPC distribution fits the data well, where the alternative is that SESPC distribution is more suitable.

Usage

```
pc.test(x, B = 1, tol = 1e-06)
```

Arguments

x	A numeric matrix with three columns containing the data as unit vectors in Euclidean coordinates.
B	The number of bootstrap re-samples. By default is set to 999. If it is equal to 1, no bootstrap is performed and the p-value is obtained through the asymptotic distribution.
tol	The tolerance to accept that the Newton-Raphson algorithm used in the IAG distribution has converged.

Details

Essentially it is a test of rotational symmetry, whether the two θ parameters are equal to zero. This works for spherical data only.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. If bootstrap was employed this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

See Also

[iagesag](#), [fishkent](#), [sespc.mle](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
iagesag(x)
pc.test(x)
```

Hypothesis test for von Mises-Fisher distribution over Kent
distribution

*Hypothesis test for von Mises-Fisher distribution over Kent distribu-
tion*

Description

The null hypothesis is whether a von Mises-Fisher distribution fits the data well, where the alternative is that Kent distribution is more suitable.

Usage

```
fishkent(x, B = 999)
```

Arguments

x	A numeric matrix containing the data as unit vectors in Euclidean coordinates.
B	The number of bootstrap re-samples. By default is set to 999. If it is equal to 1, no bootstrap is performed and the p-value is obtained through the asymptotic distribution.

Details

Essentially it is a test of rotational symmetry, whether Kent's ovalness parameter (β) is equal to zero. This works for spherical data only.

Value

This is an "hstest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. If bootstrap was employed this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Rivest L. P. (1986). Modified Kent's statistics for testing goodness of fit for the Fisher distribution in small concentrated samples. *Statistics & Probability Letters*, 4(1): 1–4.

See Also

[iagesag](#), [pc.test](#), [vmf.mle](#), [kent.mle](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
fishkent(x)
fishkent(x, B = 1)
iagesag(x)
```

Interactive 3D plot of spherical data
Interactive 3D plot of spherical data

Description

Interactive 3D plot of spherical data.

Usage

```
sphereplot(dat, col = NULL, bgcol = "snow")
```

Arguments

<code>dat</code>	A matrix with three columns, unit-vectors, spherical data.
<code>col</code>	If you want the points to appear with different colours put numbers here, otherwise leave it NULL.
<code>bgcol</code>	The color of the surface of the sphere.

Value

An interactive 3D plot of the spherical data will appear.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

See Also

[lambert](#), [vmf.contour](#), [euclid](#)

Examples

```
x <- rvmf(100, rnorm(3), 5)
sphereplot(x)
```

Inverse of Lambert's equal area projection
Inverse of Lambert's equal area projection

Description

It takes some points from the cartesian coordinates and maps them onto the sphere. The inverse of the Lambert's equal area projection.

Usage

```
lambert.inv(z, mu)
```

Arguments

z	A two- column matrix containing the Lambert's equal area projected data.
mu	The mean direction of the data on the sphere.

Details

The data are first mapped on the sphere with mean direction equal to the north pole. Then, they are rotated to have the given mean direction. It is the inverse of the Lambert's equal area projection.

Value

A matrix containing spherical data (unit vectors).

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kent, John T. (1982). The Fisher-Bingham distribution on the sphere. *Journal of the Royal Statistical Society. Series B (Methodological)* 44(1):71–80.

See Also

[lambert](#)

Examples

```
m <- rnorm(3)
m <- m / sqrt( sum(m^2) )
x <- rvmf(20, m, 19)
mu <- vmf.mle(x)$mu
y <- lambert( euclid.inv(x) )
lambert.inv(y, mu)
euclid.inv(x)
```

Inverse of the Euclidean transformation

Inverse of the Euclidean transformation

Description

It transforms the data from the Euclidean coordinates to latitude and longitude.

Usage

```
euclid.inv(U)
```

Arguments

U A matrix of unit vectors, or even one single unit vector in three dimensions.

Details

It takes the matrix of unit vectors and back transforms it to latitude and longitude.

Value

A two column matrix:

u The first column is the latitude and the second is the longitude, both expressed in degrees.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

See Also

[euclid](#), [Arotation](#), [lambert](#)

Examples

```
x <- rvmf(10, rnorm(3), 10)
euclid.inv(x)
euclid( euclid.inv(x) )
x
```

k-NN algorithm using the arc cosinus distance

k-NN algorithm using the arc cosinus distance

Description

It classifies new observations to some known groups via the k-NN algorithm.

Usage

```
dirknn(xnew, ina, x, k = 5, mesos = TRUE, parallel = FALSE, rann = FALSE)
```

Arguments

xnew	The new data whose membership is to be predicted, a numeric matrix with unit vectors.
ina	A variable indicating the groups of the data x.
x	The data, a numeric matrix with unit vectors.
k	The number of nearest neighbours, set to 5 by default. It can also be a vector with many values.
mesos	A boolean variable used only in the case of the non standard algorithm (type="NS"). Should the average of the distances be calculated (TRUE) or not (FALSE)? If it is FALSE, the harmonic mean is calculated.
parallel	If you want the standard -NN algorithm to take place in parallel set this equal to TRUE.
rann	If you have large scale datasets and want a faster k-NN search, you can use kd-trees implemented in the R package "RANN". In this case you must set this argument equal to TRUE.

Details

The standard algorithm is to keep the k nearest observations and see the groups of these observations. The new observation is allocated to the most frequent seen group. The non standard algorithm is to calculate the classical mean or the harmonic mean of the k nearest observations for each group. The new observation is allocated to the group with the smallest mean distance.

Value

A vector including:

g A matrix with the predicted group(s). It has as many columns as the values of k.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4), 467–491.

See Also

[dirknn.tune](#), [vmfda.pred](#), [mixvmf.mle](#)

Examples

```
k <- runif(4, 4, 20)
prob <- c(0.2, 0.4, 0.3, 0.1)
mu <- matrix(rnorm(16), ncol = 4)
mu <- mu / sqrt( rowSums(mu^2) )
da <- rmixvmf(200, prob, mu, k)
nu <- sample(1:200, 180)
x <- da$x[nu, ]
ina <- da$id[nu]
xx <- da$x[-nu, ]
id <- da$id[-nu]
a1 <- dirknn(xx, ina, x, k = 5, mesos = TRUE)
a2 <- dirknn(xx, ina, x, k = 5, mesos = FALSE)
b <- vmfda.pred(xx, x, ina)
table(id, a1)
table(id, a2)
```

k-NN regression

k-NN regression with Euclidean or (hyper-)spherical response and or predictor variables

Description

k-NN regression with Euclidean or (hyper-)spherical response and or predictor variables.

Usage

```
knn.reg(xnew, y, x, k = 5, res = "eucl", estim = "arithmetic")
```

Arguments

<code>xnew</code>	The new data, new predictor variables values. A matrix with either euclidean (univariate or multivariate) or (hyper-)spherical data. If you have a circular response, say u , transform it to a unit vector via $(\cos(u), \sin(u))$. If $xnew = x$, you will get the fitted values.
<code>y</code>	The currently available data, the response variables values. A matrix with either euclidean (univariate or multivariate) or (hyper-)spherical data. If you have a circular response, say u , transform it to a unit vector via $(\cos(u), \sin(u))$.
<code>x</code>	The currently available data, the predictor variables values. A matrix with either euclidean (univariate or multivariate) or (hyper-)spherical data. If you have a circular response, say u , transform it to a unit vector via $(\cos(u), \sin(u))$.
<code>k</code>	The number of nearest neighbours, set to 5 by default. This can also be a vector with many values.
<code>res</code>	The type of the response variable. If it is Euclidean, set this argument equal to "res". If it is a unit vector set it to <code>res="spher"</code> .
<code>estim</code>	Once the k observations with the smallest distance are discovered, what should the prediction be? The arithmetic average of the corresponding y values be used <code>estim="arithmetic"</code> or their harmonic average <code>estim="harmonic"</code> .

Details

This function covers a broad range of data, Euclidean and spherical, along with their combinations.

Value

A list with as many elements as the number of values of k . Each element in the list contains a matrix (or a vector in the case of Euclidean data) with the predicted response values.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

See Also

[knnreg.tune](#), [spher.reg](#), [spml.reg](#)

Examples

```

y <- iris[, 1]
x <- as.matrix(iris[, 2:4])
x <- x / sqrt( rowSums(x^2) ) ## Euclidean response
a <- knn.reg(x, y, x, k = 5, res = "eucl", estim = "arithmetic")

y <- iris[, 2:4]
y <- y / sqrt( rowSums(y^2) ) ## Spherical response
x <- iris[, 1]
a <- knn.reg(x, y, x, k = 5, res = "spher", estim = "arithmetic")

```

Lambert's equal area projection
Lambert's equal area projection

Description

It calculates the Lambert's equal area projection.

Usage

```
lambert(y)
```

Arguments

`y` A two column matrix with the data. The first column is the altitude and the second is the longitude.

Details

The spherical data are first rotated so that their mean direction is the north pole and then are projected on the plane tangent to the sphere at the north pole.

Value

A two-column matrix with the projected points.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kent, John T. (1982). The Fisher-Bingham distribution on the sphere. Journal of the Royal Statistical Society. Series B (Methodological) 44(1):71-80.

See Also

[euclid](#), [lambert.inv](#)

Examples

```
x <- rvmf(100, rnorm(3), 20)
x <- euclid.inv(x)
a <- lambert(x)
plot(a)
```

Logarithm of the Kent distribution normalizing constant
Logarithm of the Kent distribution normalizing constant

Description

Logarithm of the Kent distribution normalizing constant.

Usage

```
kent.logcon(k, b, j = 100)
```

Arguments

k	The concentration parameter, κ .
b	The ovalness parameter, β .
j	The number of the terms in the sum to use. By default this is 100.

Details

It calculates logarithm of the normalising constant of the Kent distribution.

Value

The value of the logarithm of the normalising constant of the Kent distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kent John (1982). The Fisher-Bingham distribution on the sphere. Journal of the Royal Statistical Society, Series B, 44(1): 71–80.

See Also

[fb.saddle](#), [kent.mle](#)

Examples

```
kent.logcon(10, 2)
fb.saddle( c(0, 10, 0), c(0, -2, 2) )
```

Many simple circular or angular regressions
Many simple circular or angular regressions

Description

Many regressions with one circular dependent variable and one Euclidean independent variable.

Usage

```
spml.regs(y, x, tol = 1e-07, logged = FALSE, maxiters = 100, parallel = FALSE)
```

Arguments

y	The dependent variable, it can be a numerical vector with data expressed in radians or it can be a matrix with two columns, the cosinus and the sinus of the circular data. The benefit of the matrix is that if the function is to be called multiple times with the same response, there is no need to transform the vector every time into a matrix.
x	A matrix with independent variable.
tol	The tolerance value to terminate the Newton-Raphson algorithm.
logged	Do you want the logarithm of the p-value be returned? TRUE or FALSE.
maxiters	The maximum number of iterations to implement.
parallel	Do you want the calculations to take place in parallel? The default value is FALSE.

Details

The Newton-Raphson algorithm is fitted in these regression as described in Presnell et al. (1998). For each column of x a circular regression model is fitted and the hypothesis testing of no association between y and this variable is performed.

Value

A matrix with two columns, the test statistics and their associated (log) p-values.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Presnell Brett, Morrison Scott P. and Littell Ramon C. (1998). Projected multivariate linear models for directional data. *Journal of the American Statistical Association*, 93(443): 1068–1077.

See Also

[spml.reg](#), [spml.mle](#), [iag.mle](#)

Examples

```
x <- rnorm(200)
z <- cbind(3 + 2 * x, 1 -3 * x)
y <- cbind( rnorm(100,z[, 1], 1), rnorm(100, z[, 2], 1) )
y <- y / sqrt( rowSums(y^2) )
x <- matrix( rnorm(100 * 50), ncol = 50 )
a <- Directional::spml.regs(y, x)
x <- NULL
```

Maps of the world and the continents

maps of the world and the continents

Description

It produces maps of the world and the continents.

Usage

```
asia(title = "Asia", coords = NULL)
africa(title = "Africa", coords = NULL)
europe(title = "Europe", coords = NULL)
north.america(title = "North America", coords = NULL)
oceania(title = "Oceania", coords = NULL)
south.america(title = "South America", coords = NULL)
worldmap(title = "World map", coords = NULL)
```

Arguments

<code>title</code>	A character vector with the title of the map.
<code>coords</code>	If you want specific points to appear on the plot give the coordinates as a matrix, where the first column contains the longitude and the second column contains the latitude, in degrees.

Details

Maps of the world or the continents are produced. This are experimental functions and plot the countries with specific colouring at the moment. More functionalities will be added in the future.

Value

A map of the selected continent or the whole world.

Author(s)

Christos Adam.

R implementation and documentation: Christos Adam <pada4m4@gmail.com> and Michail Tsagris.

See Also

[sphereplot](#)

Examples

```
x <- euclid.inv( rvmf(10, rnorm(3), 5) )
```

Mixtures of Von Mises-Fisher distributions

Mixtures of Von Mises-Fisher distributions

Description

It performs model based clustering for circular, spherical and hyperspherical data assuming von Mises-Fisher distributions.

Usage

```
mixvmf.mle(x, g, n.start = 10)
```

Arguments

x	A matrix with the data expressed as unit vectors.
g	The number of groups to fit. It must be greater than or equal to 2.
n.start	The number of random starts to try. See also R's built-in function kmeans for more information about this.

Details

The initial step of the algorithm is not based on a spherical k-means, but on simple k-means. The results are comparable to the package `movMF`.

Value

A list including:

param	A matrix with the mean direction, the concentrations parameter and mixing probability of each group.
loglik	The value of the maximised log-likelihood.
pred	The predicted group of each observation.
iter	The number of iteration required by the EM algorithm.

runtime The run time of the algorithm. A numeric vector. The first element is the user time, the second element is the system time and the third element is the elapsed time.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Kurt Hornik and Bettina Grün (2014). movMF: An R Package for Fitting Mixtures of von Mises-Fisher Distributions <http://cran.r-project.org/web/packages/movMF/vignettes/movMF.pdf>

See Also

[rmixvmf](#), [bic.mixvmf](#), [mixvmf.contour](#)

Examples

```
k <- runif(4, 4, 6)
prob <- c(0.2, 0.4, 0.3, 0.1)
mu <- matrix(rnorm(16), ncol = 4)
mu <- mu / sqrt( rowSums(mu^2) )
x <- rmixvmf(200, prob, mu, k)$x
mixvmf.mle(x, 3)
mixvmf.mle(x, 4)
mixvmf.mle(x, 5)
```

MLE of (hyper-)spherical rotationally symmetric distributions

MLE of (hyper-)spherical rotationally symmetric distributions

Description

MLE of (hyper-)spherical rotationally symmetric distributions.

Usage

```
vmf.mle(x, fast = FALSE, tol = 1e-07)
multivmf.mle(x, ina, tol = 1e-07, ell = FALSE)
iag.mle(x, tol = 1e-07)
spcauchy.mle(x, tol = 1e-06)
spcauchy.mle2(x, tol = 1e-06)
sipc.mle(x, tol = 1e-6)
pkbd.mle(x, tol = 1e-6)
acg.mle(x, tol = 1e-07)
```

Arguments

<code>x</code>	A matrix with directional data, i.e. unit vectors.
<code>fast</code>	IF you want a faster version, but with fewer information returned, set this equal to TRUE.
<code>ina</code>	A numerical vector with discrete numbers starting from 1, i.e. 1, 2, 3, 4,... or a factor variable. Each number denotes a sample or group. If you supply a continuous valued vector the function will obviously provide wrong results.
<code>ell</code>	This is for the <code>multivmf.mle</code> only. Do you want the log-likelihood returned? The default value is TRUE.
<code>tol</code>	The tolerance value at which to terminate the iterations.

Details

The `vmf.mle()` estimates the mean direction and concentration of a fitted von Mises-Fisher distribution.

The von Mises-Fisher distribution for groups of data is also implemented.

The `acg.mle()` fits the angular central Gaussian distribution. There is a constraint on the estimated covariance matrix; its trace is equal to the number of variables. An iterative algorithm takes place and convergence is guaranteed.

The `iag.mle()` implements MLE of the spherical projected normal distribution, for spherical data only.

The `spcauchy.mle()` is faster than the `spcauchy.mle()` because it employs the Newton-Raphson algorithm.

The `spcauchy.mle2()` estimates the parameters of the spherical Cauchy distribution, for any dimension. Despite the name sounds confusing, it is implemented for arbitrary dimensions, not only the sphere. The function employs a combination of the fixed points iteration algorithm and the Brent algorithm.

The `pkbd.mle()` estimates the parameters of the Poisson kernel based distribution (PKBD), for any dimension.

The `sipc.mle()` implements MLE of the spherical independent projected Cauchy distribution, for spherical data only.

Value

For the von Mises-Fisher a list including:

<code>loglik</code>	The maximum log-likelihood value.
<code>mu</code>	The mean direction.
<code>kappa</code>	The concentration parameter.

For the multi von Mises-Fisher a list including:

<code>loglik</code>	A vector with the maximum log-likelihood values if <code>ell</code> is set to TRUE. Otherwise NULL is returned.
<code>mi</code>	A matrix with the group mean directions.

`ki` A vector with the group concentration parameters.

For the angular central Gaussian a list including:

`iter` The number of iterations required by the algorithm to converge to the solution.

`cova` The estimated covariance matrix.

For the spherical projected normal a list including:

`iters` The number of iteration required by the Newton-Raphson.

`mesi` A matrix with two rows. The first row is the mean direction and the second is the mean vector. The first comes from the second by normalising to have unit length.

`param` A vector with the elements, the norm of mean vector, the log-likelihood and the log-likelihood of the spherical uniform distribution. The third value helps in case you want to do a log-likelihood ratio test for uniformity.

For the spherical Cauchy and the PKBD a list including:

`mesos` The mean in R^{d+1} . See Tsagris and Alenazy (2023) for a re-parametrization that applies in the spherical Cauchy also.

`mu` The mean direction.

`gamma` The norm of the mean in R^{d+1} . See Tsagris and Alenazy (2023) for a re-parametrization that applies in the spherical Cauchy also.

`rho` The concentration parameter, this takes values in $[0, 1)$.

`loglik` The log-likelihood value.

For the SIPC a list including:

`mu` The mean direction.

`loglik` The log-likelihood value.

For the angular central Gaussian a list including:

`iter` The number of iterations performed.

`cova` The covariance matrix.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
- Sra S. (2012). A short note on parameter approximation for von Mises-Fisher distributions: and a fast implementation of $I_s(x)$. Computational Statistics, 27(1): 177–190.
- Tyler D. E. (1987). Statistical analysis for the angular central Gaussian distribution on the sphere. Biometrika 74(3): 579–589.
- Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. Statistics and Computing, 28: 689–697.
- Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>
- Kato S. and McCullagh P. (2020). Some properties of a Cauchy family on the sphere derived from the Mobius transformations. Bernoulli, 26(4): 3224–3248. <https://arxiv.org/pdf/1510.07679.pdf>
- Golzy M. and Markatou M. (2020). Poisson kernel-based clustering on the sphere: convergence properties, identifiability, and a method of sampling. Journal of Computational and Graphical Statistics, 29(4): 758–770.
- Sablica L., Hornik K. and Leydold J. (2023). Efficient sampling from the PKBD distribution. Electronic Journal of Statistics, 17(2): 2180–2209.

See Also

[racg](#), [rvmf](#)

Examples

```
m <- c(0, 0, 0, 0)
s <- cov(iris[, 1:4])
x <- racg(100, s)
mod <- acg.mle(x)
mod
cov2cor(mod$cova) ## estimated covariance matrix turned into a correlation matrix
cov2cor(s) ## true covariance matrix turned into a correlation matrix
vmf.mle(x)
x <- rbind( rvmf(100,rnorm(4), 10), rvmf(100,rnorm(4), 20) )
a <- multivmf.mle(x, rep(1:2, each = 100) )
```

MLE of some circular distributions

MLE of some circular distributions

Description

MLE of some circular distributions.

Usage

```

spml.mle(x, rads = FALSE, tol = 1e-07)
wrapcauchy.mle(x, rads = FALSE, tol = 1e-07)
circexp.mle(x, rads = FALSE, tol = 1e-06)
circbeta.mle(x, rads = FALSE)
cardio.mle(x, rads = FALSE)
ggvm.mle(phi, rads = FALSE)
cipc.mle(x, rads = FALSE, tol = 1e-6)
gcpc.mle(x, rads = FALSE)
mmvm.mle(x, N, rads = FALSE)

```

Arguments

x	A numerical vector with the circular data. They can either be expressed in radians or in degrees.
phi	A numerical vector with the circular data. They can either be expressed in radians or in degrees.
N	The number of modes to consider in the multi-modal von Mises distribution.
rads	If the data are in radians set this to TRUE.
tol	The tolerance level to stop the iterative process of finding the MLEs.

Details

The parameters of the bivariate angular Gaussian (spml.mle), wrapped Cauchy, circular exponential, cardioid, circular beta, geometrically generalised von Mises, CIPC (reparametrised version of the wrapped Cauchy), GCPC (generalisation of the CIPC) and multi-modal von Mises distributions are estimated. For the Wrapped Cauchy, the iterative procedure described by Kent and Tyler (1988) is used. The Newton-Raphson algorithm for the angular Gaussian is described in the regression setting in Presnell et al. (1998). The circular exponential is also known as wrapped exponential distribution.

Value

A list including:

iters	The iterations required until convergence.
loglik	The value of the maximised log-likelihood.
param	A vector consisting of the estimates of the two parameters, the mean direction for both distributions and the concentration parameter $kappa$ and the rho for the von Mises (and the multi-modal von Mises) and wrapped Cauchy respectively. For the circular beta this contains the mean angle and the α and β parameters. For the cardioid distribution this contains the μ and rho parameters. For the generalised von Mises this is a vector consisting of the ζ , κ , μ and α parameters of the generalised von Mises distribution as described in Equation (2.7) of Dietrich and Richter (2017).
gamma	The norm of the mean vector of the angular Gaussian, the CIPC and the GCPC distributions.

mu	The mean vector of the angular Gaussian, the CIPC and the GCPC distributions.
mumu	In the case of "angular Gaussian distribution this is the mean angle in radians.
circmu	In the case of the CIPC and the GCPC this is the mean angle in radians.
rho	For the GCPC distribution this is the eigenvalue of the covariance matrix, or the covariance determinant.
lambda	The lambda parameter of the circular exponential distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.
- Sra S. (2012). A short note on parameter approximation for von Mises-Fisher distributions: and a fast implementation of $I_s(x)$. Computational Statistics, 27(1): 177–190.
- Presnell Brett, Morrison Scott P. and Littell Ramon C. (1998). Projected multivariate linear models for directional data. Journal of the American Statistical Association, 93(443): 1068–1077.
- Kent J. and Tyler D. (1988). Maximum likelihood estimation for the wrapped Cauchy distribution. Journal of Applied Statistics, 15(2): 247–254.
- Dietrich T. and Richter W. D. (2017). Classes of geometrically generalized von Mises distributions. Sankhya B, 79(1): 21–59.
- https://en.wikipedia.org/wiki/Wrapped_exponential_distribution
- Jammalamadaka S. R. and Kozubowski T. J. (2003). A new family of circular models: The wrapped Laplace distributions. Advances and Applications in Statistics, 3(1), 77-103.
- Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>
- Barnett M. J. and Kingston R. L. (2024). A note on the Hendrickson-Lattman phase probability distribution and its equivalence to the generalized von Mises distribution. Journal of Applied Crystallography, 57(2).

See Also

[circ.summary](#), [purka.mle](#), [rvonmises](#), [vmf.mle](#), [rvmf](#)

Examples

```
x <- rvonmises(1000, 3, 9)
spml.mle(x, rads = TRUE)
wrapcauchy.mle(x, rads = TRUE)
circexp.mle(x, rads = TRUE)
ggvm.mle(x, rads = TRUE)
```

MLE of some circular distributions with multiple samples

MLE of some circular distributions with multiple samples

Description

MLE of some circular distributions with multiple samples.

Usage

```
multivm.mle(x, ina, tol = 1e-07, ell = FALSE)
multispml.mle(x, ina, tol = 1e-07, ell = FALSE)
```

Arguments

x	A numerical vector with the circular data. They must be expressed in radians. For the "spml.mle" this can also be a matrix with two columns, the cosine and the sine of the circular data.
ina	A numerical vector with discrete numbers starting from 1, i.e. 1, 2, 3, 4,... or a factor variable. Each number denotes a sample or group. If you supply a continuous valued vector the function will obviously provide wrong results.
tol	The tolerance level to stop the iterative process of finding the MLEs.
ell	Do you want the log-likelihood returned? The default value is FALSE.

Details

The parameters of the von Mises and of the bivariate angular Gaussian distributions are estimated for multiple samples.

Value

A list including:

iters	The iterations required until convergence. This is returned in the wrapped Cauchy distribution only.
loglik	A vector with the value of the maximised log-likelihood for each sample.
mi	For the von Mises, this is a vector with the means of each sample. For the angular Gaussian (spml), a matrix with the mean vector of each sample
ki	A vector with the concentration parameter of the von Mises distribution at each sample.
gi	A vector with the norm of the mean vector of the angular Gaussian distribution at each sample.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
- Sra S. (2012). A short note on parameter approximation for von Mises-Fisher distributions: and a fast implementation of $I_s(x)$. Computational Statistics, 27(1): 177–190.
- Presnell Brett, Morrison Scott P. and Littell Ramon C. (1998). Projected multivariate linear models for directional data. Journal of the American Statistical Association, 93(443): 1068–1077.
- Kent J. and Tyler D. (1988). Maximum likelihood estimation for the wrapped Cauchy distribution. Journal of Applied Statistics, 15(2): 247–254.

See Also

[colspml.mle](#), [purka.mle](#)

Examples

```
y <- rcauchy(100, 3, 1)
x <- y
ina <- rep(1:2, 50)
multivm.mle(x, ina)
multispml.mle(x, ina)
```

MLE of the ESAG distribution

MLE of the ESAG distribution

Description

MLE of the ESAG distribution.

Usage

```
esag.mle(y, full = FALSE, tol = 1e-06)
```

Arguments

<code>y</code>	A matrix with the data expressed in Euclidean coordinates, i.e. unit vectors.
<code>full</code>	If you want some extra information, the inverse of the covariance matrix, the <i>rho</i> parameter (smallest eigenvalue of the covariance matrix) and the angle of rotation ψ , set this equal to TRUE. Otherwise leave it FALSE.
<code>tol</code>	A tolerance value to stop performing successive optimizations.

Details

MLE of the MLE of the ESAG distribution, on the sphere, is implemented. ESAG stands for Elliptically Symmetric Angular Gaussian and it was suggested by Paine et al. (2018). Unlike the projected normal distribution this is rotationally symmetric and is a competitor of the spherical Kent distribution (which is also elliptically symmetric).

Value

A list including:

mu	The mean vector in R^3 .
gam	The two γ parameters.
loglik	The log-likelihood value.
vinv	The inverse of the covariance matrix. It is returned if the argument "full" is TRUE.
rho	The <i>rho</i> parameter (smallest eigenvalue of the covariance matrix). It is returned if the argument "full" is TRUE.
psi	The angle of rotation ψ set this equal to TRUE. It is returned if the argument "full" is TRUE.
iag.loglik	The log-likelihood value of the isotropic angular Gaussian distribution. That is, the projected normal distribution which is rotationally symmetric.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3):689–697.

Mardia, K. V. and Jupp, P. E. (2000). *Directional statistics*. Chichester: John Wiley & Sons.

See Also

[desag](#), [resag](#), [iag.mle](#), [kent.mle](#), [acg.mle](#), [circ.summary](#), [sphereplot](#)

Examples

```
m <- colMeans( as.matrix( iris[,1:3] ) )
y <- resag(1000, m, c(1,0.5) )
esag.mle(y)
```

MLE of the Kent distribution

MLE of the Kent distribution

Description

It estimates the concentration and the ovalness parameter of some directional data assuming the Kent distribution. The mean direction and major and minor axes are also estimated.

Usage

```
kent.mle(x)
```

Arguments

`x` A matrix containing spherical data in Euclidean coordinates.

Details

The Kent distribution is fitted to some data and its parameters are estimated.

Value

A list including:

<code>runtime</code>	The run time of the procedure.
<code>G</code>	A 3 x 3 matrix whose first column is the mean direction. The second and third columns are the major and minor axes respectively.
<code>param</code>	A vector with the concentration κ and ovalness β parameters and the angle ψ used to rotate H and hence estimate G as in Kent (1982).
<code>logcon</code>	The logarithm of the normalising constant, using the third type approximation (Kume and Wood, 2005).
<code>loglik</code>	The value of the log-likelihood.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kent John (1982). The Fisher-Bingham distribution on the sphere. *Journal of the Royal Statistical Society, Series B*, 44(1): 71–80.

Kume Alfred and Wood Andrew T.A. (2005). Saddlepoint approximations for the Bingham and Fisher-Bingham normalizing constants. *Biometrika*, 92(2):465–476

See Also

[kent.mle](#), [fb.saddle](#), [vmf.mle](#), [wood.mle](#), [sphereplot](#)

Examples

```
x <- rvmf(200, rnorm(3), 15)
kent.mle(x)
vmf.mle(x)
A <- diag( c(-5, 0, 5) )
x <- rfb(200, 15, rnorm(3), A)
```

```
kent.mle(x)
vmf.mle(x)
```

MLE of the Matrix Fisher distribution on $SO(3)$

MLE of the Matrix Fisher distribution on $SO(3)$

Description

It returns the maximum likelihood estimate of the Matrix Fisher parameter $F(3 \times 3)$.

Usage

```
matrixfisher.mle(X)
```

Arguments

`X` An array containing rotation matrices in $SO(3)$.

Value

The components of $svd(\bar{X})$.

Author(s)

Anamul Sajib and Chris Fallaize.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd> and Chris Fallaize.

References

Prentice M. J. (1986). Orientation statistics without parametric assumptions. *Journal of the Royal Statistical Society. Series B: Methodological* 48(2): 214–222.

See Also

[rmatrixfisher](#)

Examples

```
F <- 10^(-1) * matrix( c(85, 11, 41, 78, 39, 60, 43, 64, 48), ncol = 3 ) ### An arbitrary F matrix
X <- rmatrixfisher(5000, F)
matrixfisher.mle(X)
svd(F)
```

MLE of the Purkayashta distribution
MLE of the Purkayashta distribution

Description

MLE of the Purkayashta distribution.

Usage

```
purka.mle(x, tol = 1e-07)
```

Arguments

x	A numerical vector with data expressed in radians or a matrix with spherical data.
tol	The tolerance value to terminate the Brent algorithm.

Details

MLE of the Purkayastha distribution is performed.

Value

A list including:

theta	The median direction.
circtheta	In case of circular data the circular mean is also returned.
alpha	The concentration parameter.
loglik	The log-likelihood.
alpha.sd	The standard error of the concentration parameter.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70–83.

Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. *Communications in Statistics-Theory and Methods*, 19(6): 1973–1986.

See Also

[circ.cor1](#)

Examples

```
x <- cbind( rnorm(100,1,1), rnorm(100, 2, 1) )
x <- x / sqrt(rowSums(x^2))
purka.mle(x)
```

MLE of the SESPC distribution

MLE of the SESPC distribution

Description

MLE of the SESPC distribution.

Usage

```
sespc.mle(y, full = FALSE, tol = 1e-06)
```

Arguments

<code>y</code>	A matrix with the data expressed in Euclidean coordinates, i.e. unit vectors.
<code>full</code>	If you want some extra information, the inverse of the covariance matrix, set this equal to TRUE. Otherwise leave it FALSE.
<code>tol</code>	A tolerance value to stop performing successive optimizations.

Details

MLE of the SESPC distribution is implemented. SESPC stands for Spherical Elliptically Symmetric Projected Cauchy and it was suggested by Tsagris and Alzeley (2023). Unlike the spherical independent projected Cauchy distribution this is rotationally symmetric and is a competitor of the spherical ESAG and Kent distributions (which are also elliptically symmetric).

Value

A list including:

<code>mu</code>	The mean vector in R^3 .
<code>theta</code>	The two θ parameters.
<code>loglik</code>	The log-likelihood value.
<code>vinv</code>	The inverse of the covariance matrix. It is returned if the argument "full" is TRUE.
<code>lambda</code>	The λ_2 parameter (smallest eigenvalue of the covariance matrix). It is returned if the argument "full" is TRUE.
<code>psi</code>	The angle of rotation ψ set this equal to TRUE. It is returned if the argument "full" is TRUE.
<code>sipc.loglik</code>	The log-likelihood value of the isotropic projected Cuchy distribution, which is rotationally symmetric.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[dsespc](#), [rsespc](#), [sipc.mle](#), [esag.mle](#), [spher.sespc.contour](#)

Examples

```
m <- colMeans( as.matrix( iris[,1:3] ) )  
y <- rsespc(1000, m, c(1,0.5) )  
sespc.mle(y)
```

MLE of the Wood bimodal distribution on the sphere

MLE of the Wood bimodal distribution on the sphere

Description

It estimates the parameters of the Wood bimodal distribution.

Usage

```
wood.mle(y)
```

Arguments

y A matrix containing two columns. The first one is the latitude and the second is the longitude, both expressed in degrees.

Details

The Wood distribution is fitted to some data and its parameters are estimated. It is a bimodal distribution which contains 5 parameters, just like the Kent distribution.

Value

A list including:

info	A 5 x 3 matrix containing the 5 parameters, γ , δ , α , β and κ along with their corresponding 95% confidence intervals all expressed in degrees.
modes	The two axis of the modes of the distribution expressed in degrees.
unitvectors	A 3 x 3 matrix with the 3 unit vectors associated with the γ and δ parameters.
loglik	The value of the log-likelihood.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Wood A.T.A. (1982). A bimodal distribution on the sphere. *Journal of the Royal Statistical Society, Series C*, 31(1): 52–58.

See Also

[kent.mle](#), [esag.mle](#), [vmf.mle](#), [sphereplot](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
x <- euclid.inv(x)
wood.mle(x)
```

Naive Bayes classifiers for circular data

Naive Bayes classifiers for directional data

Description

Naive Bayes classifiers for directional data.

Usage

```
vm.nb(xnew = NULL, x, ina, tol = 1e-07)
spm.nb(xnew = NULL, x, ina, tol = 1e-07)
```

Arguments

xnew	A numerical matrix with new predictor variables whose group is to be predicted. Each column refers to an angular variable.
x	A numerical matrix with observed predictor variables. Each column refers to an angular variable.
ina	A numerical vector with strictly positive numbers, i.e. 1,2,3 indicating the groups of the dataset. Alternatively this can be a factor variable.
tol	The tolerance value to terminate the Newton-Raphson algorithm.

Details

Each column is supposed to contain angular measurements. Thus, for each column a von Mises distribution or an circular angular Gaussian distribution is fitted. The product of the densities is the joint multivariate distribution.

Value

A list including:

mu	A matrix with the mean vectors expressed in radians.
mu1	A matrix with the first set of mean vectors.
mu2	A matrix with the second set of mean vectors.
kappa	A matrix with the kappa parameters for the vonMises distribution or with the norm of the mean vectors for the circular angular Gaussian distribution.
ni	The sample size of each group in the dataset.
est	The estimated group of the xnew observations. It returns a numerical value back regardless of the target variable being numerical as well or factor. Hence, it is suggested that you do <code>"as.numeric(ina)"</code> in order to see what is the predicted class of the new data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

See Also

[vmb.pred](#)

Examples

```
x <- matrix( runif( 100, 0, 1 ), ncol = 2 )
ina <- rbinom(50, 1, 0.5) + 1
a <- vm.nb(x, x, ina)
```

Normalised spatial median for directional data

Normalised spatial median for directional data

Description

Normalised spatial median for directional data.

Usage

```
nsmedian(x, tol = 1e-07)
```

Arguments

x	A matrix with Euclidean data, continuous variables.
tol	A tolerance level to terminate the process.

Details

The spatial median, using a fixed point iterative algorithm, for Euclidean data is calculated. It is a robust location estimate. Then it is normalised to become a unit vector. Generally speaking this might be a better alternative than then [mediandir](#).

Value

A vector with the spatial median.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Ducharme G. R. and Milasevic P. (1987). Spatial median and directional data. *Biometrika*, 74(1), 212-215.

Jyrki Mottonen, Klaus Nordhausen and Hannu Oja (2010). Asymptotic theory of the spatial median. In *Nonparametrics and Robustness in Modern Statistical Inference and Time Series Analysis: A Festschrift in honor of Professor Jana Jureckova*.

T. Karkkainen and S. Ayrano (2005). On computation of spatial median for robust data mining. *Evolutionary and Deterministic Methods for Design, Optimization and Control with Applications to Industrial and Societal Problems, EUROGEN 2005*, R. Schilling, W.Haase, J. Periaux, H. Baier, G. Bugeda (Eds) FLM, Munich. http://users.jyu.fi/~samiayr/pdf/ayramo_eurogen05.pdf

See Also

[mediandir](#)

Examples

```

m <- rnorm(3)
m <- m / sqrt( sum(m^2) )
x <- rvmf(100, m, 10)
nsmedian(x)
mediandir(x)

```

Permutation based 2-sample mean test for (hyper-)spherical data
Permutation based 2-sample mean test for (hyper-)spherical data

Description

Permutation based 2-sample mean test for (hyper-)spherical data.

Usage

```

hcf.perm(x1, x2, B = 999)
lr.perm(x1, x2, B = 999)
hclr.perm(x1, x2, B = 999)
embed.perm(x1, x2, B = 999)
het.perm(x1, x2, B = 999)

```

Arguments

x1	A matrix with the data in Euclidean coordinates, i.e. unit vectors.
x2	A matrix with the data in Euclidean coordinates, i.e. unit vectors.
B	The number of permutations to perform.

Details

The high concentration (`hcf.perm`), log-likelihood ratio (`lr.perm`), high concentration log-likelihood ratio (`hclr.perm`), embedding approach (`embed.perm`) or the non equal concentration parameters approach (`het.perm`) is used.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. Since these are permutation based tests this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.

Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. Australian & New Zealand Journal of Statistics, 59(1), 119–135.

Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. Communications in Statistics-Simulation and Computation, 53(3): 1387–1408.

See Also

[hcf.boot](#), [hcf.aov](#), [spherconc.test](#), [conc.test](#)

Examples

```
x <- rvmf(60, rnorm(3), 15)
ina <- rep(1:2, each = 30)
x1 <- x[ina == 1, ]
x2 <- x[ina == 2, ]
hcf.perm(x1, x2)
lr.perm(x1, x2)
het.boot(x1, x2)
```

Permutation based 2-sample mean test for circular data

Permutation based 2-sample mean test for circular data

Description

Permutation based 2-sample mean test for circular data.

Usage

```
hcfcirc.perm(u1, u2, rads = TRUE, B = 999)
hetcirc.perm(u1, u2, rads = TRUE, B = 999)
lrcirc.perm(u1, u2, rads = TRUE, B = 999)
hclrcirc.perm(u1, u2, rads = TRUE, B = 999)
embedcirc.perm(u1, u2, rads = TRUE, B = 999)
```

Arguments

u1	A numeric vector containing the data of the first sample.
u2	A numeric vector containing the data of the first sample.
rads	If the data are in radians, this should be TRUE and FALSE otherwise.
B	The number of permutations to perform.

Details

The high concentration (`hcfcirc.perm`), log-likelihood ratio (`lrcirc.perm`), high concentration log-likelihood ratio (`hclrcirc.perm`), embedding approach (`embedcirc.perm`) or the non equal concentration parameters approach (`hetcirc.perm`) is used.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. Since these are permutation based tests this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.
- Rumcheva P. and Presnell B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. Australian & New Zealand Journal of Statistics, 59(1): 119–135.
- Tsagris M. and Alenazi A. (2024). An investigation of hypothesis testing procedures for circular and spherical mean vectors. Communications in Statistics-Simulation and Computation, 53(3): 1387–1408.

See Also

[hcf.circaov](#), [het.aov](#)

Examples

```
u1 <- rvonmises(20, 2.4, 5)
u2 <- rvonmises(20, 2.4, 10)
hcfcirc.perm(u1, u2)
lrcirc.perm(u1, u2)
```

Prediction in discriminant analysis based on ESAG distribution

Prediction of a new observation using discriminant analysis based on ESAG distribution

Description

Prediction of a new observation using discriminant analysis based on ESAG distribution.

Usage

```
esagda.pred(ynew, y, ina)
```

Arguments

ynew	The new observation(s) (unit vector(s)) whose group is to be predicted.
y	A data matrix with unit vectors, i.e. spherical directional data.
ina	A vector indicating the groups of the data y.

Details

Prediction of the class of a new spherical vector assuming ESAG distribution.

Value

A vector with the predicted group of each new observation.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4): 467–491.

Paine P.J., Preston S.P. and Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. *Statistics and Computing*, 28(3): 689–697.

Mardia K. V. and Jupp P. E. (2000). *Directional statistics*. Chichester: John Wiley & Sons.

See Also

[esag.da](#), [vmfda.pred](#), [dirknn](#), [knn.reg](#)

Examples

```
m1 <- rnorm(3)
m2 <- rnorm(3) + 0.5
y <- rbind( rvmf(100, m1, 3), rvmf(80, m2, 5) )
ina <- c( rep(1,100), rep(2, 80) )
ynew <- rbind(rvmf(10, m1, 10), rvmf(10, m2, 5))
id <- rep(1:2, each = 10)
g <- esagda.pred(ynew, y, ina)
table(id, g)
```

Prediction in discriminant analysis based on Purkayastha distribution

Prediction of a new observation using discriminant analysis based on Purkayastha distribution

Description

Prediction of a new observation using discriminant analysis based on Purkayastha distribution.

Usage

```
purkada.pred(ynew, y, ina)
```

Arguments

ynew	The new observation(s) whose group is to be predicted. A numerical vector with data expressed in radians, or a matrix with two columns (cos and sin) for circular data. Or a matrix with 3 columns (unit vectors) for spherical data.
y	A numerical vector with data expressed in radians, or a matrix with two columns (cos and sin) for circular data. Or a matrix with 3 columns (unit vectors) for spherical data.
ina	A vector indicating the groups of the data y.

Details

Prediction of the class of a new spherical vector assuming ESAG distribution.

Value

A vector with the predicted group of each new observation.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70–83

Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. *Communications in Statistics-Theory and Methods*, 19(6): 1973–1986.

See Also

[esag.da](#), [vmfda.pred](#), [dirknn](#), [knn.reg](#)

Examples

```
m1 <- rnorm(3)
m2 <- rnorm(3) + 0.5
y <- rbind( rvmf(100, m1, 3), rvmf(80, m2, 5) )
ina <- c( rep(1,100), rep(2, 80) )
ynew <- rbind(rvmf(10, m1, 10), rvmf(10, m2, 5))
id <- rep(1:2, each = 10)
g <- purkada.pred(ynew, y, ina)
table(id, g)
```

Prediction in discriminant analysis based on von Mises-Fisher distribution

Prediction of a new observation using discriminant analysis based on von Mises-Fisher distribution

Description

Prediction of the class of a new observation using discriminant analysis based on von Mises-Fisher distribution.

Usage

```
vmfda.pred(xnew, x, ina)
```

Arguments

xnew	The new observation(s) (unit vector(s)) whose group is to be predicted.
x	A data matrix with unit vectors, i.e. directional data.
ina	A vector indicating the groups of the data x.

Details

Discriminant analysis assuming von Mises-Fisher distributions.

Value

A vector with the predicted group of each new observation.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4), 467–491.

Morris J. E. and Laycock P. J. (1974). Discriminant analysis of directional data. *Biometrika*, 61(2): 335–341.

See Also

[vmf.da](#), [mixvmf.mle](#), [dirknn](#), [knn.reg](#)

Examples

```
m1 <- rnorm(5)
m2 <- rnorm(5)
x <- rbind( rvmf(100, m1, 5), rvmf(80, m2, 10) )
ina <- c( rep(1,100), rep(2, 80) )
y <- rbind(rvmf(10, m1, 10), rvmf(10, m2, 5))
id <- rep(1:2, each = 10)
g <- vmfda.pred(y, x, ina)
table(id, g)
```

Prediction with some naive Bayes classifiers for circular data

Prediction with some naive Bayes classifiers for circular data

Description

Prediction with some naive Bayes classifiers for circular data.

Usage

```
vmnb.pred(xnew, mu, kappa, ni)
spm1nb.pred(xnew, mu1, mu2, ni)
```

Arguments

xnew	A numerical matrix with new predictor variables whose group is to be predicted. Each column refers to an angular variable.
mu	A matrix with the mean vectors expressed in radians.
mu1	A matrix with the first set of mean vectors.
mu2	A matrix with the second set of mean vectors.
kappa	A matrix with the kappa parameters for the vonMises distribution or with the norm of the mean vectors for the circular angular Gaussian distribution.
ni	The sample size of each group in the dataset.

Details

Each column is supposed to contain angular measurements. Thus, for each column a von Mises distribution or an circular angular Gaussian distribution is fitted. The product of the densities is the joint multivariate distribution.

Value

A numerical vector with 1, 2, ... denoting the predicted group.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

See Also

[vm.nb](#)

Examples

```
x <- matrix( runif( 100, 0, 1 ), ncol = 2 )
ina <- rbinom(50, 1, 0.5) + 1
a <- vm.nb(x, x, ina)
a2 <- vmnb.pred(x, a$mu, a$kappa, a$ni)
```

Projections based test of uniformity

Projections based test of uniformity

Description

It checks whether the data are uniformly distributed on the circle or the (hyper-)sphere.

Usage

```
ptest(x, B = 100)
```

Arguments

- x A matrix containing the data, unit vectors.
B The number of random uniform projections to use.

Details

For more details see Cuesta-Albertos, Cuevas and Fraiman (2009).

Value

A list including:

- pvalues The p-values of the Kolmogorov-Smirnov tests.
pvalue The p-value of the test based on the Benjamini and Heller (2008) procedure.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Cuesta-Albertos J. A., Cuevas A. and Fraiman, R. (2009). On projection-based tests for directional and compositional data. *Statistics and Computing*, 19: 367–380.

Benjamini Y. and Heller R. (2008). Screening for partial conjunction hypotheses. *Biometrics*, 64(4): 1215–1222.

See Also

[rayleigh](#), [kuiper](#)

Examples

```
x <- rvmf(100, rnorm(5), 1) ## Fisher distribution with low concentration
ptest(x)
```

Random sample of matrices in $SO(p)$

Random sample of matrices in $SO(p)$

Description

Random sample of matrices in $SO(p)$.

Usage

```
rsop(n, p)
```

Arguments

n	The sample size, the number of matrices you want to generate.
p	The dimensionality of the matrices.

Details

The idea is very simple. Start with a unit vector pointing at the north pole (1,0,...,0). Then generate random numbers from a standard normal and scale them so that they have a unit length. To put it differently, a sample of n values from the uniform distribution on the sphere is generated. Then calculate the rotation matrix required to go from the north pole to each of a generated vector.

Value

If n = 1 one matrix is returned. If n is greater than 1, an array with n matrices inside.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Amaral G.J.A., Dryden I.L. and Wood A.T.A. (2007). Pivotal Bootstrap Methods for k-Sample Problems in Directional Statistics and Shape Analysis. *Journal of the American Statistical Association*, 102(478): 695–707.

See Also

[rotation](#), [Arotation](#), [rot.matrix](#)

Examples

```
x1 <- rsop(1, 3)
x2 <- rsop(10, 3)
x3 <- rsop(100, 10)
```

Rayleigh's test of uniformity

Rayleigh's test of uniformity

Description

It checks whether the data are uniformly distributed on the circle or the (hyper-)sphere.

Usage

```
rayleigh(x, modif = TRUE, B = 999)
```

Arguments

x	A matrix containing the data, unit vectors.
modif	If modif is TRUE, the modification as suggested by Jupp (2001) is used.
B	If B is greater than 1, bootstrap calibration is performed. If it is equal to 1, classical theory is used.

Details

The Rayleigh test of uniformity is not the best, when there are two antipodal mean directions. In this case it will fail. It is good to test whether there is one mean direction or not. To put it differently, it tests whether the concentration parameter of the Fisher distribution is zero or not.

Value

This is an "hstest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. If bootstrap was employed this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

- Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
- Jupp, P. E. (2001). Modifications of the rayleigh and bingham tests for uniformity of directions. *Journal of Multivariate Analysis*, 77(2): 1-20.
- Rayleigh, L. (1919). On the problem of random vibrations, and of random flights in one, two, or three dimensions. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 37(220): 321–347.

See Also

[ptest](#), [kuiper](#), [iagesag](#)

Examples

```
x <- rvmf(100, rnorm(5), 1) ## Fisher distribution with low concentration
rayleigh(x)
```

Read a file as a Filebacked Big Matrix

Read a file as a Filebacked Big Matrix

Description

Read a file as a Filebacked Big Matrix.

Usage

```
read.fbm(file, select)
```

Arguments

file	The File to read.
select	Indices of columns to read (sorted). The length of select will be the number of columns of the resulting FBM.

Details

The functions read a file as a Filebacked Big Matrix object. For more information see the "bigstatsr" package.

Value

A Filebacked Big Matrix object.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

See Also

[vmf.mle](#), [kent.mle](#)

Examples

```
x <- matrix( runif(50 * 20, 0, 2*pi), ncol = 20 )
```

Rotation axis and angle of rotation given a rotation matrix

Rotation axis and angle of rotation given a rotation matrix

Description

Given a 3 x 3 rotation matrix, the angle and the axis of rotation are calculated.

Usage

```
Arotation(A)
```

Arguments

A A 3 x 3 rotation matrix.

Details

If the user does not supply a rotation matrix a message will appear.

Value

A list including:

angle	The angle of rotation expressed in degrees.
axis	The axis of rotation. A vector of two components, latitude and longitude, expressed in degrees.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Course webpage of Howard E. Haber. http://scipp.ucsc.edu/~haber/ph216/rotation_12.pdf

Ted Chang (1986). Spherical Regression. *Annals of Statistics*, 14(3): 907–924.

See Also

[rot.matrix](#), [rotation](#), [rsop](#)

Examples

```
ksi <- c(25.31, 24.29)
theta <- 2.38
A <- rot.matrix(ksi, theta, rads = FALSE)
A
Arotation(A)
```

Rotation matrix from a rotation axis and angle of rotation
Rotation matrix from a rotation axis and angle of rotation

Description

It calculates a rotation matrix from a rotation axis and angle of rotation.

Usage

```
rot.matrix(ksi, theta, rads = FALSE)
```

Arguments

ksi	The rotation axis, a vector with two elements, the first is the latitude and the second is the longitude.
theta	The angle of rotation.
rads	If both the ksi and theta are in rads, this should be TRUE. If both the ksi and theta are in degrees, this should be FALSE.

Details

The function accepts as arguments the rotation axis and the angle of rotation and it calculates the requested rotation matrix.

Value

A 3 x 3 rotation matrix.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Course webpage of Howard E. Haber. http://scipp.ucsc.edu/~haber/ph216/rotation_12.pdf
Ted Chang (1986). Spherical Regression. *Annals of Statistics*, 14(3): 907–924.

See Also

[Arotation](#), [rotation](#), [rsop](#)

Examples

```
ksi <- c(25.31, 24.29)
theta <- 2.38
A <- rot.matrix(ksi, theta, rads = FALSE)
A
Arotation(A)
```

Rotation matrix on $SO(3)$ from three Euler angles

Construct a rotation matrix on $SO(3)$ from the Euler angles.

Description

It forms a rotation matrix X on $SO(3)$ by using three Euler angles $(\theta_{12}, \theta_{13}, \theta_{23})$, where X is defined as $X = R_z(\theta_{12}) \times R_y(\theta_{13}) \times R_x(\theta_{23})$. Here $R_x(\theta_{23})$ means a rotation of θ_{23} radians about the x axis.

Usage

```
eul2rot(theta.12, theta.23, theta.13)
```

Arguments

theta.12	An Euler angle, a number which must lie in $(-\pi, \pi)$.
theta.23	An Euler angle, a number which must lie in $(-\pi, \pi)$.
theta.13	An Euler angle, a number which must lie in $(-\pi/2, \pi/2)$.

Details

Given three euler angles a rotation matrix X on $SO(3)$ is formed using the transformation according to Green and Mardia (2006) which is defined above.

Value

A rotation matrix.

Author(s)

Anamul Sajib <sajibstat@du.ac.bd>.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd>.

References

Green, P. J. and Mardia, K. V. (2006). Bayesian alignment using hierarchical models, with applications in proteins bioinformatics. *Biometrika*, 93(2):235–254.

See Also

[rot2eul](#)

Examples

```
# three euler angles

theta.12 <- sample( seq(-3, 3, 0.3), 1 )
theta.23 <- sample( seq(-3, 3, 0.3), 1 )
theta.13 <- sample( seq(-1.4, 1.4, 0.3), 1 )

theta.12 ; theta.23 ; theta.13

X <- eul2rot(theta.12, theta.23, theta.13)
X # A rotation matrix
det(X)

e <- rot2eul(X)$v1

theta.12 <- e[3]
theta.23 <- e[2]
theta.13 <- e[1]

theta.12 ; theta.23 ; theta.13
```

Rotation matrix to rotate a spherical vector along the direction of another

Rotation matrix to rotate a spherical vector along the direction of another

Description

A rotation matrix is calculated to rotate a unit vector along the direction of another.

Usage

```
rotation(a, b)
```

Arguments

a	The initial unit vector.
b	The target unit vector.

Details

The function calculates a rotation matrix given two vectors. This rotation matrix is the connection between the two spherical only, vectors.

Value

A rotation matrix whose dimension is equal to the length of the unit vectors.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Amaral G.J.A., Dryden I.L. and Wood A.T.A. (2007). Pivotal Bootstrap Methods for k-Sample Problems in Directional Statistics and Shape Analysis. *Journal of the American Statistical Association*, 102(478): 695–707.

See Also

[Arotation](#), [rot.matrix](#), [lambert](#), [lambert.inv](#), [rsop](#)

Examples

```
a <- rnorm(3)
a <- a/sqrt(sum(a^2))
b <- rnorm(3)
b <- b/sqrt(sum(b^2))
A <- rotation(a, b)
A
a ; b
a %*% t(A)

a <- rnorm(7)
a <- a/sqrt(sum(a^2))
b <- rnorm(7)
b <- b/sqrt(sum(b^2))
A <- rotation(a, b)
A
a ; b
a %*% t(A)
```

Saddlepoint approximations of the Fisher-Bingham distributions
Saddlepoint approximations of the Fisher-Bingham distributions

Description

It calculates the logarithm of the normalising constant of the Fisher-Bingham distribution.

Usage

```
fb.saddle(gam, lam)
```

Arguments

gam	A numeric vector containing the parameters of the Fisher part.
lam	All the eigenvalues of the Bingham part. Not just the non zero ones.

Details

It calculate the three approximations given by Kume and Wood (2005) and it uses the Fisher-Bingham parametrization of that paper.

Value

A list including:

first oder	The first order approximation
second oder	The second order approximation
third oder	The third order approximation

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kume Alfred and Wood Andrew T.A. (2005). Saddlepoint approximations for the Bingham and Fisher-Bingham normalizing constants. *Biometrika*, 92(2):465-476

See Also

[kent.logcon](#), [rfb](#), [kent.mle](#), [rbingham](#)

Examples

```

p <- 3 ; k <- 1
0.5 * p * log(2 * pi) - (p/2 - 1) * log(k) + log( besselI(k, p/2 - 1, expon.scaled = TRUE) ) + k
## normalising constant of the
## von Mises-Fisher distribution
fb.saddle( c(0, k, 0), c(0, 0, 0) ) ## saddlepoint approximation

## Normalising constant of the Kent distribution
fb.saddle( c(0, 10, 0), c(0, -2, 2) )
kent.logcon(10, 2)

```

Simulation from a Bingham distribution using any symmetric matrix A
Simulation from a Bingham distribution using any symmetric matrix A

Description

It simulates random values from a Bingham distribution with any given symmetric matrix.

Usage

```
rbingham(n, A)
```

Arguments

n	The sample size.
A	A symmetric matrix.

Details

The eigenvalues are first calculated and then Chris Fallaize and Theo Kypraio's code (`f.rbing`) is used. The resulting simulated data are then right multiplied by the eigenvectors of the matrix A.

Value

A matrix with the simulated data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

- Kent J. T., Ganeiber A. M. and Mardia K. V. (2018). A new unified approach for the simulation of a wide class of directional distributions. *Journal of Computational and Graphical Statistics*, 27(2): 291–301.
- Kent J.T., Ganeiber A.M. and Mardia K.V. (2013). A new method to simulate the Bingham and related distributions in directional data analysis with applications. <http://arxiv.org/pdf/1310.8110v1.pdf>
- Fallaize C. J. and Kypraios T. (2016). Exact bayesian inference for the Bingham distribution. *Statistics and Computing*, 26(1): 349–360. <http://arxiv.org/pdf/1401.2894v1.pdf>

See Also

[f.rbing](#), [rfb](#), [rvmf](#), [rkent](#)

Examples

```
A <- cov(iris[, 1:3])
x <- rbingham(100, A)
```

Simulation from a Matrix Fisher distribution on $SO(3)$

Simulation from a Matrix Fisher distribution on $SO(3)$

Description

It simulates random samples (rotation matrices) from a Matrix Fisher distribution with any given parameter matrix, F (3×3).

Usage

```
rmatrixfisher(n, F)
```

Arguments

n	the sample size.
F	An arbitrary 3×3 matrix.

Details

Firstly corresponding Bingham parameter A is determined for a given Matrix Fisher parameter F using John Kent et al.'s (2013) algorithm and then Bingham samples for parameter A are generated using `rbingham` code. Finally convert Bingham samples to Matrix Fisher samples according to the Kent (2013) transformation.

Value

An array with simulated rotation matrices.

Author(s)

Anamul Sajib and Chris Fallaize.

R implementation and documentation: Anamul Sajib <sajibstat@du.ac.bd> and Chris Fallaize.

References

Kent J. T., Ganeiber A. M. and Mardia K. V. (2018). A new unified approach for the simulation of a wide class of directional distributions. *Journal of Computational and Graphical Statistics*, 27(2): 291–301.

Kent J.T., Ganeiber A.M. and Mardia K.V. (2013). A new method to simulate the Bingham and related distributions in directional data analysis with applications. <http://arxiv.org/pdf/1310.8110v1.pdf>

See Also

[matrixfisher.mle](#)

Examples

```
F <- matrix( c(85, 11, 41, 78, 39, 60, 43, 64, 48), ncol = 3) / 10  ### An arbitrary F matrix
a <- rmatrixfisher(10, F)
```

Simulation of random values from a Bingham distribution
Simulating from a Bingham distribution

Description

It simulates from a Bingham distribution using the code suggested by Kent et al. (2013).

Usage

```
f.rbing(n, lam, fast = FALSE)
```

Arguments

n	Sample size.
lam	Eigenvalues of the diagonal symmetric matrix of the Bingham distribution.
fast	If you want a fast, efficient simulation set this to TRUE.

Details

The user must have calculated the eigenvalues of the diagonal symmetric matrix of the Bingham distribution. The function accepts the q-1 eigenvalues only. This means, that the user must have subtracted the lowest eigenvalue from the rest and give the non zero ones. The function uses rejection sampling and it was written by Chris Fallaize and Theo Kyraios (University of Nottingham) and kindly offered. Any questions on the code can be addressed to one of the two aforementioned people. It is slightly different than the one Kent et al. (2013) suggests.

Value

A list including:

<code>x</code>	The simulated data.
<code>avtry</code>	The estimate of M in the rejection sampling. The average number of simulated values before a value is accepted. If the argument <code>fast</code> is set to <code>TRUE</code> this information will not appear.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kent J. T., Ganeiber A. M. and Mardia K. V. (2018). A new unified approach for the simulation of a wide class of directional distributions. *Journal of Computational and Graphical Statistics*, 27(2): 291–301.

Kent J.T., Ganeiber A.M. and Mardia K.V. (2013). A new method to simulate the Bingham and related distributions in directional data analysis with applications. <http://arxiv.org/pdf/1310.8110v1.pdf>

Fallaize C. J. and Kypraios T. (2016). Exact bayesian inference for the Bingham distribution. *Statistics and Computing*, 26(1): 349–360. <http://arxiv.org/pdf/1401.2894v1.pdf>

See Also

`rfb`, `rvmf`, `rbingham`, `rkent`, `link{rsop}`

Examples

```
x <- f.rbing( 100, c(1, 0.6, 0.1) )
x
```

Simulation of random values from a mixture of von Mises-Fisher distributions

Simulation of random values from a mixture of von Mises-Fisher distributions

Description

The function simulates random values simulation from a given mixture of von Mises-Fisher distributions.

Usage

```
rmixvmf(n, probs, mu, k)
```

Arguments

n	The sample size.
probs	This is a vector with the mixing probability of each group.
mu	A matrix with the mean direction of each group.
k	A vector with the concentration parameter of each group.

Details

The function simulates random values simulation from a given mixture of von Mises-Fisher distributions using the `rvmf` function.

Value

A list including:

id	An indicator of the group of each simulated vector.
x	A matrix with the simulated data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Kurt Hornik and Bettina Grün (2014). `movMF`: An R Package for Fitting Mixtures of von Mises-Fisher Distributions <http://cran.r-project.org/web/packages/movMF/vignettes/movMF.pdf>

See Also

[mixvmf.mle](#), [rvmf](#), [bic.mixvmf](#)

Examples

```
k <- runif(3, 4, 20)
probs <- c(0.2, 0.5, 0.3)
mu <- matrix(rnorm(9), ncol = 3)
mu <- mu / sqrt( rowSums(mu^2) )
x <- rmixvmf(200, probs, mu, k)$x
bic.mixvmf(x, 5)
```

Simulation of random values from a spherical Fisher-Bingham distribution

Simulation of random values from a spherical Fisher-Bingham distribution

Description

Simulation of random values from a spherical Fisher-Bingham distribution.

Usage

```
rfb(n, k, m, A)
```

Arguments

n	The sample size.
k	The concentraion parameter (Fisher part). It has to be greater than 0.
m	The mean direction (Fisher part).
A	A symmetric matrix (Bingham part).

Details

Random values from a spherical Fisher-Bingham distribution are generated. This functions included the option of simulating from a Kent distribution also.

Value

A matrix with the simulated data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

- Kent J. T., Ganeiber A. M. and Mardia K. V. (2018). A new unified approach for the simulation of a wide class of directional distributions. *Journal of Computational and Graphical Statistics*, 27(2): 291–301.
- Kent J.T., Ganeiber A.M. and Mardia K.V. (2013). A new method to simulate the Bingham and related distributions in directional data analysis with applications. <http://arxiv.org/pdf/1310.8110v1.pdf>
- Fallaize C. J. and Kypraios T. (2016). Exact bayesian inference for the Bingham distribution. *Statistics and Computing*, 26(1): 349–360. <http://arxiv.org/pdf/1401.2894v1.pdf>

See Also

[rbingham](#), [rvmf](#), [rkent](#), [f.rbing](#)

Examples

```
k <- 15
mu <- rnorm(3)
mu <- mu / sqrt( sum(mu^2) )
A <- cov(iris[, 1:3])
x <- rfb(50, k, mu, A)
vmf.mle(x) ## fits a von Mises-Fisher distribution to the simulated data
## Next we simulate from a Kent distribution
A <- diag( c(-5, 0, 5) )
n <- 100
x <- rfb(n, k, mu, A) ## data follow a Kent distribution
kent.mle(x) ## fits a Kent distribution
vmf.mle(x) ## fits a von Mises-Fisher distribution
A <- diag( c(5, 0, -5) )
n <- 100
x <- rfb(n, k, mu, A) ## data follow a Kent distribution
kent.mle(x) ## fits a Kent distribution
vmf.mle(x) ## fits a von Mises-Fisher distribution
```

Simulation of random values from a spherical Kent distribution
Simulation of random values from a spherical Kent distribution

Description

Simulation of random values from a spherical Kent distribution.

Usage

```
rkent(n, k, m, b)
```

Arguments

n	The sample size.
k	The concentraion parameter κ . It has to be greater than 0.
m	The mean direction (Fisher part).
b	The ovalness parameter, β .

Details

Random values from a Kent distribution on the sphere are generated. The function generates from a spherical Kent distribution using [rfb](#) with an arbitrary mean direction and then rotates the data to have the desired mean direction.

Value

A matrix with the simulated data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Kent J. T., Ganeiber A. M. and Mardia K. V. (2018). A new unified approach for the simulation of a wide class of directional distributions. *Journal of Computational and Graphical Statistics*, 27(2): 291–301.

Kent J.T., Ganeiber A.M. and Mardia K.V. (2013). A new method to simulate the Bingham and related distributions in directional data analysis with applications. <http://arxiv.org/pdf/1310.8110v1.pdf>

See Also

[rfb](#), [rbingham](#), [rvmf](#), [f.rbing](#)

Examples

```
k <- 15
mu <- rnorm(3)
mu <- mu / sqrt( sum(mu^2) )
A <- diag( c(-5, 0, 5) )
x <- rfb(500, k, mu, A)
kent.mle(x)
y <- rkent(500, k, mu, A[3, 3])
kent.mle(y)
```

Simulation of random values from rotationally symmetric distributions

Simulation of random values from rotationally symmetric distributions

Description

Simulation of random values from rotationally symmetric distributions. The data can be spherical or hyper-spherical.

Usage

```
rvmf(n, mu, k)
riag(n, mu)
rspcauchy(n, mu, rho)
rpkbd(n, mu, rho)
```

Arguments

n	The sample size.
mu	A unit vector showing the mean direction for the von Mises-Fisher or the spherical Cauchy distribution. The mean vector of the Independent Angular Gaussian distribution does not have to be a unit vector.
k	The concentration parameter (κ) of the von Mises-Fisher distribution. If $\kappa = 0$, random values from the spherical uniform will be drawn.
rho	The ρ parameter of the spherical Cauchy or the Poisson kernel based distribution.

Details

The von Mises-Fisher uses the rejection sampling suggested by Wood (1994). For the Independent Angular Gaussian, values are generated from a multivariate normal distribution with the given mean vector and the identity matrix as the covariance matrix. Then each vector becomes a unit vector. For the spherical Cauchy distribution the algorithm is described in Kato and McCullagh (2020) and for the Poisson kernel based distribution, it is described in Sablica, Hornik and Leydold (2023).

Value

A matrix with the simulated data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Wood A.T.A. (1994). Simulation of the von Mises Fisher distribution. *Communications in Statistics-Simulation and Computation*, 23(1): 157–164.

Dhillon I. S. and Sra S. (2003). Modeling data using directional distributions. Technical Report TR-03-06, Department of Computer Sciences, The University of Texas at Austin. <http://citeseerx.ist.psu.edu/viewdoc/download?>

Kato S. and McCullagh P. (2020). Some properties of a Cauchy family on the sphere derived from the Mobius transformations. *Bernoulli*, 26(4): 3224–3248. <https://arxiv.org/pdf/1510.07679.pdf>

Sablica L., Hornik K. and Leydold J. (2023). Efficient sampling from the PKBD distribution. *Electronic Journal of Statistics*, 17(2): 2180–2209.

See Also

[vmf.mle](#), [iag.mle](#) [rfb](#), [racg](#), [rvonmises](#), [rmixvmf](#)

Examples

```

m <- rnorm(4)
m <- m/sqrt(sum(m^2))
x <- rvmf(100, m, 25)
m
vmf.mle(x)

```

Simulation of random values from some circular distributions

Simulation of random values from some circular distributions

Description

Simulation of random values from some circular distributions.

Usage

```

rvonmises(n, m, k, rads = TRUE)
rwrapcauchy(n, m, rho, rads = TRUE)
rspml(n, mu, rads = TRUE)
rcircbeta(n, m, a, b, rads = TRUE)
rcircpurka(n, m, a, rads = TRUE)
rcircexp(n, lambda, rads = TRUE)
rcipc(n, mu = NULL, omega, g, rads = TRUE)
rgcpc(n, mu = NULL, omega, g, rho, rads = TRUE)

```

Arguments

n	The sample size.
m	The mean angle expressed in radians or degrees.
mu	The mean vector of the SPML, CIPC and GCPC in R^2 . For the CIPC and GCPC, if this argument is not given, then the omega and g must be given.
omega	The location parameter for the CIPC and the GCPC expressed in radians or degrees.
k	The concentration parameter of the von Mises distribution. If k is zero the sample will be generated from the uniform distribution over $(0, 2\pi)$.
g	The norm of the mean vector for the CIPC and GCPC, if omega is given instead of mu.
rho	For the wrapped Cauchy distribution, this is the ρ parameter. For the GCPC distribution this is the eigenvalue parameter, or covariance determinant.
a	The α parameter of the beta distribution.
b	The β parameter of the beta distribution.
lambda	The λ parameter of the circular (wrapped) exponential distribution.
rads	If the mean angle is expressed in radians, this should be TRUE and FALSE otherwise. The simulated data will be expressed in radians or degrees depending on what the mean angle is expressed.

Details

For the von Mises distribution, the mean direction is transformed to the Euclidean coordinates (i.e. unit vector) and then the `rvmf` function is employed. It uses a rejection sampling as suggested by Andrew Wood in 1994. We have mentioned the description of the algorithm as we found it in Dhillon and Sra in 2003. Finally, the data are transformed to radians or degrees.

For the wrapped Cauchy and wrapped exponential distributions the function generates Cauchy or exponential values x and then wraps them around the circle $x = x(\text{mod}2\pi)$. For the circular beta the function has some extra steps (see Zheng Sun's master thesis).

For the CIPC and GCPC distributions, data are generated from the bivariate Cauchy distribution, normalized to have unit norm and then transformed to angles.

Value

A vector with the simulated data.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Wood A.T.A. (1994). Simulation of the von Mises Fisher distribution. *Communications in Statistics-Simulation and Computation*, 23(1): 157-164.

Dhillon I.S. and Sra S. (2003). Modeling data using directional distributions. Technical Report TR-03-06, Department of Computer Sciences, The University of Texas at Austin. <http://citeseerx.ist.psu.edu/viewdoc/download?>

Zheng Sun (2006). Comparing measures of fit for circular distributions. Master thesis, University of Victoria. https://dspace.library.uvic.ca/bitstream/handle/1828/2698/zhengsun_master_thesis.pdf;sequence=1

Lai M. (1994). Some results in the statistical analysis of directional data. Master thesis, University of Hong Kong.

Presnell B., Morrison S.P. and Littell R.C. (1998). Projected multivariate linear models for directional data. *Journal of the American Statistical Association*, 93(443): 1068–1077.

Purkayastha S. (1991). A Rotationally Symmetric Directional Distribution: Obtained through Maximum Likelihood Characterization. *The Indian Journal of Statistics, Series A*, 53(1): 70–83

Jammalamadaka S.R. and Kozubowski T.J. (2003). A new family of circular models: The wrapped Laplace distributions. *Advances and Applications in Statistics*, 3(1): 77–103.

See Also

[circ.summary](#), [rvmf](#), [racg](#)

Examples

```
x <- rvonmises(100, 2, 25, rads = TRUE)
circ.summary(x, rads = TRUE)
```

Simulation of random values from the ESAG distribution
Simulation of random values from the ESAG distribution

Description

Simulation of random values from the ESAG distribution.

Usage

```
resag(n, mu, gam)
```

Arguments

n	A number; how many vectors you want to generate.
mu	The mean vector the ESAG distribution, a vector in R^3 .
gam	The two γ parameters of the ESAG distribution.

Details

A random sample from the ESAG distribution is generated. In case the γ_s are zero, the sample is drawn from the Independent Angular Gaussian (or projected normal).

Value

An $n \times 3$ matrix with the simulated unit vectors.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.
Paine P.J., Preston S.P., Tsagris M. and Wood A.T.A. (2018). An Elliptically Symmetric Angular Gaussian Distribution. Statistics and Computing, 28(3):689–697.

See Also

[esag.mle](#), [desag](#), [spml.mle](#), [acg.mle](#), [circ.summary](#)

Examples

```
m <- colMeans( as.matrix( iris[,1:3] ) )  
y <- resag(1000, m, c(1, 0.5) )  
esag.mle(y)
```

Simulation of random values from the SESPC distribution
Simulation of random values from the SESPC distribution

Description

Simulation of random values from the SESPC distribution

Usage

```
rsepc(n, mu, theta)
```

Arguments

n	A number; how many vectors you want to generate.
mu	The mean vector the SESPC distribution, a vector in R^3 .
theta	The two θ parameters of the SESPC distribution.

Details

A random sample from the SESPC distribution is generated. In case the θ_s are zero, the sample is drawn from the SIPC (spherical independent projected Cauchy) distribution.

Value

An $n \times 3$ matrix with the simulated unit vectors.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[sespc.mle](#), [dsespc](#)

Examples

```
m <- colMeans( as.matrix( iris[,1:3] ) )
y <- rsepc(1000, m, c(1, 0.5) )
sespc.mle(y)
```

Spherical and hyper-spherical distance correlation

Spherical and hyper-spherical distance correlation

Description

Spherical and hyper-spherical distance correlation.

Usage

```
spher.dcor(x, y)
```

Arguments

x	A matrix with directional data, i.e. unit vectors.
y	A matrix with directional data, i.e. unit vectors.

Details

The distance correlation between two spherical or hyper-spherical variables is computed.

Value

A list including:

dcov	The distance covariance.
dvarX	The distance variance of x.
dvarY	The distance variance of Y.
dcor	The distance correlation.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

G.J. Szekely, M.L. Rizzo and N. K. Bakirov (2007). Measuring and Testing Independence by Correlation of Distances. *Annals of Statistics*, 35(6):2769-2794.

See Also

[circ.dcor](#)

Examples

```
y <- rvmf(50, rnorm(3), 4)
x <- rvmf(50, rnorm(3), 4)
spher.dcor(x, y)
```

Spherical and hyperspherical median

Fast calculation of the spherical and hyperspherical median

Description

It calculates, very fast, the (hyper-)spherical median of a sample.

Usage

```
mediandir(x)
mediandir_2(x)
```

Arguments

x The data, a numeric matrix with unit vectors.

Details

The "mediandir" employes a fixed point iterative algorithm stemming from the first derivative (Cabrera and Watson, 1990) to find the median direction as described by Fisher (1985) and Fisher, Lewis and Embleton (1987). In the big samples this is much much faster than "mediandir_2", since the search is based on iterations.

Value

The median direction.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

- Fisher N. I. (1985). Spherical medians. *Journal of the Royal Statistical Society. Series B*, 47(2): 342–348.
- Fisher N. I., Lewis T. and Embleton B. J. (1987). *Statistical analysis of spherical data*. Cambridge university press.
- Cabrera J. and Watson G. S. (1990). On a spherical median related distribution. *Communications in Statistics-Theory and Methods*, 19(6): 1973–1986.

See Also

[nsmedian](#), [vmf.mle](#), [kent.mle](#)

Examples

```
m <- rnorm(3)
m <- m / sqrt( sum(m^2) )
x <- rvmf(100, m, 10)
mediandir(x)
mediandir_2(x)
nsmedian(x)
```

Spherical regression using rotationally symmetric distributions
Spherical regression using rotationally symmetric distributions

Description

Spherical regression using rotationally symmetric distributions.

Usage

```
iag.reg(y, x, con = TRUE, xnew = NULL, tol = 1e-06)
vmf.reg(y, x, con = TRUE, xnew = NULL, tol = 1e-06)
sipc.reg(y, x, con = TRUE, xnew = NULL, tol = 1e-06)
```

Arguments

<code>y</code>	A matrix with 3 columns containing the (unit vector) spherical data.
<code>x</code>	The predictor variable(s), they can be continuous, spherical, categorical or a mix of them.
<code>con</code>	Do you want the constant term in the regression?
<code>xnew</code>	If you have new data use it, otherwise leave it NULL.
<code>tol</code>	A tolerance value to decide when to stop the successive optimizations.

Details

The second parametrization of the projected normal and of the von Mises-Fisher regression (Paine et al., 2020) is applied. The same is true for the SIPC distribution. For more information see the paper by Paine et al. (2020).

Value

A list including:

<code>loglik</code>	The log-likelihood of the regression model.
<code>fit</code>	This is a measure of fit of the estimated values, defined as $\sum_{i=1}^n y_i^T \hat{y}_i$. This appears if the argument "xnew" is NULL.
<code>beta</code>	The beta coefficients.
<code>seb</code>	The standard error of the beta coefficients.
<code>ki</code>	The norm of the fitted values. In the von Mises-Fisher regression this is the concentration parameter of each observation. In the projected normal this are the norms of the fitted values before being projected onto the sphere. This is returned if the argument "xnew" is NULL.
<code>est</code>	The fitted values of xnew if "xnew" is NULL. If it is not NULL, the fitted values for the "xnew" you supplied will be returned.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

P. J. Paine, S. P. Preston, M. Tsagris and Andrew T. A. Wood (2020). Spherical regression models with general covariates and anisotropic errors. *Statistics and Computing*, 30(1): 153–165. <https://link.springer.com/content/pdf/10.1007>

Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

See Also

[esag.reg](#), [esag.mle](#), [vmf.mle](#), [spml.reg](#)

Examples

```
y <- rvmf(150, rnorm(3), 5)
a1 <- iag.reg(y, iris[, 4])
a2 <- iag.reg(y, iris[, 4:5])

b1 <- vmf.reg(y, iris[, 4])
b2 <- vmf.reg(y, iris[, 4:5])
```

Spherical regression using the ESAG distribution
Spherical regression using the ESAG distribution

Description

Spherical regression using the ESAG distribution.

Usage

```
esag.reg(y, x, con = TRUE, xnew = NULL, lati = 10, longi = 10, tol = 1e-06)
```

Arguments

y	A matrix with 3 columns containing the (unit vector) spherical data.
x	The predictor variable(s), they can be continuous, spherical, categorical or a mix of them.
con	Do you want the constant term in the regression?
xnew	If you have new data use it, otherwise leave it NULL.
lati	A positive number determining the range of degrees to move left and right from the latitude center. This number and the next determine the grid of points to search for the Q matrix described in Paine et al. (2020).
longi	A positive number determining the range of degrees to move up and down from the longitude center. This number and the previous determine the grid of points to search for the Q matrix described in Paine et al. (2020).
tol	A tolerance value to decide when to stop the successive optimizations.

Details

The second parametrization of the ESAG regression (Paine et al., 2020) is applied.

Value

A list including:

loglik	The log-likelihood of the regression model.
param	A vector with three numbers. A measure of fit of the estimated values, defined as $\sum_{i=1}^n y_i^T \hat{y}_i$. This appears if the argument "xnew" is NULL. The $\rho \in (0, 1]$ (smallest eigenvalue of the covariance matrix), and the angle of rotation psi .
gam	The two γ parameters.
beta	The beta coefficients.
seb	The standard error of the beta coefficients.
est	The fitted values of xnew if "xnew" is NULL. If it is not NULL, the fitted values for the "xnew" you supplied will be returned.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

P. J. Paine, S. P. Preston, M. Tsagris and Andrew T. A. Wood (2020). Spherical regression models with general covariates and anisotropic errors. *Statistics and Computing*, 30(1): 153–165. <https://link.springer.com/content/pdf/10.1007>

See Also

[esag.mle](#), [iag.reg](#), [spml.reg](#)

Examples

```
y <- resag( 30, rnorm(3), c(1, 1) )
## this is a small example to pass CRAN's check because the default argument values
## of lati and longi require many seconds
a <- esag.reg(y, iris[1:30, 4], lati = 2, longi = 2)
```

Spherical regression using the SESPC distribution

Spherical regression using the SESPC distribution

Description

Spherical regression using the SESPC distribution.

Usage

```
sespc.reg(y, x, con = TRUE, xnew = NULL, lati = 10, longi = 10, tol = 1e-06)
```

Arguments

y	A matrix with 3 columns containing the (unit vector) spherical data.
x	The predictor variable(s), they can be continuous, spherical, categorical or a mix of them.
con	Do you want the constant term in the regression?
xnew	If you have new data use it, otherwise leave it NULL.
lati	A positive number determining the range of degrees to move left and right from the latitude center. This number and the next determine the grid of points to search for the Q matrix described in Tsagris and Alzeley (2023).
longi	A positive number determining the range of degrees to move up and down from the longitude center. This number and the previous determine the grid of points to search for the Q matrix described in Tsagris and Alzeley (2023).
tol	A tolerance value to decide when to stop the successive optimizations.

Details

Regression based on the SESPC distribution (Tsagris and Alzeley, 2023) is applied.

Value

A list including:

loglik	The log-likelihood of the regression model.
param	A vector with three numbers. A measure of fit of the estimated values, defined as $\sum_{i=1}^n y_i^T \hat{y}_i$. This appears if the argument "xnew" is NULL. The $\rho \in (0, 1]$ (smallest eigenvalue of the covariance matrix), and the angle of rotation ψ .
theta	The two θ parameters.
beta	The beta coefficients.
seb	The standard error of the beta coefficients.
est	The fitted values of xnew if "xnew" is NULL. If it is not NULL, the fitted values for the "xnew" you supplied will be returned.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alzeley O. (2023). Circular and spherical projected Cauchy distributions: A Novel Framework for Circular and Directional Data Modeling. <https://arxiv.org/pdf/2302.02468.pdf>

See Also

[esag.mle](#), [iag.reg](#), [spml.reg](#)

Examples

```
y <- rsespc( 150, rnorm(3), c(1, 1) )
## this is a small example to pass CRAN's check because the default argument values
## of lati and longi require many seconds
a <- sespc.reg(y, iris[, 4], lati = 2, longi = 2)
```

Spherical-spherical correlation
Spherical-spherical correlation

Description

Correlation between two spherical variables.

Usage

```
spher.cor(x, y)
```

Arguments

x	A spherical variable. A matrix with three columns, each row is a unit vector.
y	A spherical variable. A matrix with three columns, each row is a unit vector.

Details

A very similar to the classical correlation is calculated. In addition, a hypothesis test for no correlation is performed. Note, that this is a squared correlation actually, so negative values will never be returned.

Value

A vector including:

R-squared	The value of the squared correlation.
p-value	The p-value of the no correlation hypothesis testing.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kanti V. Mardia and Peter E. Jupp. Directional statistics, pg. 254–255.

See Also

[spher.reg](#), [vmf.mle](#), [circ.cor1](#), [circ.cor2](#)

Examples

```
x <- rvmf(100, rnorm(3), 10)
y <- rvmf(100, rnorm(3), 10)
spher.cor(x, y)
```

Spherical-spherical regression
Spherical-Spherical regression

Description

It performs regression when both the dependent and independent variables are spherical.

Usage

```
spher.reg(y, x, rads = FALSE)
```

Arguments

y	The dependent variable; a matrix with either two columns, latitude and longitude, either in radians or in degrees. Alternatively it is a matrix with three columns, unit vectors.
x	The dependent variable; a matrix with either two columns, latitude and longitude, either in radians or in degrees. Alternatively it is a matrix with three columns, unit vectors. The two matrices must agree in the scale and dimensions.
rads	If the data are expressed in latitude and longitude then it matter to know if they are in radians or degrees. If they are in radians, then this should be TRUE and FALSE otherwise. If the previous argument, euclidean, is TRUE, this one does not matter what its value is.

Details

Spherical regression as proposed by Chang (1986) is implemented. If the estimated rotation matrix has a determinant equal to -1, singular value decomposition is performed and the last unit vector of the second matrix is multiplied by -1.

Value

A list including:

A	The estimated rotation matrix.
fitted	The fitted values in Euclidean coordinates (unit vectors).

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Ted Chang (1986). Spherical Regression. *Annals of Statistics*, 14(3): 907–924.

See Also

[spher.cor](#), [spml.reg](#), [circ.cor1](#), [circ.cor2](#), [sphereplot](#)

Examples

```
mx <- rnorm(3)
mx <- mx/sqrt( sum(mx^2) )
my <- rnorm(3)
my <- my/sqrt( sum(my^2) )
x <- rvmf(100, mx, 15)
A <- rotation(mx, my)
y <- x %*% t(A)
mod <- spher.reg(y, x)
A
mod$A ## exact match, no noise
y <- x %*% t(A)
y <- y + rvmf(100, colMeans(y), 40)
mod <- spher.reg(y, x)
A
mod$A ## noise added, more realistic example
```

Summary statistics for circular data

Summary statistics for circular data

Description

It produces a few summary measures for circular data.

Usage

```
circ.summary(u, rads = FALSE, fast = FALSE, tol = 1e-07, plot = FALSE)
```

Arguments

<code>u</code>	A vector with circular data.
<code>rads</code>	If the data are in rads, then this should be TRUE, otherwise FALSE.
<code>fast</code>	A boolean variable to do a faster implementation.
<code>tol</code>	The tolerance level to stop the Newton-Raphson algorithm for finding kappa.
<code>plot</code>	If you want to see the data plotted on a circle make this TRUE.

Details

It returns the circular mean, mean resultant length, variance, standard deviation and concentration parameter. So, basically it returns the estimated values of the parameters of the von Mises distribution.

Value

If `fast = FALSE` a list including all the following. If `fast = TRUE` less items are returned.

<code>mesos</code>	The circular mean direction.
<code>confint</code>	The 95% confidence interval for the circular mean direction.
<code>kappa</code>	The concentration parameter.
<code>MRL</code>	The mean resultant length.
<code>circvariance</code>	The circular variance.
<code>circstd</code>	The circular standard deviation.
<code>loglik</code>	The log-likelihood of the fitted von Mises distribution.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[spml.mle](#), [rvonmises](#), [vm.kde](#), [vmf.mle](#), [group.vm](#), [hcf.circaov](#)

Examples

```
x <- rvonmises(50, 2.5, 15, rads = TRUE)
circ.summary(x, rads = TRUE, plot = TRUE)
```

Summary statistics for grouped circular data
Summary statistics for grouped circular data

Description

It produces a few summary measures for grouped circular data.

Usage

```
group.vm(group, fi, rads = FALSE)
```

Arguments

group	A matrix denoting the classes. Each row consists of two numbers, the lower and upper points of each class.
fi	The frequency of each class of data.
rads	If the data are in rads, then this should be TRUE, otherwise FALSE.

Details

It returns the circular mean, mean resultant length, variance, standard deviation and concentration parameter. So, basically it returns the estimated values of the parameters of the von Mises distribution. The mean resultant length though is group corrected.

Value

A list including:

mesos	The circular mean direction.
confint	The 95% confidence interval for the circular mean direction.
kappa	The concentration parameter.
MRL	The mean resultant length.
circvariance	The circular variance.
circstd	The circular standard deviation.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Pewsey Arthur, Markus Neuhauser and Graeme D. Ruxton (2013). Circular statistics in R. Oxford University Press.

Mardia K. V. and Jupp P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[circ.summary](#), [rvonmises](#), [vm.kde](#)

Examples

```
x <- rvonmises(200, 3, 10)
a <- circ.summary(x, rads = TRUE, plot = FALSE)
group <- seq(min(x) - 0.1, max(x) + 0.1, length = 6)
y <- cut(x, breaks = group, length = 6)
group <- matrix( c( group[1], rep(group[2:5], each = 2), group[6]), ncol = 2, byrow = TRUE)
fi <- as.vector( table(y) )
b <- group.vm(group, fi, rads = TRUE)
a
b
```

Test for a given mean direction

Test for a given mean direction

Description

A log-likelihood ratio test for testing whether the sample mean direction is equal to some predefined one.

Usage

```
meandir.test(x, mu, B = 999)
```

Arguments

x	A matrix with the data, unit vectors.
mu	A unit vector with the hypothesized mean direction.
B	A number either 1, so no bootstrap calibration is performed or more than 1, so bootstrap calibration is performed.

Details

The log-likelihood ratio test is employed.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	The degrees of freedom of the test. If bootstrap was employed this is "NA".
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chichester: John Wiley & Sons.

See Also

[vmf.mle](#), [kent.mle](#), [rayleigh](#)

Examples

```
mu <- rnorm(5)
mu <- mu / sqrt( sum(mu^2) )
x <- rvmf(100, mu, 10)
meandir.test(x, mu, 1)
meandir.test(x, mu, 499)
```

Test for equality of concentration parameters for spherical data

Test for equality of concentration parameters for spherical data

Description

This tests the equality of concentration parameters for spherical data only.

Usage

```
spherconc.test(x, ina)
```

Arguments

x	A matrix with the data in Euclidean coordinates, i.e. unit vectors
ina	A variable indicating the groupings of the observations.

Details

The test is designed for spherical data only.

Value

A list including:

mess	A message stating the value of the mean resultant and which test statistic was used, U1, U2 or U3.
res	A vector containing the test statistic and its p-value.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Kanti V. Mardia and Peter E. Jupp. Directional statistics, pg. 226–227.

See Also

[het.aov](#), [lr.aov](#), [embed.aov](#), [hcf.aov](#), [conc.test](#), [sphereplot](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
ina <- rep(1:4, each = 25)
spherconc.test(x, ina)
```

Test of equality of the concentration parameters for circular data

A test for testing the equality of the concentration parameter among g samples, where $g \geq 2$ for circular data

Description

A test for testing the equality of the concentration parameter among g samples, where $g \geq 2$ for circular data.

Usage

```
conc.test(u, ina, rads = FALSE)
```

Arguments

<code>u</code>	A numeric vector containing the values of all samples.
<code>ina</code>	A numerical variable or factor indicating the groups of each value.
<code>rads</code>	If the data are in radians this should be TRUE and FALSE otherwise.

Details

This test works for circular data.

Value

A list including:

<code>mess</code>	A message informing the use of the test statistic used.
<code>res</code>	A numeric vector containing the value of the test statistic and its associated p-value.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Mardia, K. V. and Jupp, P. E. (2000). Directional statistics. Chicester: John Wiley & Sons.

See Also

[embed.circaov](#), [hcf.circaov](#), [lr.circaov](#), [het.circaov](#)

Examples

```
x <- rvonmises(100, 2.4, 15)
ina <- rep(1:4,each = 25)
conc.test(x, ina, rads = TRUE)
```

The k-nearest neighbours using the cosinus distance

The k-nearest neighbours using the cosinus distance

Description

The k-nearest neighbours using the cosinus distance.

Usage

```
cosnn(xnew, x, k = 5, index = FALSE, rann = FALSE)
```

Arguments

<code>xnew</code>	The new data whose k-nearest neighbours are to be found.
<code>x</code>	The data, a numeric matrix with unit vectors.
<code>k</code>	The number of nearest neighbours, set to 5 by default. It can also be a vector with many values.
<code>index</code>	If you want the indices of the closest observations set this equal to TRUE.
<code>rann</code>	If you have large scale datasets and want a faster k-NN search, you can use kd-trees implemented in the R package "RANN". In this case you must set this argument equal to TRUE.

Details

The shortest distances or the indices of the k-nearest neighbours using the cosinus distance are returned.

Value

A matrix with the shortest distance of each xnew from x, if index is FALSE, or the indices of the nearest neighbours of each xnew from x, if index is TRUE.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4): 467–491.

See Also

[dirknn](#), [dirknn.tune](#)

Examples

```
xnew <- rvmf(10, rnorm(3), 5)
x <- rvmf(50, rnorm(3), 5)
a <- cosnn(xnew, x, k = 5)
b <- cosnn(xnew, x, k = 5, index = TRUE)
```

Transform unit vectors to angular data

Transform unit vectors to angular data

Description

Transform unit vectors to angular data.

Usage

```
etoa(x)
```

Arguments

x A numerical matrix with directional data, i.e. unit vectors.

Details

from the Euclidean coordinates the data are mapped to angles, expressed in rads.

Value

A list including:

mu A matrix with angles. The number of columns is one less than that of the original matrix.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

https://en.wikipedia.org/wiki/N-sphere#Spherical_coordinates

See Also

[vmb.pred](#)

Examples

```
x <- rvmf(10, rnorm(3), 5)
y <- etoa(x)
```

Tuning of the bandwidth parameter in the von Mises kernel

Tuning of the bandwidth parameter in the von Mises kernel for circular data

Description

Tuning of the bandwidth parameter in the von Mises kernel for circular data. Cross validation is used.

Usage

```
vmkde.tune(u, low = 0.1, up = 1, rads = TRUE)
```

Arguments

u The data, a numerical vector.
low The lower value of h to search.
up The lower value of h to search.
rads If the data are in radians this should be TRUE and FALSE otherwise.

Details

Tuning of the bandwidth parameter in the von Mises kernel for circular data via cross validation. The procedure is fast because an optimiser is used.

Value

A vector including two elements:

Optimal h	The best H found.
cv	The value of the maximised pseudo-likelihood.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Taylor C.C. (2008). Automatic bandwidth selection for circular density estimation. *Computational Statistics & Data Analysis*, 52(7), 3493–3500.

Wand M.P. and Jones M.C. (1994). *Kernel smoothing*. CrC Press.

See Also

[vm.kde](#), [vmfkde.tune](#), [vmf.kde](#)

Examples

```
u <- rvonmises(100, 2.4, 10, rads = TRUE)
vmkde.tune(u)
```

Tuning of the bandwidth parameter in the von Mises-Fisher kernel

*Tuning of the bandwidth parameter in the von Mises-Fisher kernel for
(hyper-)spherical data*

Description

Tuning of the bandwidth parameter in the von Mises-Fisher kernel for (hyper-)spherical data with cross validation.

Usage

```
vmfkde.tune(x, low = 0.1, up = 1)
```

Arguments

x	A matrix with the data in Euclidean coordinates, i.e. unit vectors.
low	The lower value of the bandwidth to search.
up	The upper value of the bandwidth to search.

Details

Fast tuning of the bandwidth parameter in the von Mises-Fisher kernel for (hyper-)spherical data via cross validation.

Value

A vector including two elements:

Optimal h	The best H found.
cv	The value of the maximised pseudo-likelihood.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Garcia P.E. (2013). Exact risk improvement of bandwidth selectors for kernel density estimation with directional data. *Electronic Journal of Statistics*, 7, 1655–1685.

Wand M.P. and Jones M.C. (1994). *Kernel smoothing*. Crc Press.

See Also

[vmf.kde](#), [vmf.kerncontour](#), [vm.kde](#), [vmkde.tune](#)

Examples

```
x <- rvmf(100, rnorm(3), 15)
vmfkde.tune(x)
```

Tuning of the k-NN algorithm using the arc cosinus distance
k-NN algorithm using the arc cosinus distance. Tuning the k neighbours

Description

It estimates the percentage of correct classification via an m-fold cross validation.

Usage

```
dirknn.tune(ina, x, k = 2:10, mesos = TRUE, nfolds = 10, folds = NULL,
parallel = FALSE, stratified = TRUE, seed = NULL, rann = FALSE, graph = FALSE)
```

Arguments

x	The data, a numeric matrix with unit vectors.
ina	A variable indicating the groups of the data x.
nfolds	How many folds to create?
k	A vector with the number of nearest neighbours to consider.
mesos	A boolean variable used only in the case of the non standard algorithm (type="NS"). Should the average of the distances be calculated (TRUE) or not (FALSE)? If it is FALSE, the harmonic mean is calculated.
folds	Do you already have a list with the folds? If not, leave this NULL.
parallel	If you want the standard -NN algorithm to take place in parallel set this equal to TRUE.
stratified	Should the folds be created in a stratified way? i.e. keeping the distribution of the groups similar through all folds?
seed	If seed is TRUE, the results will always be the same.
rann	If you have large scale datasets and want a faster k-NN search, you can use kd-trees implemented in the R package "RANN". In this case you must set this argument equal to TRUE.
graph	If this is TRUE a graph with the results will appear.

Details

The standard algorithm is to keep the k nearest observations and see the groups of these observations. The new observation is allocated to the most frequent seen group. The non standard algorithm is to calculate the classical mean or the harmonic mean of the k nearest observations for each group. The new observation is allocated to the group with the smallest mean distance.

We have made an efficient (not very much efficient though) memory allocation. Even if you have hundreds of thousands of observations, the computer will not clush, it will only take longer. Instead of calculate the distance matrix once in the beginning we calcualte the distances of the out-of-sample observations from the rest. If we calculated the distance matrix in the beginning, once, the resulting matrix could have dimensions thousands by thousands. This would not fit into the memory. If you have a few hundres of observations, the runtime is about the same (maybe less, maybe more) as calculating the distance matrix in the first place.

Value

A list including:

per	The average percent of correct classification across the neighbours.
percent	The estimated (optimal) percent of correct classification.
runtime	The run time of the algorithm. A numeric vector. The first element is the user time, the second element is the system time and the third element is the elapsed time.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

References

Tsagris M. and Alenazi A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4), 467–491.

See Also

[dirknn](#), [vmf.da](#), [mixvmf.mle](#)

Examples

```
k <- runif(4, 4, 20)
prob <- c(0.2, 0.4, 0.3, 0.1)
mu <- matrix(rnorm(16), ncol = 4)
mu <- mu / sqrt( rowSums(mu^2) )
da <- rmixvmf(200, prob, mu, k)
x <- da$x
ina <- da$id
dirknn.tune(ina, x, k = 2:6, nfolds = 5, mesos = TRUE)
dirknn.tune(ina, x, k = 2:6, nfolds = 10, mesos = TRUE)
```

Tuning of the k-NN regression

Tuning of the k-NN regression with Euclidean or (hyper-)spherical response and or predictor variables

Description

Tuning of the k-NN regression with Euclidean or (hyper-)spherical response and or predictor variables. It estimates the percentage of correct classification via an m-fold cross validation. The bias is estimated as well using the algorithm suggested by Tibshirani and Tibshirani (2009) and is subtracted.

Usage

```
knnreg.tune(y, x, nfolds = 10, A = 10, ncores = 1, res = "eucl",
  estim = "arithmetic", folds = NULL, seed = NULL, graph = FALSE)
```

Arguments

y	The currently available data, the response variables values. A matrix with either euclidean (univariate or multivariate) or (hyper-)spherical data. If you have a circular response, say u, transform it to a unit vector via (cos(u), sin(u)).
x	The currently available data, the predictor variables values. A matrix with either euclidean (univariate or multivariate) or (hyper-)spherical data. If you have a circular response, say u, transform it to a unit vector via (cos(u), sin(u)).
nfolds	How many folds to create?
A	The maximum number of nearest neighbours, set to 10 by default, starting from the 2nd nearest neighbor.
ncores	How many cores to use. This is taken into account only when the predictor variables are spherical.
res	The type of the response variable. If it is Euclidean, set this argument equal to "res". If it is a unit vector set it to res="spher".
estim	Once the k observations with the smallest distance are discovered, what should the prediction be? The arithmetic average of the corresponding y values be used estim="arithmetic" or their harmonic average estim="harmonic".
folds	Do you already have a list with the folds? If not, leave this NULL.
seed	You can specify your own seed number here or leave it NULL.
graph	If this is TRUE a graph with the results will appear.

Details

Tuning of the k-NN regression with Euclidean or (hyper-)spherical response and or predictor variables. It estimates the percentage of correct classification via an m-fold cross validation. The bias is estimated as well using the algorithm suggested by Tibshirani and Tibshirani (2009) and is subtracted. The sum of squares of prediction is used in the case of Euclidean responses. In the case of spherical responses the $\sum_i \hat{y}_i^T y_i$ is calculated.

Value

A list including:

crit	The value of the criterion to minimise/maximise for all values of the nearest neighbours.
best_k	The best value of the nearest neighbours.
performance	The bias corrected optimal value of the criterion, along with the estimated bias. For the case of Euclidean response this will be higher than the crit and for the case of spherical responses it will be lower than crit.
runtime	The run time of the algorithm. A numeric vector. The first element is the user time, the second element is the system time and the third element is the elapsed time.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr>.

See Also

[knn.reg](#), [spher.reg](#), [dirknn.tune](#)

Examples

```
y <- iris[, 1]
x <- iris[, 2:4]
x <- x/ sqrt( rowSums(x^2) ) ## Euclidean response and spherical predictors
knnreg.tune(y, x, A = 5, res = "eucl", estim = "arithmetic")

y <- iris[, 1:3]
y <- y/ sqrt( rowSums(y^2) ) ## Spherical response and Euclidean predictor
x <- iris[, 2]
knnreg.tune(y, x, A = 5, res = "spher", estim = "arithmetic")
```

Uniformity test for circular data

Uniformity tests for circular data.

Description

Hypothesis tests of uniformity for circular data.

Usage

```
kuiper(u, rads = FALSE, R = 1)
watson(u, rads = FALSE, R = 1)
```

Arguments

u	A numeric vector containing the circular data, which can be expressed in degrees or radians.
rads	A boolean variable. If the data are in radians, put this TRUE. If the data are expressed in degrees make this FALSE.
R	If R = 1 the asymptotic p-value will be calculated. If R is greater than 1 the bootstrap p-value is returned.

Details

The high concentration (hcf.circaov), log-likelihood ratio (lr.circaov), embedding approach (embed.circaov) or the non equal concentration parameters approach (het.circaov) is used.

Value

This is an "htest" class object. Thus it returns a list including:

statistic	The test statistic value.
parameter	This is usually the degrees of freedom of the test, but here this is "NA" because the asymptotic based p-value is computed in a different way or because bootstrap was employed.
p.value	The p-value of the test.
alternative	A character with the alternative hypothesis.
method	A character with the test used.
data.name	A character vector with two elements.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Jammalamadaka, S. Rao and SenGupta, A. (2001). Topics in Circular Statistics, pg. 153–55 (Kuiper's test) and pg. 156–157 (Watson's test).

See Also

[rayleigh](#), [ptest](#), [vmf.mle](#), [rvonmises](#)

Examples

```
x <- rvonmises(n = 40, m = 2, k = 10)
kuiper(x, rads = TRUE)
watson(x, rads = TRUE)
x <- rvonmises(40, m = 2, k = 0)
kuiper(x, rads = TRUE)
watson(x, rads = TRUE)
```

von Mises kernel density estimation

Kernel density estimation of circular data with a von Mises kernel

Description

Kernel density estimation of circular data with a von Mises kernel.

Usage

```
vm.kde(u, h, thumb = "none", rads = TRUE)
```

Arguments

u	A numeric vector containing the data.
h	The bandwidth.
thumb	It can be either "none", so the bandwidth the user has set will be used, "tay" for the method of Taylor (2008) or "rot" for the method of Garcia-Portugues (2013).
rads	If the data are in radians, this should be TRUE and FALSE otherwise.

Details

The user has the option to use a bandwidth he/she has found in some way (cross-validation) or estimate it as Taylor (2008) or Garcia-Portugues (2013).

Value

A list including:

h	The bandwidth. If the user chose one of "tay" or "rot" the estimated bandwidth will be returned.
f	The kernel density estimate at the observed points.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Taylor, C. C. (2008). Automatic bandwidth selection for circular density estimation. *Computational Statistics & Data Analysis*, 52(7): 3493-3500.

Garcia Portugues, E. (2013). Exact risk improvement of bandwidth selectors for kernel density estimation with directional data. *Electronic Journal of Statistics*, 7, 1655-1685.

See Also

[vmkde.tune](#), [vmfkde.tune](#), [vmf.kde](#)

Examples

```
x <- rvonmises(100, 2.4, 10, rads = TRUE)
hist(x, freq = FALSE)
f1 <- vm.kde(x, h = 0.1, thumb = "rot", rads = TRUE)$f
f2 <- vm.kde(x, h = 0.1, thumb = "tay", rads = TRUE)$f
h <- vmkde.tune(x)[1]
f3 <- vm.kde(x, h = h, thumb = "none", rads = TRUE)$f
points(x, f1, col = 1)
points(x, f2, col = 2)
points(x, f3, col = 3)
```

von Mises-Fisher kernel density estimation for (hyper-)spherical data

Kernel density estimation for (hyper-)spherical data using a von Mises-Fisher kernel

Description

A von Mises-Fisher kernel is used for the non parametric density estimation.

Usage

```
vmf.kde(x, h, thumb = "none")
```

Arguments

x	A matrix with unit vectors, i.e. the data being expressed in Euclidean coordinates.
h	The bandwidth to be used.
thumb	If this is "none", the given bandwidth is used. If it is "rot" the rule of thumb suggested by Garcia-Portugues (2013) is used.

Details

A von Mises-Fisher kernel is used for the non parametric density estimation.

Value

A list including:

h	The bandwidth used.
f	A vector with the kernel density estimate calculated for each of the data points.

Author(s)

Michail Tsagris.

R implementation and documentation: Michail Tsagris <mtsagris@uoc.gr> and Giorgos Athineou <gioathineou@gmail.com>.

References

Garcia Portugues, E. (2013). Exact risk improvement of bandwidth selectors for kernel density estimation with directional data. *Electronic Journal of Statistics*, 7, 1655–1685.

See Also

[vmfkde.tune](#), [vm.kde](#), [vmf.mle](#), [vmkde.tune](#)

Examples

```
x <- rvmf(100, rnorm(5), 15)
h <- vmfkde.tune(x)[1]
f1 <- vmf.kde(x, h = h, thumb = "none")
f2 <- vmf.kde(x, h = h, thumb = "rot")
f1$h ; f2$h
```

Index

- * **Angle of rotation**
 - Rotation axis and angle of rotation given a rotation matrix, [111](#)
 - Rotation matrix from a rotation axis and angle of rotation, [112](#)
- * **Angular central Gaussian distribution**
 - Angular central Gaussian random values simulation, [7](#)
- * **Anova**
 - Directional-package, [4](#)
- * **Axis of rotation**
 - Rotation axis and angle of rotation given a rotation matrix, [111](#)
 - Rotation matrix from a rotation axis and angle of rotation, [112](#)
- * **BIC of the mixture models**
 - BIC for the model based clustering using mixtures of von Mises-Fisher distributions, [11](#)
- * **Bimodal distribution on the sphere**
 - Density of the Wood bimodal distribution on the sphere, [57](#)
 - MLE of the Wood bimodal distribution on the sphere, [95](#)
- * **Bingham distribution**
 - Simulation from a Bingham distribution using any symmetric matrix A, [117](#)
 - Simulation of random values from a Bingham distribution, [119](#)
- * **Circular correlation type II**
 - Circular correlations between two circular variables, [20](#)
- * **Circular correlation type I**
 - Circular correlations between two circular variables, [20](#)
- * **Circular data**
 - A test for testing the equality of the concentration parameters for circular data, [6](#)
 - Test of equality of the concentration parameters for circular data, [144](#)
 - Uniformity test for circular data, [153](#)
- * **Circular-linear correlation**
 - Circular-linear correlation, [24](#)
- * **Concentration parameters**
 - Test for equality of concentration parameters for spherical data, [143](#)
- * **Contour plot**
 - Contour plot (on the plane) of the ESAG and Kent distributions without any data, [28](#)
 - Contour plot (on the sphere) of the ESAG and Kent distributions, [32](#)
 - Contour plot (on the sphere) of the SESPC distribution, [34](#)
 - Contour plot of a mixture of von Mises-Fisher distributions model, [35](#)
 - Contour plot of spherical data using a von Mises-Fisher kernel density estimate, [36](#)
 - Contour plots of some rotationally symmetric distributions, [38](#)
- * **Cross validation**
 - Cross validation in von Mises-Fisher discriminant analysis, [44](#)
 - Cross validation with ESAG discriminant analysis, [45](#)
 - Cross validation with Purkayastha discriminant analysis, [47](#)

- * **Cross-validation**
 - Tuning of the k-NN regression, [151](#)
- * **Directional data**
 - Directional-package, [4](#)
- * **Directional k-NN algorithm**
 - k-NN algorithm using the arc
cosinus distance, [74](#)
 - Tuning of the k-NN algorithm using
the arc cosinus distance, [150](#)
- * **Discriminant analysis**
 - Cross validation for estimating
the classification rate, [42](#)
 - Cross validation in von
Mises-Fisher discrminant
analysis, [44](#)
 - Cross validation with ESAG
discrminant analysis, [45](#)
 - Cross validation with Purkayastha
discrminant analysis, [47](#)
 - Directional-package, [4](#)
 - Prediction in discriminant
analysis based on ESAG
distribution, [102](#)
 - Prediction in discriminant
analysis based on Purkayastha
distribution, [103](#)
 - Prediction in discriminant
analysis based on von
Mises-Fisher distribution, [104](#)
- * **ESAG distribution**
 - Contour plot (on the sphere) of
the ESAG and Kent
distributions, [32](#)
 - Hypothesis test for IAG
distribution over the ESAG
distribution, [67](#)
 - Simulation of random values from
the ESAG distribution, [128](#)
 - Simulation of random values from
the SESPC distribution, [129](#)
- * **Equality of concentrations**
 - A test for testing the equality of
the concentration parameters
for ciruclar data, [6](#)
 - Test of equality of the
concentration parameters for
circular data, [144](#)
- * **Euclidean coordinates**
 - Euclidean transformation, [58](#)
 - Inverse of the Euclidean
transformation, [73](#)
- * **Euclidean data**
 - k-NN regression, [75](#)
 - Tuning of the k-NN regression, [151](#)
- * **Fisher-Bingham distribution**
 - Saddlepoint approximations of the
Fisher-Bingham distributions,
[116](#)
 - Simulation of random values from a
spherical Fisher-Bingham
distribution, [122](#)
- * **Goodness of fit test**
 - Hypothesis test for IAG
distribution over the ESAG
distribution, [67](#)
 - Hypothesis test for von
Mises-Fisher distribution
over Kent distribution, [69](#)
- * **Graphs**
 - Directional-package, [4](#)
- * **Grouped data**
 - Summary statistics for grouped
circular data, [140](#)
- * **Hypothesis testing**
 - A test for testing the equality of
the concentration parameters
for ciruclar data, [6](#)
 - Test for equality of concentration
parameters for spherical data,
[143](#)
 - Test of equality of the
concentration parameters for
circular data, [144](#)
 - Uniformity test for circular data,
[153](#)
- * **IAG distribution**
 - Hypothesis test for IAG
distribution over the ESAG
distribution, [67](#)
- * **Inverse transformation**
 - Inverse of Lambert's equal area
projection, [72](#)
- * **Kent distribution**
 - Contour plot (on the plane) of the
ESAG and Kent distributions
without any data, [28](#)

- Contour plot (on the sphere) of the ESAG and Kent distributions, [32](#)
- Hypothesis test for von Mises-Fisher distribution over Kent distribution, [69](#)
- Logarithm of the Kent distribution normalizing constant, [78](#)
- MLE of the Kent distribution, [90](#)
- Simulation of random values from a spherical Fisher-Bingham distribution, [122](#)
- Simulation of random values from a spherical Kent distribution, [123](#)
- * **Kernel density estimate**
 - Tuning of the bandwidth parameter in the von Mises kernel, [147](#)
 - Tuning of the bandwidth parameter in the von Mises-Fisher kernel, [148](#)
 - von Mises-Fisher kernel density estimation for (hyper-)spherical data, [156](#)
- * **Kernel density**
 - von Mises kernel density estimation, [154](#)
- * **Lambert's equal area projection**
 - Inverse of Lambert's equal area projection, [72](#)
 - Lambert's equal area projection, [77](#)
- * **Matrix Fisher distribution**
 - MLE of the Matrix Fisher distribution on $SO(3)$, [92](#)
- * **Maximum likelihood estimation**
 - MLE of the Matrix Fisher distribution on $SO(3)$, [92](#)
- * **Median direction**
 - Spherical and hyperspherical median, [131](#)
- * **Mixtures of von Mises-Fisher distributions**
 - BIC for the model based clustering using mixtures of von Mises-Fisher distributions, [11](#)
 - Contour plot of a mixture of von Mises-Fisher distributions model, [35](#)
 - Simulation of random values from a mixture of von Mises-Fisher distributions, [120](#)
- * **Model based clustering**
 - Mixtures of Von Mises-Fisher distributions, [81](#)
- * **Normalising constant**
 - Logarithm of the Kent distribution normalizing constant, [78](#)
 - Saddlepoint approximations of the Fisher-Bingham distributions, [116](#)
- * **Random values simulation**
 - Simulation of random values from a Bingham distribution, [119](#)
 - Simulation of random values from a mixture of von Mises-Fisher distributions, [120](#)
 - Simulation of random values from rotationally symmetric distributions, [124](#)
 - Simulation of random values from some circular distributions, [126](#)
- * **Regression**
 - Directional-package, [4](#)
- * **Rejection sampling**
 - Simulation of random values from a Bingham distribution, [119](#)
- * **Rotation matrix**
 - Random sample of matrices in $SO(p)$, [107](#)
 - Rotation matrix from a rotation axis and angle of rotation, [112](#)
 - Rotation matrix to rotate a spherical vector along the direction of another, [114](#)
- * **SESPC distribution**
 - Contour plot (on the sphere) of the SESPC distribution, [34](#)
 - MLE of the SESPC distribution, [94](#)
- * **SO(p)**
 - Random sample of matrices in $SO(p)$, [107](#)
- * **Saddlepoint approximation**
 - Logarithm of the Kent distribution normalizing constant, [78](#)
 - Saddlepoint approximations of the Fisher-Bingham distributions,

- 116
- * **Simulated data**
 - Simulation of random values from a spherical Fisher-Bingham distribution, 122
 - Simulation of random values from a spherical Kent distribution, 123
 - * **Simulation of random values**
 - Simulation from a Bingham distribution using any symmetric matrix A, 117
 - * **Simulation**
 - Directional-package, 4
 - * **Spherical coordinates**
 - Euclidean transformation, 58
 - Inverse of the Euclidean transformation, 73
 - * **Spherical data**
 - Directional-package, 4
 - k-NN regression, 75
 - Lambert's equal area projection, 77
 - Spherical-spherical correlation, 137
 - Spherical-spherical regression, 138
 - Test for equality of concentration parameters for spherical data, 143
 - Tuning of the k-NN regression, 151
 - * **Spherical-Spherical regression**
 - Spherical-spherical regression, 138
 - * **Squared correlation**
 - Spherical-spherical correlation, 137
 - * **Summary statistics**
 - Summary statistics for circular data, 139
 - Summary statistics for grouped circular data, 140
 - * **Supervised classification**
 - k-NN algorithm using the arc cosine distance, 74
 - Tuning of the k-NN algorithm using the arc cosine distance, 150
 - * **Tuning of the bandwidth**
 - Tuning of the bandwidth parameter in the von Mises-Fisher kernel, 148
 - * **Tuning the bandwidth**
 - Tuning of the bandwidth parameter in the von Mises kernel, 147
 - * **Uniformity test**
 - Uniformity test for circular data, 153
 - * **Von Mises distribution**
 - Summary statistics for circular data, 139
 - Summary statistics for grouped circular data, 140
 - * **Von Mises-Fisher distributions**
 - Cross validation for estimating the classification rate, 42
 - Prediction in discriminant analysis based on ESAG distribution, 102
 - Prediction in discriminant analysis based on Purkayastha distribution, 103
 - Prediction in discriminant analysis based on von Mises-Fisher distribution, 104
 - * **Wood distribution**
 - Density of the Wood bimodal distribution on the sphere, 57
 - MLE of the Wood bimodal distribution on the sphere, 95
 - * **bivariate angular Gaussian**
 - MLE of some circular distributions, 85
 - * **circular data**
 - Directional-package, 4
 - MLE of some circular distributions, 85
 - * **directional data**
 - Angular central Gaussian random values simulation, 7
 - Conversion of cosines to azimuth and plunge, 39
 - * **k-NN regression**
 - k-NN regression, 75
 - Tuning of the k-NN regression, 151
 - * **maximum likelihood estimation**
 - MLE of the Kent distribution, 90
 - MLE of the SESPC distribution, 94

- * **random values simulation**
 - Angular central Gaussian random values simulation, [7](#)
- * **simulation**
 - Simulation of random values from the ESAG distribution, [128](#)
 - Simulation of random values from the SESPC distribution, [129](#)
- * **spherical data**
 - MLE of the SESPC distribution, [94](#)
 - Simulation of random values from the ESAG distribution, [128](#)
 - Simulation of random values from the SESPC distribution, [129](#)
- * **unit vectors**
 - Generation of unit vector(s) with a given angle, [63](#)
- * **von Mises distribution**
 - Tuning of the bandwidth parameter in the von Mises kernel, [147](#)
- * **von Mises kernel**
 - von Mises kernel density estimation, [154](#)
- * **von Mises-Fisher distribution**
 - Contour plots of some rotationally symmetric distributions, [38](#)
 - Cross validation in von Mises-Fisher discriminant analysis, [44](#)
 - Cross validation with ESAG discriminant analysis, [45](#)
 - Cross validation with Purkayastha discriminant analysis, [47](#)
 - Hypothesis test for von Mises-Fisher distribution over Kent distribution, [69](#)
 - Mixtures of Von Mises-Fisher distributions, [81](#)
 - Simulation of random values from rotationally symmetric distributions, [124](#)
 - Simulation of random values from some circular distributions, [126](#)
 - Tuning of the bandwidth parameter in the von Mises-Fisher kernel, [148](#)
- * **von Mises-Fisher kernel**
 - Contour plot of spherical data using a von Mises-Fisher kernel density estimate, [36](#)
- * **von Mises-Fisher**
 - von Mises-Fisher kernel density estimation for (hyper-)spherical data, [156](#)
- * **wrapped Cauchy distribution**
 - MLE of some circular distributions, [85](#)
- A test for testing the equality of the concentration parameters for circular data, [6](#)
- acg.mle, [8](#), [90](#), [128](#)
- acg.mle (MLE of (hyper-)spherical rotationally symmetric distributions), [82](#)
- africa (Maps of the world and the continents), [80](#)
- Angular central Gaussian random values simulation, [7](#)
- Anova for (hyper-)spherical data, [8](#)
- Anova for circular data, [10](#)
- Arotation, [41](#), [42](#), [58](#), [73](#), [108](#), [113](#), [115](#)
- Arotation (Rotation axis and angle of rotation given a rotation matrix), [111](#)
- asia (Maps of the world and the continents), [80](#)
- BIC for the model based clustering using mixtures of von Mises-Fisher distributions, [11](#)
- bic.mixvmf, [51](#), [82](#), [121](#)
- bic.mixvmf (BIC for the model based clustering using mixtures of von Mises-Fisher distributions), [11](#)
- Bootstrap 2-sample mean test for (hyper-)spherical data, [12](#)
- Bootstrap 2-sample mean test for circular data, [14](#)
- Bootstrap ANOVA for (hyper-)spherical data, [15](#)
- Bootstrap ANOVA for circular data, [17](#)
- cardio.mle (MLE of some circular distributions), [85](#)

- Check visually whether matrix Fisher samples is correctly generated or not, [18](#)
- `cipc.mle` (MLE of some circular distributions), [85](#)
- `cipc.reg` (Circular or angular regression), [22](#)
- `circ.cor1`, [24](#), [25](#), [93](#), [137](#), [139](#)
- `circ.cor1` (Circular correlations between two circular variables), [20](#)
- `circ.cor2`, [21](#), [22](#), [24](#), [25](#), [137](#), [139](#)
- `circ.cor2` (Circular correlations between two circular variables), [20](#)
- `circ.cors1` (Circular correlations between one and many circular variables), [19](#)
- `circ.cors2` (Circular correlations between one and many circular variables), [19](#)
- `circ.dcor`, [130](#)
- `circ.dcor` (Circular distance correlation between two circular variables), [21](#)
- `circ.summary`, [5](#), [65](#), [87](#), [90](#), [127](#), [128](#), [141](#)
- `circ.summary` (Summary statistics for circular data), [139](#)
- `circbeta.mle` (MLE of some circular distributions), [85](#)
- `circexp.mle` (MLE of some circular distributions), [85](#)
- `circlin.cor`, [21](#), [22](#), [24](#)
- `circlin.cor` (Circular-linear correlation), [24](#)
- `circpurka.reg` (Circular or angular regression), [22](#)
- Circular correlations between one and many circular variables, [19](#)
- Circular correlations between two circular variables, [20](#)
- Circular distance correlation between two circular variables, [21](#)
- Circular or angular regression, [22](#)
- Circular-linear correlation, [24](#)
- `colspml.mle`, [89](#)
- `colspml.mle` (Column-wise MLE of the angular Gaussian and the von Mises Fisher distributions), [25](#)
- Column-wise MLE of the angular Gaussian and the von Mises Fisher distributions, [25](#)
- Column-wise uniformity Watson test for circular data, [27](#)
- `colvm.mle` (Column-wise MLE of the angular Gaussian and the von Mises Fisher distributions), [25](#)
- `colwatsons` (Column-wise uniformity Watson test for circular data), [27](#)
- `conc.test`, [5](#), [7](#), [100](#), [144](#)
- `conc.test` (Test of equality of the concentration parameters for circular data), [144](#)
- Contour plot (on the plane) of the ESAG and Kent distributions without any data, [28](#)
- Contour plot (on the sphere) of a mixture of von Mises-Fisher distributions, [29](#)
- Contour plot (on the sphere) of some spherical rotationally symmetric distributions, [30](#)
- Contour plot (on the sphere) of the ESAG and Kent distributions, [32](#)
- Contour plot (on the sphere) of the SESPC distribution, [34](#)
- Contour plot of a mixture of von Mises-Fisher distributions model, [35](#)
- Contour plot of spherical data using a von Mises-Fisher kernel density estimate, [36](#)
- Contour plots of some rotationally symmetric distributions, [38](#)
- Conversion of cosines to azimuth and plunge, [39](#)
- Converting a rotation matrix on $SO(3)$ to an unsigned unit quaternion, [40](#)
- Converting an unsigned unit quaternion to rotation matrix on $SO(3)$, [41](#)
- `cosap` (Conversion of cosines to azimuth and plunge), [39](#)
- `cosnn`, [67](#)
- `cosnn` (The k-nearest neighbours using

- the cosinus distance), 145
- Cross validation for estimating the classification rate, 42
- Cross validation in von Mises-Fisher discriminant analysis, 44
- Cross validation with ESAG discriminant analysis, 45
- Cross validation with Purkayastha discriminant analysis, 47
- Cumulative distribution function of circular distributions, 48

- dcardio (Density of some circular distributions), 52
- dcipc (Density of some circular distributions), 52
- dcircbeta (Density of some circular distributions), 52
- dcircexp, 50
- dcircexp (Density of some circular distributions), 52
- dcircpurka, 50
- dcircpurka (Density of some circular distributions), 52
- Density of a mixture of von Mises-Fisher distributions, 50
- Density of some (hyper-)spherical distributions, 51
- Density of some circular distributions, 52
- Density of the SESPC distribution, 54
- Density of the spherical ESAG and Kent distributions, 56
- Density of the Wood bimodal distribution on the sphere, 57
- desag, 5, 54, 55, 58, 90, 128
- desag (Density of the spherical ESAG and Kent distributions), 56
- dgcpc (Density of some circular distributions), 52
- dggvm (Density of some circular distributions), 52
- dirda.cv, 62
- dirda.cv (Cross validation for estimating the classification rate), 42
- Directional-package, 4
- dirknn, 44–46, 48, 67, 103–105, 146, 151
- dirknn (k-NN algorithm using the arc cosinus distance), 74
- dirknn.tune, 75, 146, 153
- dirknn.tune (Tuning of the k-NN algorithm using the arc cosinus distance), 150
- dkent, 54, 58
- dkent (Density of the spherical ESAG and Kent distributions), 56
- dmixvmf (Density of a mixture of von Mises-Fisher distributions), 50
- dmmvm, 50
- dmmvm (Density of some circular distributions), 52
- dpkbd (Density of some (hyper-)spherical distributions), 51
- dpurka (Density of some (hyper-)spherical distributions), 51
- dsepc, 95, 129
- dsepc (Density of the SESPC distribution), 54
- dspcauchy (Density of some (hyper-)spherical distributions), 51
- dspml (Density of some circular distributions), 52
- dvm, 50
- dvm (Density of some circular distributions), 52
- dvmf (Density of some (hyper-)spherical distributions), 51
- dwood (Density of the Wood bimodal distribution on the sphere), 57
- dwrapcauchy (Density of some circular distributions), 52

- embed.aov, 144
- embed.aov (Anova for (hyper-)spherical data), 8
- embed.boot (Bootstrap 2-sample mean test for (hyper-)spherical data), 12
- embed.circaov, 7, 145
- embed.circaov (Anova for circular data), 10
- embed.perm (Permutation based 2-sample mean test for

- (hyper-)spherical data), 99
- embedcirc.boot (Bootstrap 2-sample mean test for circular data), 14
- embedcirc.perm (Permutation based 2-sample mean test for circular data), 100
- esag.contour, 33
- esag.contour (Contour plot (on the plane) of the ESAG and Kent distributions without any data), 28
- esag.da, 44, 103, 104
- esag.da (Cross validation with ESAG discriminant analysis), 45
- esag.mle, 52, 57, 68, 95, 96, 128, 133, 135, 136
- esag.mle (MLE of the ESAG distribution), 89
- esag.reg, 133
- esag.reg (Spherical regression using the ESAG distribution), 134
- esagda.pred (Prediction in discriminant analysis based on ESAG distribution), 102
- etoa (Transform unit vectors to angular data), 146
- euclid, 40, 71, 73, 77
- euclid (Euclidean transformation), 58
- euclid.inv, 40, 58
- euclid.inv (Inverse of the Euclidean transformation), 73
- Euclidean transformation, 58
- eul2rot, 40, 60
- eul2rot (Rotation matrix on $SO(3)$ from three Euler angles), 113
- Euler angles from a rotation matrix on $SO(3)$, 59
- europe (Maps of the world and the continents), 80
- f.rbing, 118, 123, 124
- f.rbing (Simulation of random values from a Bingham distribution), 119
- fb.saddle, 78, 91
- fb.saddle (Saddlepoint approximations of the Fisher-Bingham distributions), 116
- fishkent, 27, 68, 69
- fishkent (Hypothesis test for von Mises-Fisher distribution over Kent distribution), 69
- Forward Backward Early Dropping selection for circular data using the SPML regression, 60
- gcpc.mle (MLE of some circular distributions), 85
- gcpc.reg (Circular or angular regression), 22
- Generate random folds for cross-validation, 62
- Generation of unit vector(s) with a given angle, 63
- ggvm.mle, 53
- ggvm.mle (MLE of some circular distributions), 85
- Goodness of fit test for grouped data, 64
- group.gof, 50
- group.gof (Goodness of fit test for grouped data), 64
- group.vm, 140
- group.vm (Summary statistics for grouped circular data), 140
- Habeck's rotation matrix generation, 65
- habeck.rot (Habeck's rotation matrix generation), 65
- Haversine distance matrix, 66
- haversine.dist (Haversine distance matrix), 66
- hcf.aov, 13, 16, 100, 144
- hcf.aov (Anova for (hyper-)spherical data), 8
- hcf.boot, 9, 16, 100
- hcf.boot (Bootstrap 2-sample mean test for (hyper-)spherical data), 12
- hcf.circaov, 7, 15, 18, 101, 140, 145
- hcf.circaov (Anova for circular data), 10
- hcf.perm, 13
- hcf.perm (Permutation based 2-sample mean test for (hyper-)spherical data), 99
- hcfboot, 9, 13

- hcfboot (Bootstrap ANOVA for (hyper-)spherical data), 15
- hcfcirc.boot, 11
- hcfcirc.boot (Bootstrap 2-sample mean test for circular data), 14
- hcfcirc.perm (Permutation based 2-sample mean test for circular data), 100
- hcfcircboot, 11, 15
- hcfcircboot (Bootstrap ANOVA for circular data), 17
- hclr.aov, 11
- hclr.aov (Anova for (hyper-)spherical data), 8
- hclr.boot (Bootstrap 2-sample mean test for (hyper-)spherical data), 12
- hclr.circaov, 9
- hclr.circaov (Anova for circular data), 10
- hclr.perm (Permutation based 2-sample mean test for (hyper-)spherical data), 99
- hclrcirc.boot (Bootstrap 2-sample mean test for circular data), 14
- hclrcirc.perm (Permutation based 2-sample mean test for circular data), 100
- het.aov, 15, 18, 101, 144
- het.aov (Anova for (hyper-)spherical data), 8
- het.boot (Bootstrap 2-sample mean test for (hyper-)spherical data), 12
- het.circaov, 7, 145
- het.circaov (Anova for circular data), 10
- het.perm (Permutation based 2-sample mean test for (hyper-)spherical data), 99
- hetboot (Bootstrap ANOVA for (hyper-)spherical data), 15
- hetcirc.boot (Bootstrap 2-sample mean test for circular data), 14
- hetcirc.perm (Permutation based 2-sample mean test for circular data), 100
- hetcircboot (Bootstrap ANOVA for circular data), 17
- Hypothesis test for IAG distribution over the ESAG distribution, 67
- Hypothesis test for SIPC distribution over the SESPC distribution, 68
- Hypothesis test for von Mises-Fisher distribution over Kent distribution, 69
- iag.mle, 80, 90, 125
- iag.mle (MLE of (hyper-)spherical rotationally symmetric distributions), 82
- iag.reg, 135, 136
- iag.reg (Spherical regression using rotationally symmetric distributions), 132
- iagd (Density of some (hyper-)spherical distributions), 51
- iagesag, 68–70, 109
- iagesag (Hypothesis test for IAG distribution over the ESAG distribution), 67
- Interactive 3D plot of spherical data, 71
- Inverse of Lambert's equal area projection, 72
- Inverse of the Euclidean transformation, 73
- k-NN algorithm using the arc cosinus distance, 74
- k-NN regression, 75
- kent.contour, 32, 33, 39
- kent.contour (Contour plot (on the plane) of the ESAG and Kent distributions without any data), 28
- kent.logcon, 116
- kent.logcon (Logarithm of the Kent distribution normalizing constant), 78
- kent.mle, 52, 57, 68, 70, 78, 90, 91, 96, 110, 116, 132, 143
- kent.mle (MLE of the Kent distribution), 90
- kmeans, 11, 81
- knn.reg, 44, 103–105, 153
- knn.reg (k-NN regression), 75
- knnreg.tune, 76

- knnreg.tune (Tuning of the k-NN regression), 151
 kuiper, 27, 107, 109
 kuiper (Uniformity test for circular data), 153

 lambert, 58, 71–73, 115
 lambert (Lambert’s equal area projection), 77
 Lambert’s equal area projection, 77
 lambert.inv, 77, 115
 lambert.inv (Inverse of Lambert’s equal area projection), 72
 Logarithm of the Kent distribution normalizing constant, 78
 lr.aov, 144
 lr.aov (Anova for (hyper-)spherical data), 8
 lr.boot (Bootstrap 2-sample mean test for (hyper-)spherical data), 12
 lr.circaov, 7, 145
 lr.circaov (Anova for circular data), 10
 lr.perm (Permutation based 2-sample mean test for (hyper-)spherical data), 99
 lrcirc.boot (Bootstrap 2-sample mean test for circular data), 14
 lrcirc.perm (Permutation based 2-sample mean test for circular data), 100

 makefolds, 43
 makefolds (Generate random folds for cross-validation), 62
 Many simple circular or angular regressions, 79
 Maps of the world and the continents, 80
 matrixfisher.mle, 119
 matrixfisher.mle (MLE of the Matrix Fisher distribution on $SO(3)$), 92
 meandir.test (Test for a given mean direction), 142
 mediandir, 98
 mediandir (Spherical and hyperspherical median), 131
 mediandir_2 (Spherical and hyperspherical median), 131

 Mixtures of Von Mises-Fisher distributions, 81
 mixvmf.contour, 12, 82
 mixvmf.contour (Contour plot of a mixture of von Mises-Fisher distributions model), 35
 mixvmf.mle, 5, 12, 30, 36, 45, 51, 75, 105, 121, 151
 mixvmf.mle (Mixtures of Von Mises-Fisher distributions), 81
 MLE of (hyper-)spherical rotationally symmetric distributions, 82
 MLE of some circular distributions, 85
 MLE of some circular distributions with multiple samples, 88
 MLE of the ESAG distribution, 89
 MLE of the Kent distribution, 90
 MLE of the Matrix Fisher distribution on $SO(3)$, 92
 MLE of the Purkayashta distribution, 93
 MLE of the SESPC distribution, 94
 MLE of the Wood bimodal distribution on the sphere, 95
 mmvm.mle (MLE of some circular distributions), 85
 multispml.mle (MLE of some circular distributions with multiple samples), 88
 multivm.mle (MLE of some circular distributions with multiple samples), 88
 multivmf.mle (MLE of (hyper-)spherical rotationally symmetric distributions), 82

 Naive Bayes classifiers for circular data, 96
 Normalised spatial median for directional data, 98
 north.america (Maps of the world and the continents), 80
 nsmedian, 132
 nsmedian (Normalised spatial median for directional data), 98

 oceania (Maps of the world and the continents), 80
 pc.test, 68, 70

- pc.test (Hypothesis test for SIPC distribution over the SESPC distribution), [68](#)
- pccardio (Cumulative distribution function of circular distributions), [48](#)
- pcipc (Cumulative distribution function of circular distributions), [48](#)
- pcircbeta (Cumulative distribution function of circular distributions), [48](#)
- pcircexp (Cumulative distribution function of circular distributions), [48](#)
- pcircpurka (Cumulative distribution function of circular distributions), [48](#)
- Permutation based 2-sample mean test for (hyper-)spherical data, [99](#)
- Permutation based 2-sample mean test for circular data, [100](#)
- pgcpc (Cumulative distribution function of circular distributions), [48](#)
- pkbd.contour (Contour plots of some rotationally symmetric distributions), [38](#)
- pkbd.mle (MLE of (hyper-)spherical rotationally symmetric distributions), [82](#)
- pmmvm (Cumulative distribution function of circular distributions), [48](#)
- Prediction in discriminant analysis based on ESAG distribution, [102](#)
- Prediction in discriminant analysis based on Purkayastha distribution, [103](#)
- Prediction in discriminant analysis based on von Mises-Fisher distribution, [104](#)
- Prediction with some naive Bayes classifiers for circular data, [105](#)
- Projections based test of uniformity, [106](#)
- pspml (Cumulative distribution function of circular distributions), [48](#)
- pctest, [109](#), [154](#)
- pctest (Projections based test of uniformity), [106](#)
- purka.contour (Contour plots of some rotationally symmetric distributions), [38](#)
- purka.da (Cross validation with Purkayastha discriminant analysis), [47](#)
- purka.mle, [50](#), [87](#), [89](#)
- purka.mle (MLE of the Purkayastha distribution), [93](#)
- purkada.pred (Prediction in discriminant analysis based on Purkayastha distribution), [103](#)
- pvm, [65](#)
- pvm (Cumulative distribution function of circular distributions), [48](#)
- pwrapcauchy (Cumulative distribution function of circular distributions), [48](#)
- quat2rot, [41](#)
- quat2rot (Converting an unsigned unit quaternion to rotation matrix on $SO(3)$), [41](#)
- racg, [85](#), [125](#), [127](#)
- racg (Angular central Gaussian random values simulation), [7](#)
- Random sample of matrices in $SO(p)$, [107](#)
- rayleigh, [107](#), [143](#), [154](#)
- rayleigh (Rayleigh's test of uniformity), [108](#)
- Rayleigh's test of uniformity, [108](#)
- rbingham, [63](#), [116](#), [120](#), [123](#), [124](#)
- rbingham (Simulation from a Bingham distribution using any symmetric matrix A), [117](#)
- rcipc (Simulation of random values from some circular distributions), [126](#)
- rcircbeta (Simulation of random values from some circular distributions), [126](#)
- rcircexp (Simulation of random values from some circular

- distributions), 126
- rcircpurka (Simulation of random values from some circular distributions), 126
- Read a file as a Filebacked Big Matrix, 110
- read.fbm (Read a file as a Filebacked Big Matrix), 110
- resag, 90
- resag (Simulation of random values from the ESAG distribution), 128
- rfb, 5, 63, 116, 118, 120, 123–125
- rfb (Simulation of random values from a spherical Fisher–Bingham distribution), 122
- rgcpc (Simulation of random values from some circular distributions), 126
- riag (Simulation of random values from rotationally symmetric distributions), 124
- rkent, 52, 57, 118, 120, 123
- rkent (Simulation of random values from a spherical Kent distribution), 123
- rmatrixfisher, 92
- rmatrixfisher (Simulation from a Matrix Fisher distribution on $SO(3)$), 118
- rmixvmf, 12, 82, 125
- rmixvmf (Simulation of random values from a mixture of von Mises–Fisher distributions), 120
- rot.matrix, 42, 108, 111, 115
- rot.matrix (Rotation matrix from a rotation axis and angle of rotation), 112
- rot2eul, 114
- rot2eul (Euler angles from a rotation matrix on $SO(3)$), 59
- rot2quat, 42
- rot2quat (Converting a rotation matrix on $SO(3)$ to an unsigned unit quaternion), 40
- rotation, 41, 42, 108, 111, 113
- rotation (Rotation matrix to rotate a spherical vector along the direction of another), 114
- Rotation axis and angle of rotation given a rotation matrix, 111
- Rotation matrix from a rotation axis and angle of rotation, 112
- Rotation matrix on $SO(3)$ from three Euler angles, 113
- Rotation matrix to rotate a spherical vector along the direction of another, 114
- rpkbd (Simulation of random values from rotationally symmetric distributions), 124
- rsepc, 95
- rsepc (Simulation of random values from the SESPC distribution), 129
- rsop, 111, 113, 115
- rsop (Random sample of matrices in $SO(p)$), 107
- rspcauchy (Simulation of random values from rotationally symmetric distributions), 124
- rspml (Simulation of random values from some circular distributions), 126
- rvmf, 8, 39, 51, 63, 85, 87, 118, 120, 121, 123, 124, 127
- rvmf (Simulation of random values from rotationally symmetric distributions), 124
- rvmnises, 8, 54, 65, 87, 125, 140, 141, 154
- rvmnises (Simulation of random values from some circular distributions), 126
- rwrapcauchy (Simulation of random values from some circular distributions), 126
- Saddlepoint approximations of the Fisher–Bingham distributions, 116
- sespc.mle, 55, 69, 129
- sespc.mle (MLE of the SESPC distribution), 94
- sespc.reg (Spherical regression using the SESPC distribution), 135
- Simulation from a Bingham distribution using any symmetric matrix A ,

- 117
- Simulation from a Matrix Fisher distribution on $SO(3)$, 118
- Simulation of random values from a Bingham distribution, 119
- Simulation of random values from a mixture of von Mises-Fisher distributions, 120
- Simulation of random values from a spherical Fisher-Bingham distribution, 122
- Simulation of random values from a spherical Kent distribution, 123
- Simulation of random values from rotationally symmetric distributions, 124
- Simulation of random values from some circular distributions, 126
- Simulation of random values from the ESAG distribution, 128
- Simulation of random values from the SESPC distribution, 129
- sipc.mle, 95
- sipc.mle (MLE of (hyper-)spherical rotationally symmetric distributions), 82
- sipc.reg (Spherical regression using rotationally symmetric distributions), 132
- south.america (Maps of the world and the continents), 80
- spcauchy.contour (Contour plots of some rotationally symmetric distributions), 38
- spcauchy.mle (MLE of (hyper-)spherical rotationally symmetric distributions), 82
- spcauchy.mle2 (MLE of (hyper-)spherical rotationally symmetric distributions), 82
- spher.cor, 24, 139
- spher.cor (Spherical-spherical correlation), 137
- spher.dcor, 22
- spher.dcor (Spherical and hyper-spherical distance correlation), 130
- spher.esag.contour, 29, 30, 32, 35
- spher.esag.contour (Contour plot (on the sphere) of the ESAG and Kent distributions), 32
- spher.kent.contour (Contour plot (on the sphere) of the ESAG and Kent distributions), 32
- spher.mixvmf.contour, 32
- spher.mixvmf.contour (Contour plot (on the sphere) of a mixture of von Mises-Fisher distributions), 29
- spher.pkbd.contour (Contour plot (on the sphere) of some spherical rotationally symmetric distributions), 30
- spher.purka.contour, 33
- spher.purka.contour (Contour plot (on the sphere) of some spherical rotationally symmetric distributions), 30
- spher.reg, 24, 76, 137, 153
- spher.reg (Spherical-spherical regression), 138
- spher.sespc.contour, 95
- spher.sespc.contour (Contour plot (on the sphere) of the SESPC distribution), 34
- spher.spcauchy.contour, 35
- spher.spcauchy.contour (Contour plot (on the sphere) of some spherical rotationally symmetric distributions), 30
- spher.vmf.contour, 30
- spher.vmf.contour (Contour plot (on the sphere) of some spherical rotationally symmetric distributions), 30
- spherconc.test, 100
- spherconc.test (Test for equality of concentration parameters for spherical data), 143
- sphereplot, 39, 81, 90, 91, 96, 139, 144
- sphereplot (Interactive 3D plot of spherical data), 71
- Spherical and hyper-spherical distance correlation, 130

- Spherical and hyperspherical median, [131](#)
- Spherical regression using rotationally symmetric distributions, [132](#)
- Spherical regression using the ESAG distribution, [134](#)
- Spherical regression using the SESPC distribution, [135](#)
- Spherical-spherical correlation, [137](#)
- Spherical-spherical regression, [138](#)
- spml.fbed (Forward Backward Early Dropping selection for circular data using the SPML regression), [60](#)
- spml.mle, [26](#), [61](#), [80](#), [128](#), [140](#)
- spml.mle (MLE of some circular distributions), [85](#)
- spml.nb (Naive Bayes classifiers for circular data), [96](#)
- spml.reg, [5](#), [20](#), [21](#), [25](#), [26](#), [61](#), [76](#), [80](#), [133](#), [135](#), [136](#), [139](#)
- spml.reg (Circular or angular regression), [22](#)
- spml.regs, [61](#)
- spml.regs (Many simple circular or angular regressions), [79](#)
- spmlnb.pred (Prediction with some naive Bayes classifiers for circular data), [105](#)
- Summary statistics for circular data, [139](#)
- Summary statistics for grouped circular data, [140](#)
- tang.conc (A test for testing the equality of the concentration parameters for circular data), [6](#)
- Test for a given mean direction, [142](#)
- Test for equality of concentration parameters for spherical data, [143](#)
- Test of equality of the concentration parameters for circular data, [144](#)
- The k-nearest neighbours using the cosine distance, [145](#)
- Transform unit vectors to angular data, [146](#)
- Tuning of the bandwidth parameter in the von Mises kernel, [147](#)
- Tuning of the bandwidth parameter in the von Mises-Fisher kernel, [148](#)
- Tuning of the k-NN algorithm using the arc cosine distance, [150](#)
- Tuning of the k-NN regression, [151](#)
- Uniformity test for circular data, [153](#)
- vec (Generation of unit vector(s) with a given angle), [63](#)
- visual.check (Check visually whether matrix Fisher samples is correctly generated or not), [18](#)
- vm.kde, [140](#), [141](#), [148](#), [149](#), [156](#)
- vm.kde (von Mises kernel density estimation), [154](#)
- vm.nb, [106](#)
- vm.nb (Naive Bayes classifiers for circular data), [96](#)
- vmf.contour, [29](#), [36](#), [37](#), [71](#)
- vmf.contour (Contour plots of some rotationally symmetric distributions), [38](#)
- vmf.da, [46](#), [48](#), [105](#), [151](#)
- vmf.da (Cross validation in von Mises-Fisher discriminant analysis), [44](#)
- vmf.kde, [37](#), [148](#), [149](#), [155](#)
- vmf.kde (von Mises-Fisher kernel density estimation for (hyper-)spherical data), [156](#)
- vmf.kerncontour, [29](#), [36](#), [39](#), [149](#)
- vmf.kerncontour (Contour plot of spherical data using a von Mises-Fisher kernel density estimate), [36](#)
- vmf.mle, [26](#), [39](#), [45](#), [70](#), [87](#), [91](#), [96](#), [110](#), [125](#), [132](#), [133](#), [137](#), [140](#), [143](#), [154](#), [156](#)
- vmf.mle (MLE of (hyper-)spherical rotationally symmetric distributions), [82](#)
- vmf.reg (Spherical regression using rotationally symmetric distributions), [132](#)

- vmfda.pred, [44–46](#), [48](#), [75](#), [103](#), [104](#)
- vmfda.pred (Prediction in discriminant analysis based on von Mises-Fisher distribution), [104](#)
- vmfkde.tune, [36](#), [37](#), [148](#), [155](#), [156](#)
- vmfkde.tune (Tuning of the bandwidth parameter in the von Mises-Fisher kernel), [148](#)
- vmkde.tune, [149](#), [155](#), [156](#)
- vmkde.tune (Tuning of the bandwidth parameter in the von Mises kernel), [147](#)
- vmnb.pred, [97](#), [147](#)
- vmnb.pred (Prediction with some naive Bayes classifiers for circular data), [105](#)
- von Mises kernel density estimation, [154](#)
- von Mises-Fisher kernel density estimation for (hyper-)spherical data, [156](#)

- watson, [27](#)
- watson (Uniformity test for circular data), [153](#)
- wood.mle, [57](#), [58](#), [91](#)
- wood.mle (MLE of the Wood bimodal distribution on the sphere), [95](#)
- worldmap (Maps of the world and the continents), [80](#)
- wrapcauchy.mle (MLE of some circular distributions), [85](#)