Package 'lomb'

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Type Package

Title Lomb-Scargle Periodogram

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Author Thomas Ruf, partially based on C original by Press et al. (Numerical Recipes) and the Python module Astropy.

Maintainer Thomas Ruf <Thomas.Ruf@vetmeduni.ac.at>

Description Computes the Lomb-Scargle Periodogram for unevenly sampled time series. Includes a randomization procedure to obtain exact p-values.

License GPL (>= 3)

Encoding UTF-8

LazyData true

Imports ggplot2, gridExtra, plotly, pracma

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`lomb-package` *Lomb-Scargle Periodogram*

Description

The Lomb-Scargle periodogram is the most widely used method to detect even weak periodic components in unequally sampled time series. It can also be used for equally sampled time series.

Details

Package:	lomb
Type:	Package
Version:	2.1.0
Date:	2022-02-22
License:	GPL-3

Function `lsp` computes the Lomb-Scargle periodogram for unevenly sampled times series (e.g., series with missing data). P-values for the highest peak in the periodogram are computed from the exponential distribution. Alternatively, function `randlsp` computes a p-value for the largest peak in the periodogram by repeatedly randomising the time-series sequence. Both functions allow setting the range of frequencies to be inspected, as well as the stepsize (oversampling factor) used for frequency scanning.

Author(s)

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Maintainer: Thomas Ruf <thomas.ruf@vetmeduni.ac.at>

References

Ruf, T. (1999) The Lomb-Scargle Periodogram in Biological Rhythm Research: Analysis of Incomplete and Unequally Spaced Time-Series. *Biological Rhythm Research* **30**: 178–201

Examples

```
data(lynx)
lsp(lynx)
```

getpeaks *Retrieve periodogram peaks*

Description

Retrieves and displays the npeaks largest peaks in the periodogram-

Usage

```
getpeaks(object,npeaks,plotit)
```

Arguments

object	object must be of class "lsp"
npeaks	number of peaks to get
plotit	if TRUE show plot

Value

Returns a list with

data	A dataframe with times an heights of peaks
plot	An annotated periodogram

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>

See Also

show

Examples

```
per=lsp(lynx,ofac=5)
getpeaks(per,6) # obtain the 6 largest  peaks
```

ggamma *Utility function called by pbaluev()*

Description

From astropy.timeseries

Usage

```
ggamma(N)
```

Arguments

N	A positive number

Value

sqrt(2 / N) * exp(lgamma(N / 2) - lgamma((N - 1) / 2))

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>.

References

VanderPlas, J. & Ivezic, Z. (2015) Periodograms for Multiband Astronomical Time Series.*The Astrophysical Journal* **812.1**:18

See Also

pbaluev

Examples

```
ggamma(3)
```

ibex *Rumen Temperature In An Alpine Ibex*

Description

Telemetric measurements of rumen temperature in a free-living alpine ibex (*Capra ibex*) measured at unequal time intervals.

Usage

```
data(ibex)
```

Format

A data frame with 1201 observations on 3 variables.

date a character variable giving date and time of measurements.

hours a numerical variable giving hours elapsed since the first measurement.

temp a numerical variable giving rumen (stomach) temperature in degrees Celsius.

Source

A subset of data from Signer, C., Ruf, T., Arnold, W. (2011) *Functional Ecology* **25**: 537-547.

Examples

```
data(ibex)
datetime <- as.POSIXlt(ibex$date)
plot(datetime,ibex$temp,pch=19,cex=0.3)
```

levopt *compute level*

Description

utility function to determine deviation from p-value

Usage

```
levopt(x, alpha, fmax, tm)
```

Arguments

x

alpha

fmax

tm

Value

(log(prob)-log(alpha))^2

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>.

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lsp *Lomb-Scargle Periodogram*

Description

Computes the Lomb-Scargle periodogram for a time series with irregular (or regular) sampling intervals. Allows selecting a frequency range to be inspected, as well as the spacing of frequencies scanned.

Usage

```
lsp(x, times = NULL, from = NULL, to = NULL, type = c("frequency", "period"),
    ofac = 1, alpha = 0.01, normalize=c("standard","press"), plot = TRUE, ...)
```

Arguments

x	The data to be analysed. x can be either a two-column numerical dataframe or matrix, with sampling times in column 1 and measurements in column 2, a single numerical vector containing measurements, or a single vector ts object (which will be converted to a numerical vector).
times	If x is a single vector, times can be provided as a numerical vector of equal length containing sampling times. If x is a vector and times is NULL, the data are assumed to be equally sampled and times is set to 1:length(x).
from	The starting frequency (or period, depending on type) to begin scanning for periodic components.
to	The highest frequency (or period, depending on type) to scan.
type	Either "frequency" (the default) or "period". Determines the type of the periodogram x-axis.
ofac	The oversampling factor. Must be an integer>=1. Larger values of ofac lead to finer scanning of frequencies but may be time-consuming for large datasets and/or large frequency ranges (from...to).
alpha	The significance level. The periodogram plot shows a horizontal dashed line. Periodogram peaks exceeding this line can be considered significant at alpha. Defaults to 0.01. Only used if plot=TRUE.

normalize	The type of normalization used, either "standard" or "press". If normalization is standard (the default) the periodogram is confined to the interval 0-1, and the statistical significance of the largest peak in the periodogram is computed according to Baluev (2008).if normalization is set to "press" the periodogram will be normalized using the factor 1/(2 * var(y)) and the p-value for the significance of the largest peak in the periodogram is computed from the exponential distribution, as outlined in Press et al. (1994), see below
plot	Logical. If plot=TRUE the periodogram is plotted.
...	Further graphical parameters affecting the periodogram plot.

Details

For a more robust - but potentially time-consuming estimation of p-values (when n is large) see randlsp.

Significance levels in both lsp and randlsp increase with the number of frequencies inspected. Therefore, if the frequency-range of interest can be narrowed down *a priori*, use arguments "from" and "to" to do so.

Value

A named list with the following components:

normalize	The type of normalization used.
scanned	A vector containing the frequencies/periods scanned.
power	A vector containing the normalised power corresponding to scanned frequencies/periods.
data	Names of the data vectors analysed.
n	The length of the data vector.
type	The periodogram type used, either "frequency" or "period".
ofac	The oversampling factor used.
n.out	The length of the output (powers). This can be >n if ofac >1.
alpha	The false alarm probability used.
sig.level	Powers > sig.level can be considered significant peaks at p=alpha.
peak	The maximum power in the frequency/period interval inspected.
peak.at	The frequency/period at which the maximum peak occurred.
p.value	The probability that the maximum peak occurred by chance.

Note

For a description of the properties of the Lomb-Scargle Periodogram, its computation and comparison with other methods see Ruf, T. (1999). Function lsp uses the algorithm given by Press et al (1994). The Lomb-Scargle Periodogram was originally proposed by Lomb N.R. (1976) and further extended by Scargle J.D. (1982). An improved method for assessing the statistical significance of candidate periodicities by Baluev (2008), based on extreme value theory, is also implemented. This implementation uses code modified from the astropy.timeseries Python package (VanderPlas et al. 2012, 2015).

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at> based on code by Press et al (1994).

References

Baluev, R. V. (2008). Assessing the statistical significance of periodogram peaks. *Monthly Notices of the Royal Astronomical Society*, **385(3)**, 1279-1285.

Lomb N.R. (1976) Least-squares frequency analysis of unequally spaced data. *Astrophysics and Space Science* **39**:447–462

Press W.H., Teukolsky S.A., Vetterling S.T., Flannery, B.P. (1994) *Numerical recipes in C: the art of scientific computing*.2nd edition. Cambridge University Press, Cambridge, 994pp.

Ruf, T. (1999) The Lomb-Scargle Periodogram in Biological Rhythm Research: Analysis of Incomplete and Unequally Spaced Time-Series. *Biological Rhythm Research* **30**: 178–201.

Scargle J.D. (1982) Studies in astronomical time series. II. Statistical aspects of spectral analysis of unevenly spaced data. *The Astrophysical Journal* **302**: 757–763.

VanderPlas, J., Connolly, A. Ivezic, Z. & Gray, A. (2012) Introduction to astroML: Machine learning for astrophysics. *Proceedings of the Conference on Intelligent Data Understanding*

VanderPlas, J. & Ivezic, Z. (2015) Periodograms for Multiband Astronomical Time Series.*The Astrophysical Jounal* **812.1**:18

See Also

randlsp summary.lsp

Examples

```
# ibex contains an unevenly sampled time series
data(ibex)
lsp(ibex[,2:3],ofac=5)
lsp(ibex$temp,times=ibex$hours,type='period',ofac=5)

# lynx contains evenly sampled data
lsp(lynx)
lynx.spec <- lsp(lynx,type='period',from=2,to=20,ofac=5)
summary(lynx.spec)

# generate unevenly sampled data
time=(runif(200,1,1000))
y=2*cos(time/6)+rnorm(200,0,4)
lsp(y,times=time,ofac=10, to=0.3)
```

pbaluev *False alarm probability*

Description

Computes the statistical significance of peaks (range 0-1) in the standardized perodogram. Typically not called by the user.

Usage

```
pbaluev(Z,fmax,tm)
```

Arguments

Z	the height of a periodogram peak
fmax	the highest frequency inspected
tm	a vector with measurement timepoints

Details

Based on results in extreme value theory, improved analytic estimations of false alarm probabilities are given.

Value

Returns the significance of the largest peak in the periodogram.

Note

Code based on astropy.timeseries

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>.

References

Baluev, R. V. (2008). Assessing the statistical significance of periodogram peaks. *Monthly Notices of the Royal Astronomical Society*, **385(3)**, 1279-1285.

See Also

summary.lsp

Examples

```
pbaluev(0.19,2.0,1:100)
```

pershow *show periodogram*

Description

Shows a periodogram in browser window as line and dot plot. When moving the cursor close to dots times an peak-heights of the periodogram are shown.

Usage

```
pershow(object) # object of class "lsp"
```

Arguments

object

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>

See Also

getpeaks

Examples

```
per=lsp(lynx,ofac=5)
pershow(per)
```

plot.lsp *Plot Lomb-Scargle Periodogram*

Description

Plots the normalised power as a function of frequency (or period, depending on type in function lsp).

Usage

```
## S3 method for class 'lsp'
plot(x, main = "Lomb-Scargle Periodogram", xlabel = NULL,
    ylabel = "normalized power", level = TRUE, plot=TRUE, ...)
```

Arguments

x	Object of class lsp as returned from function lsp.
main	Character. Main title of the periodogram plot. Defaults to "Lomb-Sargle Periodogram".
xlabel	Character. X-axis label of the periodogram plot.
ylabel	Character. Y-axis label of the periodogram plot.
level	Logical. If TRUE, the significance level is displayed as a dashed line.
plot	If TRUE, the periodogram is plotted.
...	Additional graphics parameters

Details

Usually, this function is only called by function lsp. It maybe called by the user for some control of the output. For better control, plot results from lsp ($scanned, $power) as desired.

Value

Invisibly returns the object of class lsp it is called with.

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>

See Also

lsp

Examples

```
data(ibex)
ibex.spec <- lsp(ibex[,2:3],type='period', from=12,to=36,ofac=10, plot=FALSE)

plot.lsp(ibex.spec, main="Tb in Capra ibex",xlabel="Period (h)",ylabel="Power",level=FALSE)
```

---

randlsp *Randomise Lomb-Scargle Periodogram*

Description

randlsp is used to obtain robust p-values for the significance of the largest peak in a Lomb-Scargle periodogram by randomisation. The data sequence is scrambled repeatedly and the probability of random peaks reaching or exceeding the peak in the original (unscrambled) periodogram is computed.

Usage

```
randlsp(repeats=1000,x, times = NULL, from = NULL, to = NULL,
    type = c("frequency", "period"), ofac = 1, alpha = 0.01,
    plot = TRUE, trace = TRUE, ...)
```

Arguments

repeats	An integer determining the number of repeated randomisations. Large numbers (>=1000) are better but can make the procedure time-consuming.
x	The data to be analysed. x can be either a two-column numerical dataframe or matrix, with sampling times in columnn 1 and measurements in column 2, a single numerical vector containing measurements, or a single vector ts object (which will be converted to a numerical vector).
times	If x is a single vector, times can be provided as a numerical vector of equal length containing sampling times. If x is a vector and times is NULL, the data are assumed to be equally sampled and times is set to 1:length(x).
from	The starting frequency (or period, depending on type) to begin scanning for periodic components.
to	The highest frequency (or period, depending on type) to scan.
type	Either "frequency" (the default) or "period". Determines the type of the periodogram x-axis.
ofac	The oversampling factor. Must be an integer >=1. Larger values of ofac lead to finer scanning of frequencies but may be time-consuming for large datasets and/or large frequency ranges (from...to).
alpha	The significance level. The periodogram plot shows a horizontal dashed line. Periodogram peaks exceeding this line can be considered significant at alpha. Defaults to 0.01. Only used if plot=TRUE.
plot	Logical. If TRUE, two plots are displayed (i) The periodogram of the original (unscrambled) data (ii) A histogram of peaks occurring by chance during sequence randomisation. A vertical line is drawn at the height of the peak in a periodogram of the original data.
trace	Logical. If TRUE, information about the progress of the randomisation procedure is printed during the running of randlsp.
...	Additional graphical parameters affecting the histogram plot.

Details

Function randlsp preserves the actual measurement intervals, which may affect the periodogram (see Nemec & Nemec 1985, below). Hence, this is a conservative randomisation procedure.

P-values from both randlsp and lsp increase with the number of frequencies inspected. Therefore, if the frequency-range of interest can be narrowed down *a priori*, use arguments "from" and "to" to do so.

Value

A named list with the following items:

scanned	A vector containing the frequencies/periods scanned.
power	A vector containing the normalised power corresponding to scanned frequencies/periods.
data	Names of the data vectors analysed.
n	The length of the data vector.
type	The periodogram type used, either "frequency" or "period".
ofac	The oversampling factor used.
n.out	The length of the output (powers). This can be >n if ofac >1.
peak	The maximum power in the frequency/period interval inspected.
peak.at	The frequency/period at which the maximum peak occurred.
random.peaks	A vector of peaks (with length=repeats) of maximum power values computed from randomised data.
repeats	The number of randomisations.
p.value	The probability that the peak in the original data occurred by chance, computed from randomising the data sequence.

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>

References

Nemec A.F.L, Nemec J.M. (1985) A test of significance for periods derived using phase-dispersion-miminimization techniques. *The Astronomical Journal* **90**:2317–2320

See Also

lsp

Examples

```
data(lynx)
set.seed(444)
rand.times <- sample(1:length(lynx),30) # select a random vector of sampling times
randlsp(repeats=1000,lynx[rand.times],times=rand.times)
```

summary.lsp *Summarise Lomb-Scargle Periodogram Results*

Description

Summary method for class lsp.

Usage

```
## S3 method for class 'lsp'
summary(object,...)
```

Arguments

object	an object of class lsp.
...	currently, no other arguments are required.

Value

summary.lsp returns a one column data.frame with results from function lsp. Row names and contents are as follows:

Time	Name of the sampling time variable.
Data	Name of the measured variable.
Type	either "frequency" or "period".
Oversampling factor	The degree of oversampling (>=1).
From	The lowest frequency (or period, depending on type) inspected.
To	The highest frequency (or period, depending on type) inspected.
# frequencies	The number of frequencies (or periods, depending on type) inspected.
PNmax	The peak normalised power in the periodogram.
At frequency	The frequency at which PNmax occurred.
At period	The period at which PNmax occurred.
P-value (PNmax)	The probability that PNmax occurred by chance, computed from the exponential distribution.

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>

See Also

lsp

Examples

```
data(lynx)
summary(lsp(lynx))
```

`summary.randlsp` *Summarise Randomised Lomb-Scargle Periodogram Results*

Description

Summary method for class randlsp.

Usage

```
## S3 method for class 'randlsp'
summary(object,...)
```

Arguments

`object`	an object of class randlsp.
`...`	currently, no other arguments are required.

Value

summary.randlsp returns a one column data.frame with results from function randlsp. Row names and contents are as follows:

`Time`	Name of the sampling time variable.
`Data`	Name of the measured variable.
`Type`	either "frequency" or "period".
`Oversampling`	The degree of oversampling (>=1).
`From`	The lowest frequency (or period, depending on type) inspected.
`To`	The highest frequency (or period, depending on type) inspected.
`# frequencies`	The number of frequencies (or periods, depending on type) inspected.
`PNmax`	The peak normalised power in the periodogram.
`At frequency`	The frequency at which PNmax occurred.
`At period`	The period at which PNmax occurred.
`Repeats`	The number of randomisations.
`P-value (PNmax)`	The probability that PNmax occurred by chance, computed from randomising the data sequence.

Author(s)

Thomas Ruf <thomas.ruf@vetmeduni.ac.at>

See Also

randlsp

Examples

```
data(lynx)
summary(randlsp(repeats=500,lynx))
```

---

theme_lsp *lsp theme for ggplot2*

Description

Import lsp ggplot2 theme. It builds on theme_bw.

Usage

```
theme_lsp(bs=18)
```

Arguments

bs	basesize of font

Value

A theme element

Examples

```
plot(lsp(lynx))+theme_lsp(25)
```

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