Package 'cosinor2'

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Title Extended Tools for Cosinor Analysis of Rhythms

Description Statistical procedures for calculating population–mean cosinor, non–stationary cosinor, estimation of best–fitting period, tests of population rhythm differences and more. See Cornélissen, G. (2014). <doi:10.1186/1742-4682-11-16>.

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Imports cowplot (>= 0.9.3), scales (>= 1.0.0), magrittr (>= 1.5),
   stringr (>= 1.3.1), purrr(>= 0.2.5), ggplot2 (>= 3.0.0),
   matrixStats (>= 0.52.2), Hmisc (>= 4.0-3)

License GPL-3

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RoxygenNote 6.1.0

LazyData True

URL https://github.com/amutak/cosinor2

BugReports https://github.com/amutak/cosinor2/issues

NeedsCompilation no

Repository CRAN

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Suggests knitr, rmarkdown

VignetteBuilder knitr

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correct.acrophase   *Acrophase Correction*

Description

Corrects the value of the acrophase parameter of the cosinor model, placing it in the appropriate quadrant.

Usage

```
correct.acrophase(x)
```

Arguments

x   An object of the cosinor.lm class.

Details

The acrophase parameter of a cosinor model is found by solving an equation with inverse tangent of an expression which contains linearized cosinor parameters. However, multiple numeric entities may result in a same value of tangent and just calculating the inverse tangent may result with the wrong value of the acrophase. This function corrects the acrophase from the cosinor.lm object according to the procedure from Bingham et al. (1982). More specifically, the acrophase is calculated as:

$$K + g * arctan|\frac{\gamma}{\beta}|$$

where values of K and g depend on the signs of β and γ and can be derived from the following table:

sign β	sign γ	K	g
+	+	0	-1
+	-	-2π	1
-	+	$-\pi$	1
-	-	$-\pi$	-1

References

Bingham, C., Arbogast, B., Guillaume Cornélissen, G., Lee, J.K. & Halberg, F. (1982). Inferential Statistical Methods for Estimating and Comparing Cosinor Parameters. *Chronobiologia*, *9(4)*, 397-439.

Examples

```
fit.temperature<-cosinor.lm(Temperature~time(Time), period = 24, data = temperature_zg)
correct.acrophase(fit.temperature)
```

---

cosinor.detect	*Rhythm Detection Test*

Description

Performs the rhythm detection test, a global test for the significance of the estimated model for single cosinor and population-mean cosinor.

Usage

```
cosinor.detect(x)
```

Arguments

x   An object of the `cosinor.lm` or `population.cosinor.lm` class.

Details

The rhythm detection test, also called the zero-amplitude test, tests the overall significance of the cosinor model. The test is actually an F-ratio and is calculated as following (according to the procedure described in Cornélissen, 2014):

$$F = \frac{\frac{\sum(\widehat{Y_i}-\bar{Y})^2}{2}}{\frac{\sum(Y_i-\bar{Y})^2}{N-3}}$$

with $df_1 = 2$ and $df_2 = N - 3$, where $\widehat{Y_i}$ is the ith estimated value, Y_i is the ith observed value, $\bar{Y}$ is the arithmetic mean of observed values and N is the number of timepoints. For the population-mean cosinor model, the test is calculated according to the procedure described in Bingham et al. (1982) as follows:

$$F = \frac{k(k-2)}{2(k-1)} \frac{1}{1-(\frac{\widehat{\sigma}_{\beta\gamma}}{\widehat{\sigma}_\beta\widehat{\sigma}_\gamma})^2} \left[\frac{\beta^2}{\widehat{\sigma}_\beta^2} - 2\frac{\widehat{\sigma}_{\beta\gamma}}{\widehat{\sigma}_\beta\widehat{\sigma}_\gamma}\frac{\beta\gamma}{\widehat{\sigma}_\beta\widehat{\sigma}_\gamma} + \frac{\gamma^2}{\widehat{\sigma}_\gamma^2}\right]$$

with $df_1 = 2$ and $df_2 = k - 2$, where k is the number of subjects in the population, $\widehat{\sigma}_\beta$ and $\widehat{\sigma}_\gamma$ are standard deviations of population β and γ coefficients and $\widehat{\sigma}_{\beta\gamma}$ is the covariance of population β and γ coefficients.

References

Cornélissen, G. (2014). Cosinor-Based Rhythmometry. *Theoretical Biology and Medical Modeling*, *11*, Article 16.

Bingham, C., Arbogast, B., Guillaume Cornélissen, G., Lee, J.K. & Halberg, F. (1982). Inferential Statistical Methods for Estimating and Comparing Cosinor Parameters. *Chronobiologia*, *9(4)*, 397-439.

Examples

```
fit.temperature<-cosinor.lm(Temperature~time(Time), period = 24, data = temperature_zg)
cosinor.detect(fit.temperature)

fit.november<-population.cosinor.lm(data = PANAS_november, time = PANAS_time,
period = 7)
cosinor.detect(fit.november)
```

---

cosinor.poptests   *Comparison of Cosinor Parameters of Two Populations*

Description

Runs the tests that compare MESORs, amplitudes and acrophases of two different populations.

Usage

```
cosinor.poptests(pop1, pop2)
```

Arguments

pop1	An object of the `population.cosinor.lm` class calculated on the first population.
pop2	An object of the `population.cosinor.lm` class calculated on the second population.

Details

Bingham et al. (1982) describe tests for comparing population MESORs, amplitudes and acrophases. These tests are esentially F-ratios with $df_1 = m - 1$ and $df_2 = K - m$, where m is the number of populations and K is the total number of subjects. The tests for MESOR, amplitude and acrophase differences respectively are calculated as follows:

$$F_M = \frac{\sum_{j=1}^m k_j (\widehat{M}_j - \widehat{M})^2}{(m-1)\widehat{\sigma}_M^2}$$

$$F_\phi = \frac{\frac{\sum_{j=1}^m k_j A_j^2 * sin^2(\widehat{\phi}_j - \tilde{\phi})}{m-1}}{\widehat{\sigma}_\beta^2 sin^2\tilde{\phi} + 2\widehat{\sigma}_{\beta\gamma} cos\tilde{\phi} sin\tilde{\phi} + \widehat{\sigma}_\gamma^2 cos^2\tilde{\phi}}$$

$$F_A = \frac{\frac{\sum_{j=1}^{m}(\widehat{A}_j - \widehat{A})^2}{m-1}}{\widehat{\sigma}_{\beta}^2 cos^2\widehat{\phi} - 2\widehat{\sigma}_{\beta\gamma}cos\widehat{\phi}sin\widehat{\phi} + \widehat{\sigma}_{\gamma}^2 sin^2\widehat{\phi}}$$

where $\widehat{M}$, $\widehat{A}$ and $\widehat{\phi}$ are weighted averages of parameters across populations calculated as:

$$\widehat{M} = \frac{\sum_{j=1}^{m} k_j \widehat{M}_j}{K}$$

$$\widehat{A} = \frac{\sum_{j=1}^{m} k_j \widehat{A}_j}{K}$$

$$\widehat{\phi} = \frac{\sum_{j=1}^{m} k_j \widehat{\phi}_j}{K}$$

$\tilde{\phi}$ is derived from the following expression:

$$tan2\tilde{\phi} = \frac{\sum_{j=1}^{m} k_j \widehat{A}_j^2 sin2\widehat{\phi}_j}{\sum_{j=1}^{m} k_j \widehat{A}_j^2 cos2\widehat{\phi}_j}$$

where $2\tilde{\phi}$ lies between $-\frac{\pi}{2}$ and $\frac{\pi}{2}$ if the denomanator is positive or between $\frac{\pi}{2}$ and $\frac{3\pi}{2}$ if the denominator is negative, k_j is the number of subjects in the jth population, $\widehat{M}_j$, $\widehat{A}_j$ and $\widehat{\phi}_j$ are the cosinor parameters of the jth population and $\widehat{\sigma}_{\beta}$, $\widehat{\sigma}_{\gamma}$ and $\widehat{\sigma}_{\beta\gamma}$ are the estimates of pooled standard deviations (and covariance) calculated as following:

$$\widehat{\sigma}_{\beta} = \frac{\sum_{j=1}^{m}(k_j - 1)\widehat{\sigma}_{\beta_j}}{K - m}$$

$$\widehat{\sigma}_{\gamma} = \frac{\sum_{j=1}^{m}(k_j - 1)\widehat{\sigma}_{\gamma_j}}{K - m}$$

$$\widehat{\sigma}_{\beta\gamma} = \frac{\sum_{j=1}^{m}(k_j - 1)\widehat{\sigma}_{\beta_j \gamma_j}}{K - m}$$

where $\widehat{\sigma}_{\beta_j}$, $\widehat{\sigma}_{\gamma_j}$ and $\widehat{\sigma}_{\beta_j \gamma_j}$ are the standard devations and covariance of β and γ parameters in the jth population.

Note

These tests should only be performed on independent samples. If the acrophases of two populations are significantly different, the results of the amplitude difference test are not reliable and should not be interpreted. While it's possible to perform tests which compare more than two populations, this function can only compare two populations.

References

Bingham, C., Arbogast, B., Guillaume Cornélissen, G., Lee, J.K. & Halberg, F. (1982). Inferential Statistical Methods for Estimating and Comparing Cosinor Parameters. *Chronobiologia*, *9(4)*, 397-439.

Examples

```
fit.extraverts<-population.cosinor.lm(data = PA_extraverts, time = PA_time,
period = 24)
fit.introverts<-population.cosinor.lm(data = PA_introverts, time = PA_time,
period = 24)
cosinor.poptests(pop1 = fit.extraverts, pop2 = fit.introverts)
```

---

cosinor.PR   *Percent Rhythm*

Description

Calculates Percent Rhythm, the measure of the relative strength of a rhythm.

Usage

```
cosinor.PR(x)
```

Arguments

x   An object of the `cosinor.lm` or `population.cosinor.lm` class.

Details

Percent Rhythm is the coefficient of determination obtained by squaring the correlation between observed and estimated values.

Examples

```
fit.temperature<-cosinor.lm(Temperature~time(Time), period = 24, data = temperature_zg)
cosinor.PR(fit.temperature)

fit.november<-population.cosinor.lm(data = PANAS_november, time = PANAS_time,
period = 7)
cosinor.PR(fit.november)
```

PANAS_november   *Self-reported mood*

Description

A dataset containing the responses of 19 subjects on the shortened version of the PANAS questionnaire (Watson, Clark & Tellegen, 1988) in November 2015.

Usage

```
PANAS_november
```

Format

A data frame with 19 rows and 30 variables:

X01, X02, X03, X04, X05, X06, X07, X08, X09, X10, X11, X12, X13, X14, X15, X16, X17, X18, X19, X20, X21, X22, X
Responses of subjects at 30 measurement points (days).

Details

Measurements were taken every day after 8 PM.

Note

The data contained in this dataset has been reduced compared to the original data that included more subjects. This dataset contains only the subjects that have responded to the PANAS questionnaire on more than 85% of the timepoints in both of the research cycles (July and November).

Source

Mutak, A. i Vukasović Hlupić, T. (2017). Exogeneity of the Circaseptan Mood Rhythm and Its Relation to the Working Week. *Review of Psychology*, *24* (1-2), 15-28.

References

Watson, D., Clark, L. A. & Tellegen, A. (1988). Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales. *Journal of Personality and Social Psychology*, *54(6)*, 1063-1070.

PANAS_time *Measurement times of self-reported mood*

Description

A dataset containing the measurement times (dates) of self reported mood contained in the data frame PANAS_november

Usage

PANAS_time

Format

A numeric vector of length 30.

Source

Mutak, A. i Vukasović Hlupić, T. (2017). Exogeneity of the Circaseptan Mood Rhythm and Its Relation to the Working Week. *Review of Psychology*, *24* (1-2), 15-28.

PA_extraverts   *Self-reported positive affect of extraverts*

Description

A dataset containing the responses of 24 subjects on the Positive Affect scale of the shortened version of the PANAS questionnaire (Watson, Clark & Tellegen, 1988) in January 2017.

Usage

PA_extraverts

Format

A data frame with 24 rows and 6 variables:

X1, X2, X3, X4, X5, X6 Responses of subjects at 6 measurement points (hours).

Details

Measurements were taken at 10 AM, 12 PM, 2 PM, 4 PM, 6 PM and 8 PM $\pm$ 30 minutes in the period of January 16 - 22, 2017. The data contained in this dataset has been averaged for each hour across 7 days of measurement.

Source

Mutak, A., Pavlović, M. & Zibar, K. (2017, May). *Postoje li razlike između introverata i ekstraverata u cirkadijurnim ritmovima raspoloženja?* [*Are There Differences Between Introverts and Extraverts in Circadian Mood Rhythms?*]. Study presented at the 3rd *Regionalni susret studenata psihologije - SPIRI* [*Regional Meeting of Psychology Students - SPIRI*] conference, Rijeka, Croatia.

References

Watson, D., Clark, L. A. & Tellegen, A. (1988). Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales. *Journal of Personality and Social Psychology*, *54(6)*, 1063-1070.

PA_introverts   *Self-reported positive affect of introverts*

Description

A dataset containing the responses of 29 subjects on the Positive Affect scale of the shortened version of the PANAS questionnaire (Watson, Clark & Tellegen, 1988) in January 2017.

Usage

```
PA_introverts
```

Format

A data frame with 29 rows and 6 variables:

X1, X2, X3, X4, X5, X6 Responses of subjects at 6 measurement points (hours).

Details

Measurements were taken at 10 AM, 12 PM, 2 PM, 4 PM, 6 PM and 8 PM $\pm$ 30 minutes in the period of January 16 - 22, 2017. The data contained in this dataset has been averaged for each hour across 7 days of measurement.

Source

Mutak, A., Pavlović, M. & Zibar, K. (2017, May). *Postoje li razlike između introverata i ekstraverata u cirkadijurnim ritmovima raspoloženja?* [*Are There Differences Between Introverts and Extraverts in Circadian Mood Rhythms?*]. Study presented at the 3rd *Regionalni susret studenata psihologije - SPIRI* [*Regional Meeting of Psychology Students - SPIRI*] conference, Rijeka, Croatia.

References

Watson, D., Clark, L. A. & Tellegen, A. (1988). Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales. *Journal of Personality and Social Psychology*, *54(6)*, 1063-1070.

PA_time	*Measurement times of self-reported positive affect*

Description

A dataset containing the measurement times (hours) of self reported positive affect contained in the data frames `PA_extravers` and `PA_introverts`.

Usage

```
PA_time
```

Format

A numeric vector of length 6.

Source

Mutak, A., Pavlović, M. & Zibar, K. (2017, May). *Postoje li razlike između introverata i ekstrav-erata u cirkadijurnim ritmovima raspoloženja?* [*Are There Differences Between Introverts and Extraverts in Circadian Mood Rhythms?*]. Study presented at the 3rd *Regionalni susret studenata psihologije - SPIRI* [*Regional Meeting of Psychology Students - SPIRI*] conference, Rijeka, Croatia.

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periodogram	*Periodogram*

Description

Estimates the best-fitting period using iterative cosinor procedure.

Usage

```
periodogram(data, time, periods = time, na.action = na.omit,
  alpha = 0.05)
```

Arguments

data	A data frame containing responses of subjects collected over time, with subjects in the rows and timepoints in the columns.
time	A vector containing the times at which the data was collected. If this vector includes midnight, it should be coded as 24 instead of 0.
periods	A vector containing periods that are to be included in the periodogram. Defaults to the same periods as provided in the vector time.
na.action	Action to be performed on missing values. Defaults to na.omit.
alpha	Significance level for determining if a rhythm with a given period is significant or not. Defaults to .05.

Details

Iterative cosinor procedure is performed as described in Klemfuss & Clopton (1993). Cosinor is performed iteratively with the period (τ) increased by 1 in each iteration. Percent Rhythm is calculated in each iteration, which allows for an estimation of the best fitting period. A periodogram can be plotted, which shows Percent Rhythm (coefficient of determination) for each period. On the plot, periods with significant rhythm are shown as a point and periods with insignificant rhythm are shown as a cross.

Note

The range of periods included in iterations starts from 3 (sinusoidality of the curve is not achieved for $\tau < 3$) and ends with the number of timepoints in the data.

References

Klemfuss, H. & Clopton, P. L. (1993). Seeking Tau: A Comparison of Six Methods. *Journal of Interdisciplinary Cycle Research*, *24(1)*, 1-16.

See Also

cosinor.PR

Examples

```
periodogram(data = PANAS_november, time = PANAS_time)

periodogram(data = t(data.frame(temperature_zg$Temperature)), time = temperature_zg$Time)
```

---

population.cosinor.lm   *Population-Mean Cosinor*

Description

Calculates the population-mean cosinor.

Usage

```
population.cosinor.lm(data, time, period, na.action = na.omit,
  alpha = 0.05, plot = T)
```

Arguments

data	A data frame containing responses of subjects collected over time, with subjects in the rows and timepoints in the columns.
time	A vector containing the times at which the data was collected.
period	Duration of one cycle of rhythm.
na.action	Action to be performed on missing values. Defaults to na.omit.
alpha	Significance level for calculating population cosinor parameters confidence intervals. Defaults to .05 (confidence intervals are 5% risk intervals).
plot	Logical, display plot after calculation? Defaults to TRUE.

Details

According to the procedure described in Cornélissen (2014), to calculate population-mean cosinor, single cosinors are first performed on each subject and linearized parameters are averaged, which allows for calculation of delinearized parameters. After such a procedure is completed, confidence intervals of population-mean cosinor parameters can be calculated as described in Bingham et al. (1982) using the following formulae:

$$\widehat{M} \pm \frac{t_{1-\frac{\alpha}{2}}\widehat{\sigma}_M}{\sqrt{k}}$$

$$\widehat{\phi} + arctan(\frac{c_{23}t_{1-\frac{\alpha}{2}}^2 \pm t_{1-\frac{\alpha}{2}}\sqrt{c_{33}}\sqrt{\widehat{A}^2 - \frac{(c_{22}c_{33}-c_{23}^2)t_{1-\frac{\alpha}{2}}^2}{c_{33}}}}{\widehat{A}^2 - c_{22}t_{1-\frac{\alpha}{2}}^2})$$

$$\widehat{A} \pm t_{1-\frac{\alpha}{2}}\sqrt{c_{22}}$$

where c_{22}, c_{23} and c_{33} are elements of the sampling scheme matrix, calculated as follows:

$$c_{22} = \frac{\widehat{\sigma}_\beta^2 \widehat{\beta}^2 + 2\widehat{\sigma}_{\beta\gamma}\widehat{\beta}\widehat{\gamma} + \widehat{\sigma}_\gamma^2 \widehat{\gamma}^2}{k\widehat{A}^2}$$

$$c_{23} = \frac{-(\widehat{\sigma}_\beta^2 - \widehat{\sigma}_\gamma^2)(\widehat{\beta}\widehat{\gamma}) + \widehat{\sigma}_{\beta\gamma}(\widehat{\beta}^2 - \widehat{\gamma}^2)}{k\widehat{A}^2}$$

$$c_{33} = \frac{\widehat{\sigma}_\beta^2 \widehat{\gamma}^2 - 2\widehat{\sigma}_{\beta\gamma}\widehat{\beta}\widehat{\gamma} + \widehat{\sigma}_\gamma^2 \widehat{\beta}^2}{k\widehat{A}^2}$$

where $\widehat{M}$, $\widehat{A}$, $\widehat{\phi}$, $\widehat{\beta}$ and $\widehat{\gamma}$ are population-mean cosinor parameters, $\widehat{\sigma}_M$, $\widehat{\sigma}_\beta$ and $\widehat{\sigma}_\gamma$ are the standard deviations of the single cosinor parameters, $\widehat{\sigma}_{\beta\gamma}$ is the covariance of the single cosinor β and γ coefficients, k is the number of subjects in a population and $t_{1-\frac{\alpha}{2}}$ is the two-tailed inverse of the t-distribution with α level of significance and $k-1$ degrees of freedom.

Value

Object of the `population.cosinor.lm` class containing the following objects:

`single.cos`	A list of objects containing all performed single cosinors.
`pop.mat`	A data frame containing the cosinor parameters of each subject in the population.
`coefficients`	Delinearized population-mean cosinor coefficients.
`emp.mean`	Empirical mean of the data across all timepoints.
`fitted.values`	Estimated values of the rhythm caclculated using the cosinor model.
`residuals`	The difference between empirical mean and the fitted values.
`conf.int`	Values of upper and lower limits of confidence intervals of delinearized cosinor parameters.

Note

If the confidence interval of the population amplitude includes zero, confidence interval of the acrophase cannot be calculated reliably. If this case occurs while using this function, the user will be warned and acrophase confidence interval limits will be set to NA.

References

Cornélissen, G. (2014). Cosinor-Based Rhythmometry. *Theoretical Biology and Medical Modeling*, *11*, Article 16.

Bingham, C., Arbogast, B., Guillaume Cornélissen, G., Lee, J.K. & Halberg, F. (1982). Inferential Statistical Methods for Estimating and Comparing Cosinor Parameters. *Chronobiologia*, *9(4)*, 397-439.

Examples

```
population.cosinor.lm(data = PANAS_november, time = PANAS_time,
period = 7, na.action = "na.exclude")
```

---

ssections	*Serial Sections*

Description

Performs serial section analysis of rhythmic data and fits non-stationary cosinor models.

Usage

```
ssections(data, time, period, interval, increment, na.action = na.omit,
  alpha = 0.05)
```

Arguments

data	A data frame containing responses of subjects collected over time, with subjects in the rows and timepoints in the columns.
time	A vector containing the times at which the data was collected.
period	Duration of one cycle of rhythm.
interval	Length of an interval (number of timepoints) on which cosinor analyses will be ran.
increment	A number indicating for how much timepoints should the interval be displaced throughout the data. Note that the value of the increment cannot be higher than the value of the interval.
na.action	Action to be performed on missing values. Defaults to `na.omit`.
alpha	Significance level for calculating population cosinor parameters confidence intervals. Defaults to .05 (confidence intervals are 5% risk intervals).

Details

Cornélissen (2014) describes procedures for rhythmometric analysis of non-stationary data. First, an interval of an user-specified length (I) is chosen and usual cosinor analysis (i.e. single cosinor or population-mean cosinor) is performed on the interval. The interval is then displaced throughout the data by an user-specified increment (Δt) and cosinor analysis is then performed on the new interval. Intervals can be overlapping (Δt<I) or non-overlapping (Δt=I). A rhythm detection test is also calculated in each interval. After values of cosinor parameters have been obtained for each interval, they and their confidence intervals can be plotted, along with the *p*-values from the rhythm detection test.

Value

Object of the `Serial sections` class containing the following objects:

coefficients   Cosinor coefficients in each of the intervals.

emp.mean   Empirical mean of the data across all timepoints.

p-values   *p*-values from the rhythm detection test in each interval.

cosinors   A list containing all cosinor objects calculated in each interval.

plots   Stacked plots showing the empirical data, cosinor parameters and their confidence intervals, p-values of the rhythm detection test and number of measurements across time.

Note

The value of increment cannot be higher than the value of the interval.

References

Cornélissen, G. (2014). Cosinor-Based Rhythmometry. *Theoretical Biology and Medical Modeling*, *11*, Article 16.

Examples

```
ssections(data = PANAS_november, time = PANAS_time, period = 7,
interval = 7, increment = 1)
```

---

temperature_zg   *Daily air temperature in Zagreb*

Description

A dataset containing the air temperature in Zagreb on July 1, 2015.

Usage

```
temperature_zg
```

Format

A data frame with two variables:

Temperature Air temperature in Zagreb on July 1, 2015.

Time Time of the day when the temperature was measured.

Details

Measurements were taken every 30 minutes throughout the whole day.

Source

Croatian Meteorological and Hydrological Service, <http://www.meteo.hr>

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