Package 'ravetools'

January 20, 2023

Type Package

Title Signal Processing Toolbox for Analyzing 'Electrophysiology' Data

Version 0.0.9

Language en-US

Description Implemented fast and memory-efficient 'Notch'-filter, 'Welch-periodogram', and discrete wavelet transform algorithm for hours of high-resolution signals; providing fundamental toolbox for 'iEEG' preprocess pipelines. Documentation and examples about 'RAVE' project are provided at <https://openwetware.org/wiki/RAVE>, and the paper by John F. Magnotti, Zhengjia Wang, Michael S. Beauchamp (2020) <doi:10.1016/j.neuroimage.2020.117341>; see 'citation(``ravetools'')' for details.

BugReports https://github.com/dipterix/ravetools/issues

URL https://dipterix.org/ravetools/

License GPL-3

Encoding UTF-8

RoxygenNote 7.2.1

Depends R (>= 4.0.0)

SystemRequirements fftw3 (libfftw3-dev (deb), or fftw-devel (rpm))

Imports graphics, stats, filearray (>= 0.1.3), Rcpp (>= 1.0.8), waveslim (>= 1.8.2), signal (>= 0.7.7), pracma, digest (>= 0.6.29), splines

LinkingTo Rcpp

Suggests fftwtools, bit64, microbenchmark, testthat

NeedsCompilation yes

Author Zhengjia Wang [aut, cre, cph], Beauchamp lab [cph], Karim Rahim [cph] (R package fftwtools), Prerau Lab [cph] (Multitaper Spectrogram Code), RcppParallel Authors [cph] (TinyParallel Code comes from RcppParallel), Marcus Geelnard [cph] (TinyThread library)

Maintainer Zhengjia Wang <dipterix.wang@gmail.com>

Repository CRAN

Date/Publication 2023-01-20 20:30:01 UTC

R topics documented:

`band_pass` *Band-pass signals*

Description

Band-pass signals

Usage

```
band_pass1(x, sample_rate, lb, ub, domain = 1, ...)

band_pass2(
  x,
  sample_rate,
  lb,
  ub,
  order,
```

```
  method = c("fir", "butter"),
  direction = c("both", "forward", "backward"),
  window = "hamming",
  ...
)
```

Arguments

x	input signals, numeric vector or matrix. x must be row-major if input is a matrix: each row is a channel, and each column is a time-point.
sample_rate	sampling frequency
lb	lower frequency bound of the band-passing filter, must be positive
ub	upper frequency bound of the band-passing filter, must be greater than the lower bound and smaller than the half of sampling frequency
domain	1 if x is in time-domain, or 0 if x is in frequency domain
...	ignored
order	the order of the filter, must be positive integer and be less than one-third of the sample rate
method	filter type, choices are 'fir' and 'butter'
direction	filter direction, choices are 'forward', 'backward', and 'both' directions
window	window type, can be a character, a function, or a vector. For character, window is a function name in the signal package, for example, 'hanning'; for a function, window takes one integer argument and returns a numeric vector with length of that input; for vectors, window is a numeric vector o length order+1.

Value

Filtered signals, vector if x is a vector, or matrix of the same dimension as x

Examples

```
t <- seq(0, 1, by = 0.0005)
x <- sin(t * 0.4 * pi) + sin(t * 4 * pi) + 2 * sin(t * 120 * pi)

y1 <- band_pass1(x, 2000, 0.1, 1)
y2 <- band_pass1(x, 2000, 1, 5)
y3 <- band_pass1(x, 2000, 10, 80)

order <- floor(2000 / 3)
z1 <- band_pass2(x, 2000, 0.1, 1, method = "fir", order = order)
z2 <- band_pass2(x, 2000, 1, 5, method = "fir", order = order)
z3 <- band_pass2(x, 2000, 10, 80, method = "fir", order = order)

par(mfrow = c(1, 2))
plot(t, x, type = 'l', xlab = "Time", ylab = "",
     main = "Mixture of 0.2, 2, and 60Hz")
```

```
lines(t, y1, col = 'red')
lines(t, y2, col = 'blue')
lines(t, y3, col = 'green')
legend(
  "topleft", c("Input", "Pass: 0.1-1Hz", "Pass 1-5Hz", "Pass 10-80Hz"),
  col = c(par("fg"), "red", "blue", "green"), lty = 1
)

plot(t, x, type = 'l', xlab = "Time", ylab = "",
     main = "Mixture of 0.2, 2, and 60Hz")
lines(t, z1, col = 'red')
lines(t, z2, col = 'blue')
lines(t, z3, col = 'green')
legend(
  "topleft", c("Input", "Pass: 0.1-1Hz", "Pass 1-5Hz", "Pass 10-80Hz"),
  col = c(par("fg"), "red", "blue", "green"), lty = 1
)
```

`baseline_array` *Calculate Contrasts of Arrays in Different Methods*

Description

Provides five methods to baseline an array and calculate contrast.

Usage

```
baseline_array(x, along_dim, unit_dims = seq_along(dim(x))[-along_dim], ...)

## S3 method for class 'array'
baseline_array(
  x,
  along_dim,
  unit_dims = seq_along(dim(x))[-along_dim],
  method = c("percentage", "sqrt_percentage", "decibel", "zscore", "sqrt_zscore",
    "subtract_mean"),
  baseline_indexpoints = NULL,
  baseline_subarray = NULL,
  ...
)
```

Arguments

`x`	array (tensor) to calculate contrast
`along_dim`	integer range from 1 to the maximum dimension of `x`. baseline along this dimension, this is usually the time dimension.

`unit_dims` integer vector, baseline unit: see Details.

`...` passed to other methods

`method` character, baseline method options are: `"percentage"`, `"sqrt_percentage"`, `"decibel"`, `"zscore"`, and `"sqrt_zscore"`

`baseline_indexpoints`
integer vector, which index points are counted into baseline window? Each index ranges from 1 to `dim(x)[[along_dim]]`. See Details.

`baseline_subarray`
sub-arrays that should be used to calculate baseline; default is `NULL` (automatically determined by `baseline_indexpoints`).

Details

Consider a scenario where we want to baseline a bunch of signals recorded from different locations. For each location, we record `n` sessions. For each session, the signal is further decomposed into frequency-time domain. In this case, we have the input `x` in the following form:

$$session x frequency x time x location$$

Now we want to calibrate signals for each session, frequency and location using the first 100 time points as baseline points, then the code will be

$$baseline_array(x, along_dim = 3, baseline_window = 1:100, unit_dims = c(1,2,4))$$

`along_dim=3` is dimension of time, in this case, it's the third dimension of `x`. `baseline_indexpoints=1:100`, meaning the first 100 time points are used to calculate baseline. `unit_dims` defines the unit signal. Its value `c(1,2,4)` means the unit signal is per session (first dimension), per frequency (second) and per location (fourth).

In some other cases, we might want to calculate baseline across frequencies then the unit signal is $frequency x time$, i.e. signals that share the same session and location also share the same baseline. In this case, we assign `unit_dims=c(1,4)`.

There are five baseline methods. They fit for different types of data. Denote z is an unit signal, z_0 is its baseline slice. Then these baseline methods are:

`"percentage"`

$$\frac{z - \bar{z_0}}{\bar{z_0}} \times 100\%$$

`"sqrt_percentage"`

$$\frac{\sqrt{z} - \sqrt{\bar{z_0}}}{\sqrt{\bar{z_0}}} \times 100\%$$

`"decibel"`

$$10 \times (\log_{10}(z) - \log_{10}(\bar{z_0}))$$

`"zscore"`

$$\frac{z - \bar{z_0}}{sd(z_0)}$$

`"sqrt_zscore"`

$$\frac{\sqrt{z} - \sqrt{\bar{z_0}}}{sd(\sqrt{z_0})}$$

Value

Contrast array with the same dimension as x.

Examples

```
# Set ncores = 2 to comply to CRAN policy. Please don't run this line
ravetools_threads(n_threads = 2L)


library(ravetools)
set.seed(1)

# Generate sample data
dims = c(10,20,30,2)
x = array(rnorm(prod(dims))^2, dims)

# Set baseline window to be arbitrary 10 timepoints
baseline_window = sample(30, 10)

# ----- baseline percentage change ------

# Using base functions
re1 <- aperm(apply(x, c(1,2,4), function(y){
  m <- mean(y[baseline_window])
  (y/m - 1) * 100
}), c(2,3,1,4))

# Using ravetools
re2 <- baseline_array(x, 3, c(1,2,4),
                      baseline_indexpoints = baseline_window,
                      method = 'percentage')

# Check different, should be very tiny (double precisions)
range(re2 - re1)

# Check speed for large dataset
if(interactive()){

ravetools_threads(n_threads = -1)

dims <- c(200,20,300,2)
x <- array(rnorm(prod(dims))^2, dims)
# Set baseline window to be arbitrary 10 timepoints
baseline_window <- seq_len(100)
f1 <- function(){
  aperm(apply(x, c(1,2,4), function(y){
    m <- mean(y[baseline_window])
    (y/m - 1) * 100
  }), c(2,3,1,4))
}
f2 <- function(){
```

```
  # equivalent as bl = x[,,baseline_window, ]
  #
  baseline_array(x, along_dim = 3,
                 baseline_indexpoints = baseline_window,
                 unit_dims = c(1,2,4), method = 'percentage')
}
range(f1() - f2())
microbenchmark::microbenchmark(f1(), f2(), times = 10L)

}
```

---

collapse *Collapse array*

Description

Collapse array

Usage

```
collapse(x, keep, ...)

## S3 method for class 'array'
collapse(
  x,
  keep,
  average = TRUE,
  transform = c("asis", "10log10", "square", "sqrt"),
  ...
)
```

Arguments

x	A numeric multi-mode tensor (array), without NA
keep	Which dimension to keep
...	passed to other methods
average	collapse to sum or mean
transform	transform on the data before applying collapsing; choices are 'asis' (no change), '10log10' (used to calculate decibel), 'square' (sum-squared), 'sqrt' (square-root and collapse)

Value

a collapsed array with values to be mean or summation along collapsing dimensions

Examples

```
# Set ncores = 2 to comply to CRAN policy. Please don't run this line
ravetools_threads(n_threads = 2L)

# Example 1
x = matrix(1:16, 4)

# Keep the first dimension and calculate sums along the rest
collapse(x, keep = 1)
rowMeans(x)  # Should yield the same result

# Example 2
x = array(1:120, dim = c(2,3,4,5))
result = collapse(x, keep = c(3,2))
compare = apply(x, c(3,2), mean)
sum(abs(result - compare)) # The same, yield 0 or very small number (1e-10)


if(interactive()){
ravetools_threads(n_threads = -1)

# Example 3 (performance)

# Small data, no big difference
x = array(rnorm(240), dim = c(4,5,6,2))
microbenchmark::microbenchmark(
  result = collapse(x, keep = c(3,2)),
  compare = apply(x, c(3,2), mean),
  times = 1L, check = function(v){
    max(abs(range(do.call('-', v)))) < 1e-10
  }
)

# large data big difference
x = array(rnorm(prod(300,200,105)), c(300,200,105,1))
microbenchmark::microbenchmark(
  result = collapse(x, keep = c(3,2)),
  compare = apply(x, c(3,2), mean),
  times = 1L , check = function(v){
    max(abs(range(do.call('-', v)))) < 1e-10
  })

}
```

`decimate` *Decimate with 'FIR' or 'IIR' filter*

Description

Decimate with 'FIR' or 'IIR' filter

Usage

```
decimate(x, q, n = if (ftype == "iir") 8 else 30, ftype = "fir")
```

Arguments

x	signal to be decimated
q	integer factor to down-sample by
n	filter order used in the down-sampling; default is 30 if ftype='fir', or 8 if ftype='iir'
ftype	filter type, choices are 'fir' (default) and 'iir'

Details

This function is migrated from signal package, but with bugs fixed on 'FIR' filters. The result agrees with 'Matlab' decimate function with 'FIR' filters. Under 'IIR' filters, the function is identical with signal::decimate, and is slightly different with 'Matlab' version.

Value

Decimated signal

Examples

```
x <- 1:100
y <- decimate(x, 2, ftype = "fir")
y

# compare with signal package
z <- signal::decimate(x, 2, ftype = "fir")

# Compare decimated results
plot(x, type = 'l')
points(seq(1,100, 2), y, col = "green")
points(seq(1,100, 2), z, col = "red")
```

detrend *Remove the trend for one or more signals*

Description

'Detrending' is often used before the signal power calculation.

Usage

```
detrend(x, trend = c("constant", "linear"), break_points = NULL)
```

Arguments

x	numerical or complex, a vector or a matrix
trend	the trend of the signal; choices are 'constant' and 'linear'
break_points	integer vector, or NULL; only used when trend is 'linear' to remove piecewise linear trend; will throw warnings if trend is 'constant'

Value

The signals with trend removed in matrix form; the number of columns is the number of signals, and number of rows is length of the signals

Examples

```
x <- rnorm(100, mean = 1) + c(
  seq(0, 5, length.out = 50),
  seq(5, 3, length.out = 50))
plot(x)

plot(detrend(x, 'constant'))
plot(detrend(x, 'linear'))
plot(detrend(x, 'linear', 50))
```

diagnose_channel *Show channel signals with diagnostic plots*

Description

The diagnostic plots include 'Welch Periodogram' (pwelch) and histogram (hist)

Usage

```
diagnose_channel(
  s1,
  s2 = NULL,
  sc = NULL,
  srate,
  name = "",
  try_compress = TRUE,
  max_freq = 300,
  window = ceiling(srate * 2),
  noverlap = window/2,
  std = 3,
  which = NULL,
  main = "Channel Inspection",
  col = c("black", "red"),
  cex = 1.2,
  cex.lab = 1,
  lwd = 0.5,
  plim = NULL,
  nclass = 100,
  start_time = 0,
  boundary = NULL,
  mar = c(3.1, 4.1, 2.1, 0.8) * (0.25 + cex * 0.75) + 0.1,
  mgp = cex * c(2, 0.5, 0),
  xaxs = "i",
  yaxs = "i",
  xline = 1.66 * cex,
  yline = 2.66 * cex,
  tck = -0.005 * (3 + cex),
  ...
)
```

Arguments

s1	the main signal to draw
s2	the comparing signal to draw; usually s1 after some filters; must be in the same sampling rate with s1; can be NULL
sc	decimated s1 to show if srate is too high; will be automatically generated if NULL
srate	sampling rate
name	name of s1, or a vector of two names of s1 and s2 if s2 is provided
try_compress	whether try to compress (decimate) s1 if srate is too high for performance concerns
max_freq	the maximum frequency to display in 'Welch Periodograms'
window, noverlap	see pwelch

std	the standard deviation of the channel signals used to determine boundary; default is plus-minus 3 standard deviation
which	NULL or integer from 1 to 4; if NULL, all plots will be displayed; otherwise only the subplot will be displayed
main	the title of the signal plot
col	colors of s1 and s2
cex, lwd, mar, cex.lab, mgp, xaxs, yaxs, tck, ...	graphical parameters; see par
plim	the y-axis limit to draw in 'Welch Periodograms'
nclass	number of classes to show in histogram (hist)
start_time	the starting time of channel (will only be used to draw signals)
boundary	a red boundary to show in channel plot; default is to be automatically determined by std
xline, yline	distance of axis labels towards ticks

Value

A list of boundary and y-axis limit used to draw the channel

Examples

```
library(ravetools)

# Generate 20 second data at 2000 Hz
time <- seq(0, 20, by = 1 / 2000)
signal <- sin( 120 * pi * time) +
  sin(time * 20*pi) +
  exp(-time^2) *
  cos(time * 10*pi) +
  rnorm(length(time))

signal2 <- notch_filter(signal, 2000)

diagnose_channel(signal, signal2, srate = 2000,
                 name = c("Raw", "Filtered"), cex = 1)
```

---

fast_cov *Calculate massive covariance matrix in parallel*

Description

Speed up covariance calculation for large matrices. The default behavior is the same as cov ('pearson', no NA handling).

Usage

```
fast_cov(x, y = NULL, col_x = NULL, col_y = NULL, df = NA)
```

Arguments

x	a numeric vector, matrix or data frame; a matrix is highly recommended to maximize the performance
y	NULL (default) or a vector, matrix or data frame with compatible dimensions to x; the default is equivalent to y = x
col_x	integers indicating the subset indices (columns) of x to calculate the covariance, or NULL to include all the columns; default is NULL
col_y	integers indicating the subset indices (columns) of y to calculate the covariance, or NULL to include all the columns; default is NULL
df	a scalar indicating the degrees of freedom; default is nrow(x)-1

Value

A covariance matrix of x and y. Note that there is no NA handling. Any missing values will lead to NA in the resulting covariance matrices.

Examples

```
# Set ncores = 2 to comply to CRAN policy. Please don't run this line
ravetools_threads(n_threads = 2L)

x <- matrix(rnorm(400), nrow = 100)

# Call `cov(x)` to compare
fast_cov(x)

# Calculate covariance of subsets
fast_cov(x, col_x = 1, col_y = 1:2)

if(interactive()){

# Speed comparison, better to use multiple cores (4, 8, or more)
# to show the differences.

ravetools_threads(n_threads = -1)
x <- matrix(rnorm(100000), nrow = 1000)
microbenchmark::microbenchmark(
  fast_cov = {
    fast_cov(x, col_x = 1:50, col_y = 51:100)
  },
  cov = {
    cov(x[,1:50], x[,51:100])
  },
  unit = 'ms', times = 10
)
```

```
}
```

`fast_quantile` *Compute quantiles*

Description

Compute quantiles

Usage

```
fast_quantile(x, prob = 0.5, na.rm = FALSE, ...)

fast_median(x, na.rm = FALSE, ...)

fast_mvquantile(x, prob = 0.5, na.rm = FALSE, ...)

fast_mvmedian(x, na.rm = FALSE, ...)
```

Arguments

`x`	numerical-value vector for `fast_quantile` and `fast_median`, and column-major matrix for `fast_mvquantile` and `fast_mvmedian`
`prob`	a probability with value from 0 to 1
`na.rm`	logical; if true, any `NA` are removed from `x` before the quantiles are computed
`...`	reserved for future use

Value

`fast_quantile` and `fast_median` calculate univariate quantiles (single-value return); `fast_mvquantile` and `fast_mvmedian` calculate multivariate quantiles (for each column, result lengths equal to the number of columns).

Examples

```
fast_quantile(runif(1000), 0.1)
fast_median(1:100)

x <- matrix(rnorm(100), ncol = 2)
fast_mvquantile(x, 0.2)
fast_mvmedian(x)

# Compare speed for vectors (usually 30% faster)
x <- rnorm(10000)
```

```
microbenchmark::microbenchmark(
  fast_median = fast_median(x),
  base_median = median(x),
  # bioc_median = Biobase::rowMedians(matrix(x, nrow = 1)),
  times = 100, unit = "milliseconds"
)

# Multivariate cases
# (5~7x faster than base R)
# (3~5x faster than Biobase rowMedians)
x <- matrix(rnorm(100000), ncol = 20)
microbenchmark::microbenchmark(
  fast_median = fast_mvmedian(x),
  base_median = apply(x, 2, median),
  # bioc_median = Biobase::rowMedians(t(x)),
  times = 10, unit = "milliseconds"
)
```

`filter_signal` *Filter one-dimensional signal*

Description

The function is written from the scratch. The result has been compared against the 'Matlab' `filter` function with one-dimensional real inputs. Other situations such as matrix `b` or multi-dimensional `x` are not implemented.

Usage

```
filter_signal(b, a, x, z)
```

Arguments

`b`	one-dimensional real numerical vector, the moving-average coefficients of an ARMA filter
`a`	the auto-regressive (recursive) coefficients of an ARMA filter
`x`	numerical vector input (real value)
`z`	initial condition, must have length of `n-1`, where `n` is the maximum of lengths of `a` and `b`; default is all zeros

Value

A list of two vectors: the first vector is the filtered signal; the second vector is the final state of `z`

Examples

```
t <- seq(0, 1, by = 0.01)
x <- sin(2 * pi * t * 2.3)
bf <- signal::butter(2, c(0.15, 0.3))

res <- filter_signal(bf$b, bf$a, x)
y <- res[[1]]
z <- res[[2]]

## Matlab (2022a) equivalent:
# t = [0:0.01:1];
# x = sin(2 * pi * t * 2.3);
# [b,a] = butter(2,[.15,.3]);
# [y,z] = filter(b, a, x)
```

`filtfilt` *Forward and reverse filter a one-dimensional signal*

Description

The result has been tested against 'Matlab' `filtfilt` function. Currently this function only supports one filter at a time.

Usage

```
filtfilt(b, a, x)
```

Arguments

b	one-dimensional real numerical vector, the moving-average coefficients of an ARMA filter
a	the auto-regressive (recursive) coefficients of an ARMA filter
x	numerical vector input (real value)

Value

The filtered signal, normally the same length as the input signal `x`.

Examples

```
t <- seq(0, 1, by = 0.01)
x <- sin(2 * pi * t * 2.3)
bf <- signal::butter(2, c(0.15, 0.3))
```

```
res <- filtfilt(bf$b, bf$a, x)

## Matlab (2022a) equivalent:
# t = [0:0.01:1];
# x = sin(2 * pi * t * 2.3);
# [b,a] = butter(2,[.15,.3]);
# res = filtfilt(b, a, x)
```

`interpolate_stimulation` *Find and interpolate stimulation signals*

Description

Find and interpolate stimulation signals

Usage

```
interpolate_stimulation(
  x,
  sample_rate,
  duration = 40/sample_rate,
  ord = 4L,
  nknots = 100,
  nsd = 1,
  nstim = NULL,
  regularization = 0.5
)
```

Arguments

`x`	numerical vector representing a analog signal
`sample_rate`	sampling frequency
`duration`	time in second: duration of interpolation
`ord`	spline order, default is 4
`nknots`	a rough number of knots to use, default is 100
`nsd`	number of standard deviation to detect stimulation signals, default is 1
`nstim`	number of stimulation pulses, default is to auto-detect
`regularization`	regularization parameter in case of inverting singular matrices, default is 0.5

Value

Interpolated signal with an attribute of which sample points are interpolated

Examples

```
x0 <- rnorm(1000) / 5 + sin(1:1000 / 300)

# Simulates pulase signals
x <- x0
x[400:410] <- -100
x[420:430] <- 100

fitted <- interpolate_stimulation(x, 100, duration = 0.3, nknots = 10, nsd = 2)

par(mfrow = c(2, 1))

plot(fitted, type = 'l', col = 'blue', lwd = 2)
lines(x, col = 'red')
lines(x0, col = 'black')
legend("topleft", c("Interpolated", "Observed", "Underlying"),
       lty = 1, col = c("blue", "red", "black"))

pwelch(x0, 100, 200, 100, plot = 1, col = 'black', ylim = c(-50, 50))
pwelch(x, 100, 200, 100, plot = 2, col = 'red')
pwelch(fitted, 100, 200, 100, plot = 2, col = 'blue')
```

---

matlab_palette *'Matlab' heat-map plot palette*

Description

'Matlab' heat-map plot palette

Usage

```
matlab_palette()
```

Value

vector of 64 colors

`multitaper` *Compute 'multitaper' spectral densities of time-series data*

Description

Compute 'multitaper' spectral densities of time-series data

Usage

```
multitaper_config(
  data_length,
  fs,
  frequency_range = NULL,
  time_bandwidth = 5,
  num_tapers = NULL,
  window_params = c(5, 1),
  nfft = NA,
  detrend_opt = "linear"
)

multitaper(
  data,
  fs,
  frequency_range = NULL,
  time_bandwidth = 5,
  num_tapers = NULL,
  window_params = c(5, 1),
  nfft = NA,
  detrend_opt = "linear"
)
```

Arguments

`data_length`	length of data
`fs`	sampling frequency in 'Hz'
`frequency_range`	frequency range to look at; length of two
`time_bandwidth`	a number indicating time-half bandwidth product; i.e. the window duration times the half bandwidth of main lobe; default is `5`
`num_tapers`	number of 'DPSS' tapers to use; default is `NULL` and will be automatically computed from `floor(2*time_bandwidth - 1)`
`window_params`	vector of two numbers; the first number is the window size in seconds; the second number if the step size; default is `c(5, 1)`
`nfft`	'NFFT' size, positive; see 'Details'

detrend_opt	how you want to remove the trend from data window; options are 'linear' (default), 'constant', and 'off'
data	numerical vector, signal traces

Details

The original source code comes from 'Prerau' Lab (see 'Github' repository 'multitaper_toolbox' under user 'preraulab'). The results tend to agree with their 'Python' implementation with precision on the order of at 1E-7 with standard deviation at most 1E-5. The original copy was licensed under a Creative Commons Attribution 'NC'-'SA' 4.0 International License (https://creativecommons.org/licenses/by-nc-sa/4.0/).

This package ('ravetools') redistributes the multitaper function under minor modifications on nfft. In the original copy there is no parameter to control the exact numbers of nfft, and the nfft is always the power of 2. While choosing nfft to be the power of 2 is always recommended, the modified code allows other choices.

Value

multitaper_config returns a list of configuration parameters for the filters; multitaper also returns the time, frequency and corresponding spectral power.

Examples

```
time <- seq(0, 3, by = 0.001)
x <- sin(time * 20*pi) + exp(-time^2) * cos(time * 10*pi)

res <- multitaper(
  x, 1000, frequency_range = c(0,15),
  time_bandwidth=1.5,
  window_params=c(2,0.01)
)


image(
  x = res$time,
  y = res$frequency,
  z = 10 * log10(res$spec),
  xlab = "Time (s)",
  ylab = 'Frequency (Hz)',
  col = matlab_palette()
)
```

---

notch_filter *Apply 'Notch' filter*

Description

Apply 'Notch' filter

Usage

```
notch_filter(
  s,
  sample_rate,
  lb = c(59, 118, 178),
  ub = c(61, 122, 182),
  domain = 1
)
```

Arguments

s	numerical vector if domain=1 (voltage signals), or complex vector if domain=0
sample_rate	sample rate
lb	filter lower bound of the frequencies to remove
ub	filter upper bound of the frequencies to remove; shares the same length as lb
domain	1 if the input signal is in the time domain, 0 if it is in the frequency domain

Details

Mainly used to remove electrical line frequencies at 60, 120, and 180 Hz.

Value

filtered signal in time domain (real numerical vector)

Examples

```
time <- seq(0, 3, 0.005)
s <- sin(120 * pi * time) + rnorm(length(time))

# Welch periodogram shows a peak at 60Hz
pwelch(s, 200, plot = 1, log = "y")

# notch filter to remove 60Hz
s1 <- notch_filter(s, 200, lb = 59, ub = 61)
pwelch(s1, 200, plot = 2, log = "y", col = "red")
```

parallel-options *Set or get thread options*

Description

Set or get thread options

Usage

```
detect_threads()

ravetools_threads(n_threads = "auto", stack_size = "auto")
```

Arguments

n_threads	number of threads to set
stack_size	Stack size (in bytes) to use for worker threads. The default used for "auto" is 2MB on 32-bit systems and 4MB on 64-bit systems.

Value

detect_threads returns an integer of default threads that is determined by the number of CPU cores; ravetools_threads returns nothing.

Examples

```
if(interactive()){
  detect_threads()
  ravetools_threads(n_threads = 2)
}
```

plot_signals *Plot one or more signal traces in the same figure*

Description

Plot one or more signal traces in the same figure

Usage

```
plot_signals(
  signals,
  sample_rate = 1,
  col = graphics::par("fg"),
  space = 0.995,
  space_mode = c("quantile", "absolute"),
  start_time = 0,
  duration = NULL,
  compress = TRUE,
  channel_names = NULL,
  time_shift = 0,
  xlab = "Time (s)",
  ylab = "Electrode",
  lwd = 0.5,
  new_plot = TRUE,
  xlim = NULL,
  cex = 1,
  cex.lab = 1,
  mar = c(3.1, 2.1, 2.1, 0.8) * (0.25 + cex * 0.75) + 0.1,
  mgp = cex * c(2, 0.5, 0),
  xaxs = "r",
  yaxs = "i",
  xline = 1.5 * cex,
  yline = 1 * cex,
  tck = -0.005 * (3 + cex),
  ...
)
```

Arguments

signals	numerical matrix with each row to be a signal trace and each column contains the signal values at a time point
sample_rate	sampling frequency
col	signal color, can be vector of one or more
space	vertical spacing among the traces; for values greater than 1, the spacing is absolute; default is `0.995`; for values less equal to 1, this is the percentile of the whole data. However, the quantile mode can be manually turned off is `"absolute"` is required; see space_mode
space_mode	mode of spacing, only used when space is less equal to one; default is quantile
start_time	the time to start drawing relative to the first column
duration	duration of the signal to draw
compress	whether to compress signals if the data is too large
channel_names	NULL or a character vector of channel names
time_shift	the actual start time of the signal. Unlike start_time, this should be the actual physical time represented by the first column

xlab, ylab, lwd, xlim, cex, cex.lab, mar, mgp, xaxs, yaxs, tck, ...	plot parameters; see plot and par
new_plot	whether to draw a new plot; default is true
xline, yline	the gap between axis and label

Examples

```
n <- 1000
base_signal <- c(rep(0, n/2), sin(seq(0,10,length.out = n/2))) * 10
signals <- rbind(rnorm(n) + base_signal,
                 rbinom(n, 10, 0.3) + base_signal,
                 rt(n, 5) + base_signal)
plot_signals(signals, sample_rate = 100)
plot_signals(signals, sample_rate = 100, start_time = 5)
plot_signals(signals, sample_rate = 100,
             start_time = 5, time_shift = 100)
```

---

pwelch *Calculate 'Welch Periodogram'*

Description

pwelch is for single signal trace only; mv_pwelch is for multiple traces. Currently mv_pwelch is experimental and should not be called directly.

Usage

```
pwelch(
  x,
  fs,
  window = 64,
  noverlap = 8,
  nfft = 256,
  col = "black",
  xlim = NULL,
  ylim = NULL,
  main = "Welch periodogram",
  plot = 0,
  log = c("xy", "", "x", "y"),
  ...
)

## S3 method for class 'pwelch'
print(x, ...)
```

```
## S3 method for class 'pwelch'
plot(
  x,
  log = c("xy", "x", "y", ""),
  se = FALSE,
  xticks,
  type = "l",
  add = FALSE,
  col = graphics::par("fg"),
  col.se = "orange",
  alpha.se = 0.5,
  lty = 1,
  lwd = 1,
  cex = 1,
  las = 1,
  main = "Welch periodogram",
  xlab,
  ylab,
  xlim = NULL,
  ylim = NULL,
  xaxs = "i",
  yaxs = "i",
  xline = 1.2 * cex,
  yline = 2 * cex,
  mar = c(2.6, 3.8, 2.1, 0.6) * (0.5 + cex/2),
  mgp = cex * c(2, 0.5, 0),
  tck = -0.02 * cex,
  grid = TRUE,
  ...
)

mv_pwelch(x, margin, fs, nfft)
```

Arguments

x	'pwelch' instance returned by pwelch function
fs	sample rate, average number of time points per second
window	window length in time points, default size is 64
noverlap	overlap between two adjacent windows, measured in time points; default is 8
nfft	number of basis functions to apply
col, xlim, ylim,	main, type, cex, las, xlab, ylab, lty, lwd, xaxs, yaxs, mar, mgp, tck parameters passed to plot.default
plot	integer, whether to plot the result or not; choices are 0, no plot; 1 plot on a new canvas; 2 add to existing canvas
log	indicates which axis should be log10-transformed, used by the plot function. For 'x' axis, it's log10-transform; for 'y' axis, it's 10log10-transform (decibel unit). Choices are "xy", "x", "y", and "".

`...`	will be passed to `plot.pwelch` or ignored
`se`	logical or a positive number indicating whether to plot standard error of mean; default is false. If provided with a number, then a multiple of standard error will be drawn. This option is only available when power is in log-scale (decibel unit)
`xticks`	ticks to show on frequency axis
`add`	logical, whether the plot should be added to existing canvas
`col.se, alpha.se`	controls the color and opacity of the standard error
`xline, yline`	controls how close the axis labels to the corresponding axes
`grid`	whether to draw rectangular grid lines to the plot; only respected when `add=FALSE`; default is true
`margin`	the margin in which `pwelch` should be applied to

Value

A list with class `'ravetools-pwelch'` that contains the following items:

`freq` frequencies used to calculate the 'periodogram'

`spec` resulting spectral power for each frequency

`window` window function (in numerical vector) used

`noverlap` number of overlapping time-points between two adjacent windows

`nfft` number of basis functions

`fs` sample rate

`x_len` input signal length

`method` a character string `'Welch'`

Examples

```
x <- rnorm(1000)
pwel <- pwelch(x, 100)
pwel

plot(pwel, log = "xy")
```

raw-to-sexp *Convert raw vectors to R vectors*

Description

Convert raw vectors to R vectors

Usage

```
raw_to_uint8(x)

raw_to_uint16(x)

raw_to_uint32(x)

raw_to_int8(x)

raw_to_int16(x)

raw_to_int32(x)

raw_to_int64(x)

raw_to_float(x)

raw_to_string(x)
```

Arguments

x	raw vector of bytes

Details

For numeric conversions, the function names are straightforward. For example, `raw_to_uintN` converts raw vectors to unsigned integers, and `raw_to_intN` converts raw vectors to signed integers. The number `'N'` stands for the number of bits used to store the integer. For example `raw_to_uint8` uses 8 bits (1 byte) to store an integer, hence the value range is `0-255`.

The input data length must be multiple of the element size represented by the underlying data. For example `uint16` integer uses 16 bites, and one raw number uses 8 bits, hence two raw vectors can form one unsigned integer-16. That is, `raw_to_uint16` requires the length of input to be multiple of two. An easy calculation is: the length of `x` times 8, must be divided by `'N'` (see last paragraph for definition).

The returned data uses the closest available R native data type that can fully represent the data. For example, R does not have single `float` type, hence `raw_to_float` returns `double` type, which can represent all possible values in `float`. For `raw_to_uint32`, the potential value range is `0 - (2^32-1)`. This exceeds the limit of R integer type `(-2^31) - (2^31-1)`. Therefore, the returned values will be real (double float) data type.

There is no native data type that can store integer-64 data in R, package `bit64` provides `integer64` type, which will be used by `raw_to_int64`. Currently there is no solution to convert raw to unsigned integer-64 type.

`raw_to_string` converts raw to character string. This function respects `null` character, hence is slightly different than the native `rawToChar`, which translates raw byte-by-byte. If each raw byte represents a valid character, then the above two functions returns the same result. However, when the characters represented by raw bytes are invalid, `raw_to_string` will stop parsing and returns only the valid characters, while `rawToChar` will still try to parse, and most likely to result in errors. Please see Examples for comparisons.

Value

Numeric vectors, except for `raw_to_string`, which returns a string.

Examples

```
# 0x00, 0x7f, 0x80, 0xFF
x <- as.raw(c(0, 127, 128, 255))

raw_to_uint8(x)

# The first bit becomes the integer sign
# 128 -> -128, 255 -> -1
raw_to_int8(x)

## Comments based on little endian system

# 0x7f00 (32512), 0xFF80 (65408 unsigned, or -128 signed)
raw_to_uint16(x)
raw_to_int16(x)

# 0xFF807F00 (4286611200 unsigned, -8356096 signed)
raw_to_uint32(x)
raw_to_int32(x)

# ---------------------------- String ----------------------------

# ASCII case: all valid
x <- charToRaw("This is an ASCII string")

raw_to_string(x)
rawToChar(x)

x <- c(charToRaw("This is the end."),
       as.raw(0),
       charToRaw("*** is invalid"))

# rawToChar will raise error
raw_to_string(x)

# ---------------------------- Integer64 -----------------------
```

```
# Runs on little endian system
x <- as.raw(c(0x80, 0x00, 0x7f, 0x80, 0xFF, 0x50, 0x7f, 0x00))

# Calculate bitstring, which concaternates the followings
# 10000000 (0x80), 00000000 (0x00), 01111111 (0x7f), 10000000 (0x80),
# 11111111 (0xFF), 01010000 (0x50), 01111111 (0x7f), 00000000 (0x00)

if(.Platform$endian == "little") {
  bitstring <- paste0(
    "0000000001111111101010000111111111",
    "1000000001111111000000010000000"
  )
} else {
  bitstring <- paste0(
    "0000000100000000111111100000001",
    "1111111100001010111111100000000"
  )
}

# This is expected value
bit64::as.integer64(structure(
  bitstring,
  class = "bitstring"
))

# This is actual value
raw_to_int64(x)
```

`shift_array` *Shift array by index*

Description

Re-arrange arrays in parallel

Usage

```
shift_array(x, along_margin, unit_margin, shift_amount)
```

Arguments

`x`	array, must have at least matrix
`along_margin`	which index is to be shifted
`unit_margin`	which dimension decides `shift_amount`
`shift_amount`	shift amount along `along_margin`

Details

A simple use-case for this function is to think of a matrix where each row is a signal and columns stand for time. The objective is to align (time-lock) each signal according to certain events. For each signal, we want to shift the time points by certain amount.

In this case, the shift amount is defined by `shift_amount`, whose length equals to number of signals. `along_margin=2` as we want to shift time points (column, the second dimension) for each signal. `unit_margin=1` because the shift amount is depend on the signal number.

Value

An array with same dimensions as the input `x`, but with index shifted. The missing elements will be filled with `NA`.

Examples

```
# Set ncores = 2 to comply to CRAN policy. Please don't run this line
ravetools_threads(n_threads = 2L)



x <- matrix(1:10, nrow = 2, byrow = TRUE)
z <- shift_array(x, 2, 1, c(1,2))

y <- NA * x
y[1,1:4] = x[1,2:5]
y[2,1:3] = x[2,3:5]

# Check if z ang y are the same
z - y

# array case
# x is Trial x Frequency x Time
x <- array(1:27, c(3,3,3))

# Shift time for each trial, amount is 1, -1, 0
shift_amount <- c(1,-1,0)
z <- shift_array(x, 3, 1, shift_amount)

if(interactive()){

par(mfrow = c(3, 2), mai = c(0.8, 0.6, 0.4, 0.1))
for( ii in 1:3 ){
  image(t(x[ii, ,]), ylab = 'Frequency', xlab = 'Time',
        main = paste('Trial', ii))
  image(t(z[ii, ,]), ylab = 'Frequency', xlab = 'Time',
        main = paste('Shifted amount:', shift_amount[ii]))
}

}
```

`wavelet` *'Morlet' wavelet transform (Discrete)*

Description

Transform analog voltage signals with 'Morlet' wavelets: complex wavelet kernels with $\pi/2$ phase differences.

Usage

```
wavelet_kernels(freqs, srate, wave_num)

morlet_wavelet(
  data,
  freqs,
  srate,
  wave_num,
  precision = c("float", "double"),
  trend = c("constant", "linear", "none"),
  signature = NULL,
  ...
)

wavelet_cycles_suggest(
  freqs,
  frequency_range = c(2, 200),
  cycle_range = c(3, 20)
)
```

Arguments

`freqs`	frequency in which `data` will be projected on
`srate`	sample rate, number of time points per second
`wave_num`	desired number of cycles in wavelet kernels to balance the precision in time and amplitude (control the smoothness); positive integers are strongly suggested
`data`	numerical vector such as analog voltage signals
`precision`	the precision of computation; choices are `'float'` (default) and `'double'`.
`trend`	choices are `'constant'`: center the signal at zero; `'linear'`: remove the linear trend; `'none'` do nothing
`signature`	signature to calculate kernel path to save, internally used
`...`	further passed to `detrend`;
`frequency_range`	frequency range to calculate, default is 2 to 200
`cycle_range`	number of cycles corresponding to `frequency_range`. For default frequency range (2 - 200), the default `cycle_range` is 3 to 20. That is, 3 wavelet kernel cycles at 2 Hertz, and 20 cycles at 200 Hertz.

Value

`wavelet_kernels` returns wavelet kernels to be used for wavelet function; `morlet_wavelet` returns a file-based array if `precision` is `'float'`, or a list of real and imaginary arrays if `precision` is `'double'`

Examples

```
if(interactive()){

# generate sine waves
time <- seq(0, 3, by = 0.01)
x <- sin(time * 20*pi) + exp(-time^2) * cos(time * 10*pi)

plot(time, x, type = 'l')

# freq from 1 - 15 Hz; wavelet using float precision
freq <- seq(1, 15, 0.2)
coef <- morlet_wavelet(x, freq, 100, c(2,3))

# to get coefficients in complex number from 1-10 time points
coef[1:10, ]

# power
power <- Mod(coef[])^2

# Power peaks at 5Hz and 10Hz at early stages
# After 1.0 second, 5Hz component fade away
image(power, x = time, y = freq, ylab = "frequency")

# wavelet using double precision
coef2 <- morlet_wavelet(x, freq, 100, c(2,3), precision = "double")
power2 <- (coef2$real[])^2 + (coef2$imag[])^2

image(power2, x = time, y = freq, ylab = "frequency")

# The maximum relative change of power with different precisions
max(abs(power/power2 - 1))

# display kernels
freq <- seq(1, 15, 1)
kern <- wavelet_kernels(freq, 100, c(2,3))
print(kern)

plot(kern)

}
```

Index