Package 'ravetools'

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Type Package

Title Signal and Image Processing Toolbox for Analyzing Intracranial Electroencephalography Data

Version 0.2.1

Language en-US

Description Implemented fast and memory-efficient Notch-filter, Welch-periodogram, discrete wavelet spectrogram for minutes of high-resolution signals, fast 3D convolution, image registration, 3D mesh manipulation; providing fundamental toolbox for intracranial Electroencephalography (iEEG) pipelines. Documentation and examples about 'RAVE' project are provided at <https://rave.wiki>, 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://rave.wiki, https://dipterix.org/ravetools/

License GPL (>= 2)

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Depends R (>= 4.0.0)

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

Copyright Karim Rahim (author of R package 'fftwtools', licensed under 'GPL-2' or later) is the original author of 'src/ffts.h' and 'src/ffts.cpp'. Prerau's Lab wrote the original 'R/multitaper.R', licensed under 'MIT'. Marcus Geelnard wrote the source code of 'TinyThread' library ('MIT' license) located at 'inst/include/tthread'. Stefan Schlager wrote the original code that converts R objects to 'vcg' (see 'src/vcgCommon.h', licensed under 'GPL-2' or later). Visual Computing Lab is the copyright holder of 'vcglib' source code (see 'src/vcglib', licensed under GPL-2 or later).

Imports graphics, stats, filearray (>= 0.1.3), Rcpp, waveslim (>= 1.8.2), pracma, digest (>= 0.6.29), splines, RNiftyReg (>= 2.7.1), R6 (>= 2.5.1), gsignal (>= 0.3.5)

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LazyData true

NeedsCompilation yes

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Contents

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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)

oldpar <- par(mfrow = c(2, 2), mar = c(3.1, 2.1, 3.1, 0.1))
# ---- Using band_pass1 -----------------------------------------------
```

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

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,
  cex = 0.6
)

# plot pwelch
pwelch(x, fs = 2000, window = 4000, noverlap = 2000, plot = 1)
pwelch(y1, fs = 2000, window = 4000, noverlap = 2000,
       plot = 2, col = "red")
pwelch(y2, fs = 2000, window = 4000, noverlap = 2000,
       plot = 2, col = "blue")
pwelch(y3, fs = 2000, window = 4000, noverlap = 2000,
       plot = 2, col = "green")


# ---- Using band_pass2 with FIR filters --------------------------------

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)

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,
  cex = 0.6
)

# plot pwelch
pwelch(x, fs = 2000, window = 4000, noverlap = 2000, plot = 1)
pwelch(z1, fs = 2000, window = 4000, noverlap = 2000,
       plot = 2, col = "red")
pwelch(z2, fs = 2000, window = 4000, noverlap = 2000,
       plot = 2, col = "blue")
pwelch(z3, fs = 2000, window = 4000, noverlap = 2000,
       plot = 2, col = "green")
```

```
# ---- Clean this demo ------------------------------------------------
par(oldpar)
```

`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:

$$sessionxfrequencyxtimexlocation$$

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 $frequencyxtime$, 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"`

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

`"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, might take a while to profile

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)
```

---

butter_max_order *'Butterworth' filter with maximum order*

Description

Large filter order might not be optimal, but at lease this function provides a feasible upper bound for the order such that the filter has a stable AR component.

Usage

```
butter_max_order(
  w,
  type = c("low", "high", "pass", "stop"),
  r = 10 * log10(2),
  tol = .Machine$double.eps
)
```

Arguments

w	scaled frequency ranging from 0 to 1, where 1 is 'Nyquist' frequency
type	filter type
r	decibel attenuation at frequency w, default is around 3 dB (half power)
tol	tolerance of reciprocal condition number, default is .Machine$double.eps.

Value

'Butterworth' filter in 'Arma' form.

Examples

```
# Find highest order (sharpest transition) of a band-pass filter
sample_rate <- 500
nyquist <- sample_rate / 2

type <- "pass"
w <- c(1, 50) / nyquist
Rs <- 6     # power attenuation at w

# max order filter
```

```
filter <- butter_max_order(w, "pass", Rs)

# -6 dB cutoff should be around 1 ~ 50 Hz
diagnose_filter(filter$b, filter$a, fs = sample_rate)
```

`check_filter` *Check 'Arma' filter*

Description

Check 'Arma' filter

Usage

```
check_filter(b, a, w = NULL, r_expected = NULL, fs = NULL)
```

Arguments

`b`	moving average (`MA`) polynomial coefficients.
`a`	auto-regressive (`AR`) polynomial coefficients.
`w`	normalized frequency, ranging from 0 to 1, where 1 is 'Nyquist'
`r_expected`	attenuation in decibel of each `w`
`fs`	sample rate, used to infer the frequencies and formatting print message, not used in calculation; leave it blank by default

Value

A list of power estimation and the reciprocal condition number of the `AR` coefficients.

Examples

```
# create a butterworth filter with -3dB (half-power) at [1, 5] Hz
# and -60dB stop-band attenuation at [0.5, 6] Hz

sample_rate <- 20
nyquist <- sample_rate / 2

specs <- buttord(
  Wp = c(1, 5) / nyquist,
  Ws = c(0.5, 6) / nyquist,
  Rp = 3,
  Rs = 60
)
filter <- butter(specs)

# filter quality is poor because the AR-coefficients
```

```
# creates singular matrix with unstable inverse,
# this will cause `filtfilt` to fail
check_filter(
  b = filter$b, a = filter$a,

  # frequencies (normalized) where power is evaluated
  w = c(1, 5, 0.5, 6) / nyquist,

  # expected power
  r_expected = c(3, 3, 60, 60)

)
```

`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)




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
  })
```

---

convolve *Convolution of* 1D, 2D, 3D *data via* FFT

Description

Use the 'Fast-Fourier' transform to compute the convolutions of two data with zero padding. This function is mainly designed for image convolution. For forward and backward convolution/filter, see `filtfilt`.

Usage

```
convolve_signal(x, filter)

convolve_image(x, filter)

convolve_volume(x, filter)
```

Arguments

`x`	one-dimensional signal vector, two-dimensional image, or three-dimensional volume; numeric or complex
`filter`	kernel with the same number of dimensions as `x`

Details

This implementation uses 'Fast-Fourier' transform to perform `1D`, `2D`, or `3D` convolution. Compared to implementations using original mathematical definition of convolution, this approach is much faster, especially for image and volume convolutions.

The input `x` is zero-padded beyond edges. This is most common in image or volume convolution, but less optimal for periodic one-dimensional signals. Please use other implementations if non-zero padding is needed.

The convolution results might be different to the ground truth by a precision error, usually at `1e-13` level, depending on the `'FFTW3'` library precision and implementation.

Value

Convolution results with the same length and dimensions as `x`. If `x` is complex, results will be complex, otherwise results will be real numbers.

Examples

```
# ---- 1D convolution -----------------------------------
x <- cumsum(rnorm(100))
filter <- dnorm(-2:2)
# normalize
filter <- filter / sum(filter)
smoothed <- convolve_signal(x, filter)

plot(x, pch = 20)
lines(smoothed, col = 'red')

# ---- 2D convolution -----------------------------------
```

```
x <- array(0, c(100, 100))
x[
  floor(runif(10, min = 1, max = 100)),
  floor(runif(10, min = 1, max = 100))
] <- 1

# smooth
kernel <- outer(dnorm(-2:2), dnorm(-2:2), FUN = "*")
kernel <- kernel / sum(kernel)

y <- convolve_image(x, kernel)

oldpar <- par(mfrow = c(1,2))
image(x, asp = 1, axes = FALSE, main = "Origin")
image(y, asp = 1, axes = FALSE, main = "Smoothed")
par(oldpar)
```

`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 `gsignal` package, but with padding and indexing fixed. The results agree with 'Matlab'.

Value

Decimated signal

Examples

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

# compare with signal package
z <- gsignal::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")
```

`design_filter` *Design a digital filter*

Description

Provides 'FIR' and 'IIR' filter options; default is 'FIR', see also `design_filter_fir`; for 'IIR' filters, see `design_filter_iir`.

Usage

```
design_filter(
  sample_rate,
  data = NULL,
 method = c("fir_kaiser", "firls", "fir_remez", "butter", "cheby1", "cheby2", "ellip"),
  high_pass_freq = NA,
  high_pass_trans_freq = NA,
  low_pass_freq = NA,
  low_pass_trans_freq = NA,
  passband_ripple = 0.1,
  stopband_attenuation = 40,
  filter_order = NA,
  ...,
  data_size = length(data)
)
```

Arguments

`sample_rate`	data sample rate
`data`	data to be filtered, can be optional (`NULL`)
`method`	filter method, options are `"fir"` (default), `"butter"`, `"cheby1"`, `"cheby2"`, and `"ellip"`

high_pass_freq, low_pass_freq
: high-pass or low-pass frequency, see design_filter_fir or design_filter_iir

high_pass_trans_freq, low_pass_trans_freq
: transition bandwidths, see design_filter_fir or design_filter_iir

passband_ripple
: allowable pass-band ripple in decibel; default is 0.1

stopband_attenuation
: minimum stop-band attenuation (in decibel) at transition frequency; default is 40 dB.

filter_order
: suggested filter order; 'RAVE' may or may not adopt this suggestion depending on the data and numerical feasibility

...
: passed to filter generator functions

data_size
: used by 'FIR' filter design to determine maximum order, ignored in 'IIR' filters; automatically derived from data

Value

If data is specified and non-empty, this function returns filtered data via forward and backward filtfilt; if data is NULL, then returns the generator function.

Examples

```
sample_rate <- 200
t <- seq(0, 10, by = 1 / sample_rate)
x <- sin(t * 4 * pi) + sin(t * 20 * pi) +
  2 * sin(t * 120 * pi) + rnorm(length(t), sd = 0.4)

# ---- Using FIR ------------------------------------------------

# Low-pass filter
y1 <- design_filter(
  data = x,
  sample_rate = sample_rate,
  low_pass_freq = 3, low_pass_trans_freq = 0.5
)

# Band-pass cheby1 filter 8-12 Hz with custom transition
y2 <- design_filter(
  data = x,
  method = "cheby1",
  sample_rate = sample_rate,
  low_pass_freq = 12, low_pass_trans_freq = .25,
  high_pass_freq = 8, high_pass_trans_freq = .25
)

y3 <- design_filter(
  data = x,
  sample_rate = sample_rate,
  low_pass_freq = 80,
```

```
  high_pass_freq = 30
)

oldpar <- par(mfrow = c(2, 1),
              mar = c(3.1, 2.1, 3.1, 0.1))
plot(t, x, type = 'l', xlab = "Time", ylab = "",
     main = "Mixture of 2, 10, and 60Hz", xlim = c(0,1))
# lines(t, y, col = 'red')
lines(t, y3, col = 'green')
lines(t, y2, col = 'blue')
lines(t, y1, col = 'red')
legend(
  "topleft", c("Input", "Low: 3Hz", "Pass 8-12Hz", "Pass 30-80Hz"),
  col = c(par("fg"), "red", "blue", "green"), lty = 1,
  cex = 0.6
)

# plot pwelch
pwelch(x, fs = sample_rate, window = sample_rate * 2,
       noverlap = sample_rate, plot = 1, ylim = c(-100, 10))
pwelch(y1, fs = sample_rate, window = sample_rate * 2,
       noverlap = sample_rate, plot = 2, col = "red")
pwelch(y2, fs = sample_rate, window = sample_rate * 2,
       noverlap = sample_rate, plot = 2, col = "blue")
pwelch(y3, fs = sample_rate, window = sample_rate * 2,
       noverlap = sample_rate, plot = 2, col = "green")


# ---- Clean this demo ----------------------------------------------------
par(oldpar)
```

`design_filter_fir` *Design* `'FIR'` *filter using* `firls`

Description

Design `'FIR'` filter using `firls`

Usage

```
design_filter_fir(
  sample_rate,
  filter_order = NA,
  data_size = NA,
  high_pass_freq = NA,
  high_pass_trans_freq = NA,
  low_pass_freq = NA,
  low_pass_trans_freq = NA,
```

```
  stopband_attenuation = 40,
  scale = TRUE,
  method = c("kaiser", "firls", "remez")
)
```

Arguments

sample_rate	sampling frequency
filter_order	filter order, leave NA (default) if undecided
data_size	minimum length of data to apply the filter, used to decide the maximum filter order. For 'FIR' filter, data length must be greater than 3xfilter_order
high_pass_freq	high-pass frequency; default is NA (no high-pass filter will be applied)
high_pass_trans_freq	high-pass frequency band-width; default is automatically inferred from data size. Frequency high_pass_freq - high_pass_trans_freq is the corner of the stop-band
low_pass_freq	low-pass frequency; default is NA (no low-pass filter will be applied)
low_pass_trans_freq	low-pass frequency band-width; default is automatically inferred from data size. Frequency low_pass_freq + low_pass_trans_freq is the corner of the stop-band
stopband_attenuation	allowable power attenuation (in decibel) at transition frequency; default is 40 dB.
scale	whether to scale the filter for unity gain
method	method to generate 'FIR' filter, default is using kaiser estimate, other choices are firls (with hamming window) and remez design.

Details

Filter type is determined from high_pass_freq and low_pass_freq. High-pass frequency is ignored if high_pass_freq is NA, hence the filter is low-pass filter. When low_pass_freq is NA, then the filter is high-pass filter. When both high_pass_freq and low_pass_freq are valid (positive, less than 'Nyquist'), then the filter is a band-pass filter if band-pass is less than low-pass frequency, otherwise the filter is band-stop.

Although the peak amplitudes are set at 1 by low_pass_freq and high_pass_freq, the transition from peak amplitude to zero require a transition, which is tricky but also important to set. When 'FIR' filters have too steep transition boundaries, the filter tends to have ripples in peak amplitude, introducing artifacts to the final signals. When the filter is too flat, components from unwanted frequencies may also get aliased into the filtered signals. Ideally, the transition bandwidth cannot be too steep nor too flat. In this function, users may control the transition frequency bandwidths via low_pass_trans_freq and high_pass_trans_freq. The power at the end of transition is defined by stopband_attenuation, with default value of 40 (i.e. -40 dB, this number is automatically negated during the calculation). By design, a low-pass 5 Hz filter with 1 Hz transition bandwidth results in around -40 dB power at 6 Hz.

Value

'FIR' filter in 'Arma' form.

Examples

```
# ---- Basic ----------------------------

sample_rate <- 500
data_size <- 1000

# low-pass at 5 Hz, with auto transition bandwidth
# from kaiser's method, with default stopband attenuation = 40 dB
filter <- design_filter_fir(
  low_pass_freq = 5,
  sample_rate = sample_rate,
  data_size = data_size
)

# Passband ripple is around 0.08 dB
# stopband attenuation is around 40 dB
print(filter)

diagnose_filter(
  filter$b, filter$a,
  fs = sample_rate,
  n = data_size,
  cutoffs = c(-3, -6, -40),
  vlines = 5
)

# ---- Advanced -------------------------------------------

sample_rate <- 500
data_size <- 1000

# Rejecting 3-8 Hz, with transition bandwidth 0.5 Hz at both ends
# Using least-square (firls) to generate FIR filter
# Suggesting the filter order n=160
filter <- design_filter_fir(
  low_pass_freq = 3, low_pass_trans_freq = 0.5,
  high_pass_freq = 8, high_pass_trans_freq = 0.5,
  filter_order = 160,
  sample_rate = sample_rate,
  data_size = data_size,
  method = "firls"
)

#
print(filter)

diagnose_filter(
  filter$b, filter$a,
```

```
  fs = sample_rate,
  n = data_size,
  cutoffs = c(-1, -40),
  vlines = c(3, 8)
)
```

`design_filter_iir` *Design an 'IIR' filter*

Description

Design an 'IIR' filter

Usage

```
design_filter_iir(
  method = c("butter", "cheby1", "cheby2", "ellip"),
  sample_rate,
  filter_order = NA,
  high_pass_freq = NA,
  high_pass_trans_freq = NA,
  low_pass_freq = NA,
  low_pass_trans_freq = NA,
  passband_ripple = 0.1,
  stopband_attenuation = 40
)
```

Arguments

`method`	filter method name, choices are `"butter"`, `"cheby1"`, `"cheby2"`, and `"ellip"`
`sample_rate`	sampling frequency
`filter_order`	suggested filter order. Notice filters with higher orders may become numerically unstable, hence this number is only a suggested number. If the filter is unstable, this function will choose a lower order; leave this input `NA` (default) if undecided.
`high_pass_freq`	high-pass frequency; default is `NA` (no high-pass filter will be applied)
`high_pass_trans_freq`	high-pass frequency band-width; default is automatically inferred from filter type.
`low_pass_freq`	low-pass frequency; default is `NA` (no low-pass filter will be applied)
`low_pass_trans_freq`	low-pass frequency band-width; default is automatically inferred from filter type.

passband_ripple
: allowable pass-band ripple in decibel; default is `0.1`

stopband_attenuation
: minimum stop-band attenuation (in decibel) at transition frequency; default is `40` dB.

Value

A filter in 'Arma' form.

Examples

```
sample_rate <- 500

my_diagnose <- function(
    filter, vlines = c(8, 12), cutoffs = c(-3, -6)) {
  diagnose_filter(
    b = filter$b,
    a = filter$a,
    fs = sample_rate,
    vlines = vlines,
    cutoffs = cutoffs
  )
}

# ---- Default using butterworth to generate 8-12 bandpass filter ----

# Butterworth filter with cut-off frequency
# 7 ~ 13 (default transition bandwidth is 1Hz) at -3 dB
filter <- design_filter_iir(
  method = "butter",
  low_pass_freq = 12,
  high_pass_freq = 8,
  sample_rate = 500
)

filter

my_diagnose(filter)

## explicit bandwidths and attenuation (sharper transition)

# Butterworth filter with cut-off frequency
# passband ripple is 0.5 dB (8-12 Hz)
# stopband attenuation is 40 dB (5-18 Hz)
filter <- design_filter_iir(
  method = "butter",
  low_pass_freq = 12, low_pass_trans_freq = 6,
  high_pass_freq = 8, high_pass_trans_freq = 3,
  sample_rate = 500,
  passband_ripple = 0.5,
  stopband_attenuation = 40
```

```
)

filter

my_diagnose(filter)

# ---- cheby1 --------------------------------

filter <- design_filter_iir(
  method = "cheby1",
  low_pass_freq = 12,
  high_pass_freq = 8,
  sample_rate = 500
)

my_diagnose(filter)

# ---- cheby2 --------------------------------

filter <- design_filter_iir(
  method = "cheby2",
  low_pass_freq = 12,
  high_pass_freq = 8,
  sample_rate = 500
)

my_diagnose(filter)

# ----- ellip --------------------------------

filter <- design_filter_iir(
  method = "ellip",
  low_pass_freq = 12,
  high_pass_freq = 8,
  sample_rate = 500
)

my_diagnose(filter)
```

---

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)
```

---

diagnose_filter *Diagnose digital filter*

Description

Generate frequency response plot with sample-data simulation

Usage

```
diagnose_filter(
  b,
  a,
  fs,
  n = 512,
  whole = FALSE,
  sample = stats::rnorm(n, mean = sample_signal(n), sd = 0.2),
  vlines = NULL,
  xlim = "auto",
  cutoffs = c(-3, -6, -12)
)
```

Arguments

b	the moving-average coefficients of an ARMA model
a	the auto-regressive coefficients of an ARMA filter; default is 1
fs	sampling frequency in Hz
n	number of points at which to evaluate the frequency response; default is 512
whole	whether to evaluate beyond Nyquist frequency; default is false
sample	sample signal of length n for simulation
vlines	additional vertical lines (frequencies) to plot
xlim	frequency limit of frequency response plot; default is "auto", can be "full" or a numeric of length 2
cutoffs	cutoff decibel powers to draw on the frequency plot, also used to calculate the frequency limit when xlim is "auto"

Value

Nothing

Examples

```
library(ravetools)

# sample rate
srate <- 500

# signal length
npts <- 1000

# band-pass
bpass <- c(1, 50)

# Nyquist
fn <- srate / 2
w <- bpass / fn

# ---- FIR filter -------------------------------------------------
order <- 160

# FIR1 is MA filter, a = 1
filter <- fir1(order, w, "pass")

diagnose_filter(
  b = filter$b, a = filter$a, n = npts,
  fs = srate, vlines = bpass
)

# ---- Butter filter ----------------------------------------------
```

```
filter <- butter(3, w, "pass")

diagnose_filter(
  b = filter$b, a = filter$a, n = npts,
  fs = srate, vlines = bpass
)
```

---

dijkstras-path *Calculate distances along a surface*

Description

Calculate surface distances of graph or mesh using 'Dijkstra' method.

Usage

```
dijkstras_surface_distance(
  positions,
  faces,
  start_node,
  face_index_start = NA,
  max_search_distance = NA,
  ...
)

surface_path(x, target_node)
```

Arguments

positions	numeric matrix with no NA values. The number of row is the total count of nodes (vertices), and the number of columns represent the node dimension. Each row represents a node.
faces	integer matrix with each row containing indices of nodes. For graphs, faces is a matrix with two columns defining the connecting edges; for '3D' mesh, faces is a three-column matrix defining the face index of mesh triangles.
start_node	integer, row index of positions on where to start calculating the distances. This integer must be 1-indexed and cannot exceed the total number of positions rows
face_index_start	integer, the start of the nodes in faces; please specify this input explicitly if the first node is not contained in faces. Default is NA (determined by the minimal number in faces). The reason to set this input is because some programs use 1 to represent the first node, some start from 0.

max_search_distance
: numeric, maximum distance to iterate; default is NA, that is to iterate and search the whole mesh

...
: reserved for backward compatibility

x
: distance calculation results returned by dijkstras_surface_distance function

target_node
: the target node number to reach (from the starting node); target_node is always 1-indexed.

Value

dijkstras_surface_distance returns a list distance table with the meta configurations. surface_path returns a data frame of the node ID (from start_node to target_node) and cumulative distance along the shortest path.

Examples

```
# ---- Toy example --------------------

# Position is 2D, total 6 points
positions <- matrix(runif(6 * 2), ncol = 2)

# edges defines connected nodes
edges <- matrix(ncol = 2, byrow = TRUE, data = c(
  1,2,
  2,3,
  1,3,
  2,4,
  3,4,
  2,5,
  4,5,
  2,5,
  4,6,
  5,6
))

# calculate distances
ret <- dijkstras_surface_distance(
  start_node = 1,
  positions = positions,
  faces = edges,
  face_index_start = 1
)

# get shortest path from the first node to the last
path <- surface_path(ret, target_node = 6)

# plot the results
from_node <- path$path[-nrow(path)]
to_node <- path$path[-1]
plot(positions, pch = 16, axes = FALSE,
```

```
     xlab = "X", ylab = "Y", main = "Dijkstra's shortest path")
segments(
  x0 = positions[edges[,1],1], y0 = positions[edges[,1],2],
  x1 = positions[edges[,2],1], y1 = positions[edges[,2],2]
)

points(positions[path$path,], col = "steelblue", pch = 16)
arrows(
  x0 = positions[from_node,1], y0 = positions[from_node,2],
  x1 = positions[to_node,1], y1 = positions[to_node,2],
  col = "steelblue", lwd = 2, length = 0.1, lty = 2
)

points(positions[1,,drop=FALSE], pch = 16, col = "orangered")
points(positions[6,,drop=FALSE], pch = 16, col = "purple3")

# ---- Example with mesh ---------------------------------

## Not run:

  # Please install the down-stream package `threeBrain`
  # and call library(threeBrain)
  # the following code set up the files

  read.fs.surface <- internal_rave_function(
    "read.fs.surface", "threeBrain")
  default_template_directory <- internal_rave_function(
    "default_template_directory", "threeBrain")
  surface_path <- file.path(default_template_directory(),
                            "N27", "surf", "lh.pial")
  if(!file.exists(surface_path)) {
    internal_rave_function(
      "download_N27", "threeBrain")()
  }

  # Example starts from here --->
  # Load the mesh
  mesh <- read.fs.surface(surface_path)

  # Calculate the path with maximum radius 100
  ret <- dijkstras_surface_distance(
    start_node = 1,
    positions = mesh$vertices,
    faces = mesh$faces,
    max_search_distance = 100,
    verbose = TRUE
  )

  # get shortest path from the first node to node 43144
  path <- surface_path(ret, target_node = 43144)

  # plot
  from_nodes <- path$path[-nrow(path)]
```

```
  to_nodes <- path$path[-1]
  # calculate colors
  pal <- colorRampPalette(
    colors = c("red", "orange", "orange3", "purple3", "purple4")
  )(1001)
  col <- pal[ceiling(
    path$distance / max(path$distance, na.rm = TRUE) * 1000
  ) + 1]
  oldpar <- par(mfrow = c(2, 2), mar = c(0, 0, 0, 0))
  for(xdim in c(1, 2, 3)) {
    if( xdim < 3 ) {
      ydim <- xdim + 1
    } else {
      ydim <- 3
      xdim <- 1
    }
    plot(
      mesh$vertices[, xdim], mesh$vertices[, ydim],
      pch = ".", col = "#BEBEBE33", axes = FALSE,
      xlab = "P - A", ylab = "S - I", asp = 1
    )
    segments(
      x0 = mesh$vertices[from_nodes, xdim],
      y0 = mesh$vertices[from_nodes, ydim],
      x1 = mesh$vertices[to_nodes, xdim],
      y1 = mesh$vertices[to_nodes, ydim],
      col = col
    )
  }

  # plot distance map
  distances <- ret$paths$distance
  col <- pal[ceiling(distances / max(distances, na.rm = TRUE) * 1000) + 1]
  selection <- !is.na(distances)

  plot(
    mesh$vertices[, 2], mesh$vertices[, 3],
    pch = ".", col = "#BEBEBE33", axes = FALSE,
    xlab = "P - A", ylab = "S - I", asp = 1
  )
  points(
    mesh$vertices[selection, c(2, 3)],
    col = col[selection],
    pch = "."
  )

  # reset graphic state
  par(oldpar)


## End(Not run)
```

`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)
```

```
# 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"
)
```

---

fill_surface *Fill a volume cube based on water-tight surface*

Description

Create a cube volume (256 'voxels' on each margin), fill in the 'voxels' that are inside of the surface.

Usage

```
fill_surface(
  surface,
  inflate = 0,
  IJK2RAS = NULL,
  preview = FALSE,
  preview_frame = 128
)
```

Arguments

surface	a surface mesh, can be mesh objects from rgl or freesurferformats packages
inflate	amount of 'voxels' to inflate on the final result; must be a non-negative integer. A zero inflate value means the resulting volume is tightly close to the surface
IJK2RAS	volume 'IJK' (zero-indexed coordinate index) to 'tkrRAS' transform, default is automatically determined leave it 'NULL' if you don't know how to set it
preview	whether to preview the results; default is false
preview_frame	integer from 1 to 256 the depth frame used to generate preview.

Details

This function creates a volume (256 on each margin) and fill in the volume from a surface mesh. The surface vertex points will be embedded into the volume first. These points may not be connected together, hence for each 'voxel', a cube patch will be applied to grow the volume. Then, the volume will be bucket-filled from a corner, forming a negated mask of "outside-of-surface" area. The inverted bucket-filled volume is then shrunk so the mask boundary tightly fits the surface

Value

A list containing the filled volume and parameters used to generate the volume

Author(s)

Zhengjia Wang

Examples

```
# takes > 5s to run example

# Generate a sphere
surface <- vcg_sphere()
surface$vb[1:3, ] <- surface$vb[1:3, ] * 50

fill_surface(surface, preview = TRUE)
```

---

filter-window *Filter window functions*

Description

Filter window functions

Usage

```
hanning(n)

hamming(n)

blackman(n)

blackmannuttall(n)

blackmanharris(n)

flattopwin(n)

bohmanwin(n)
```

Arguments

n	number of time-points in window

Value

A numeric vector of window with length n

Examples

```
hanning(10)
hamming(11)
blackmanharris(21)
```

---

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. For double filters (forward-backward), see `filtfilt`.

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 <- gsignal::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 <- gsignal::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)
```

---

fir1 *Window-based* FIR *filter design*

Description

Generate a `fir1` filter that is checked against `Matlab` `fir1` function.

Usage

```
fir1(
  n,
  w,
  type = c("low", "high", "stop", "pass", "DC-0", "DC-1"),
  window = hamming,
  scale = TRUE,
  hilbert = FALSE
)
```

Arguments

`n`	filter order
`w`	band edges, non-decreasing vector in the range 0 to 1, where 1 is the `Nyquist` frequency. A scalar for high-pass or low-pass filters, a vector pair for band-pass or band-stop, or a vector for an alternating pass/stop filter.
`type`	type of the filter, one of `"low"` for a low-pass filter, `"high"` for a high-pass filter, `"stop"` for a stop-band (band-reject) filter, `"pass"` for a pass-band filter, `"DC-0"` for a band-pass as the first band of a multi-band filter, or `"DC-1"` for a band-stop as the first band of a multi-band filter; default `"low"`

window	smoothing window function or a numerical vector. The filter is the same shape as the smoothing window. When window is a function, window(n+1) will be called, otherwise the length of the window vector needs to have length of n+1; default: hamming
scale	whether to scale the filter; default is true
hilbert	whether to use 'Hilbert' transformer; default is false

Value

The FIR filter coefficients with class 'Arma'. The moving average coefficient is a vector of length n+1.

---

firls *Least-squares linear-phase* FIR *filter design*

Description

Produce a linear phase filter from the weighted mean squared such that error in the specified bands is minimized.

Usage

```
firls(N, freq, A, W = NULL, ftype = "")
```

Arguments

N	filter order, must be even (if odd, then will be increased by one)
freq	vector of frequency points in the range from 0 to 1, where 1 corresponds to the Nyquist frequency.
A	vector of the same length as freq containing the desired amplitude at each of the points specified in freq.
W	weighting function that contains one value for each band that weights the mean squared error in that band. W must be half the length of freq.
ftype	transformer type; default is ""; alternatively, 'h' or 'hilbert' for 'Hilbert' transformer.

Value

The FIR filter coefficients with class 'Arma'. The moving average coefficient is a vector of length n+1.

freqz2 *Frequency response of digital filter*

Description

Compute the z-plane frequency response of an ARMA model.

Usage

```
freqz2(b, a = 1, fs = 2 * pi, n = 512, whole = FALSE, ...)
```

Arguments

b	the moving-average coefficients of an ARMA model
a	the auto-regressive coefficients of an ARMA filter; default is 1
fs	sampling frequency in Hz
n	number of points at which to evaluate the frequency response; default is 512
whole	whether to evaluate beyond Nyquist frequency; default is false
...	ignored

Value

A list of frequencies and corresponding responses in complex vector

grow_volume *Grow volume mask*

Description

Grow volume mask

Usage

```
grow_volume(volume, x, y = x, z = x, threshold = 0.5)
```

Arguments

volume	volume mask array, must be 3-dimensional array
x, y, z	size of grow along each direction
threshold	threshold after convolution

Value

A binary volume mask

Examples

```
oldpar <- par(mfrow = c(2,3), mar = c(0.1,0.1,3.1,0.1))

mask <- array(0, c(21,21,21))
mask[11,11,11] <- 1
image(mask[11,,], asp = 1,
      main = "Original mask", axes = FALSE)
image(grow_volume(mask, 2)[11,,], asp = 1,
      main = "Dilated (size=2) mask", axes = FALSE)
image(grow_volume(mask, 5)[11,,], asp = 1,
      main = "Dilated (size=5) mask", axes = FALSE)

mask[11, sample(11,2), sample(11,2)] <- 1
image(mask[11,,], asp = 1,
      main = "Original mask", axes = FALSE)
image(grow_volume(mask, 2)[11,,], asp = 1,
      main = "Dilated (size=2) mask", axes = FALSE)
image(grow_volume(mask, 5)[11,,], asp = 1,
      main = "Dilated (size=5) mask", axes = FALSE)

par(oldpar)
```

---

internal_rave_function

Get external function from 'RAVE'

Description

Internal function used for examples relative to 'RAVE' project and should not be used directly.

Usage

```
internal_rave_function(name, pkg, inherit = TRUE, on_missing = NULL)
```

Arguments

name	function or variable name
pkg	'RAVE' package name
inherit	passed to get0
on_missing	default value to return of no function is found

Value

Function object if found, otherwise on_missing.

`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)
```

```
oldpar <- 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')

par(oldpar)
```

---

left_hippocampus_mask *Left 'Hippocampus' of 'N27-Collin' brain*

Description

Left 'Hippocampus' of 'N27-Collin' brain

Usage

```
left_hippocampus_mask
```

Format

A three-mode integer mask array with values of `1` ('Hippocampus') and `0` (other brain tissues)

---

matlab_palette *'Matlab' heat-map plot palette*

Description

'Matlab' heat-map plot palette

Usage

```
matlab_palette()
```

Value

vector of 64 colors

mesh_from_volume *Generate 3D mesh surface from volume data*

Description

This function is soft-deprecated. Please use vcg_mesh_volume, vcg_uniform_remesh, and vcg_smooth_explicit or vcg_smooth_implicit.

Usage

```
mesh_from_volume(
  volume,
  output_format = c("rgl", "freesurfer"),
  IJK2RAS = NULL,
  threshold = 0,
  verbose = TRUE,
  remesh = TRUE,
  remesh_voxel_size = 1,
  remesh_multisample = TRUE,
  remesh_automerge = TRUE,
  smooth = FALSE,
  smooth_lambda = 10,
  smooth_delta = 20,
  smooth_method = "surfPreserveLaplace"
)
```

Arguments

volume	3-dimensional volume array
output_format	resulting data format, choices are 'rgl' and 'freesurfer'
IJK2RAS	volume 'IJK' (zero-indexed coordinate index) to 'tkrRAS' transform, default is automatically determined
threshold	threshold used to create volume mask; the surface will be created to fit the mask boundaries
verbose	whether to verbose the progress
remesh	whether to re-sample the mesh using vcg_uniform_remesh
remesh_voxel_size, remesh_multisample, remesh_automerge	see arguments in vcg_uniform_remesh
smooth	whether to smooth the mesh via vcg_smooth_explicit
smooth_lambda, smooth_delta, smooth_method	see vcg_smooth_explicit

Value

A 'mesh3d' surface if output_format is 'rgl', or 'fs.surface' surface otherwise.

Examples

```
volume <- array(0, dim = c(8,8,8))
volume[4:5, 4:5, 4:5] <- 1

graphics::image(x = volume[4,,])

# you can use rgl::wire3d(mesh) to visualize the mesh
mesh <- mesh_from_volume(volume, verbose = FALSE)
```

`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

```
# Takes long to run

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()
)
```

`new_matrix4` *Create a* `Matrix4` *instance for* `'Affine'` *transform*

Description

Create a `Matrix4` instance for `'Affine'` transform

Usage

```
new_matrix4()

as_matrix4(m)
```

Arguments

`m`	a matrix or a vector to be converted to the `Matrix4` instance; `m` must be one of the followings: for matrices, the dimension must be `4x4`, `3x4` (the last row will be `0 0 0 1`), or `3x3` (linear transform); for vectors, the length must be `16`, `12` (will append `0 0 0 1` internally), `3` (translation), or `1` (scale).

Value

A `Matrix4` instance

See Also

`new_vector3`, `new_quaternion`

new_quaternion *Create a* Quaternion *instance to store '3D' rotation*

Description

Create instances that mimic the 'three.js' syntax.

Usage

```
new_quaternion(x = 0, y = 0, z = 0, w = 1)

as_quaternion(q)
```

Arguments

x, y, z, w	numeric of length one
q	R object to be converted to Quaternion

Value

A Quaternion instance

See Also

new_vector3, new_matrix4

new_vector3 *Create a* Vector3 *instance to store '3D' points*

Description

Create instances that mimic the 'three.js' syntax.

Usage

```
new_vector3(x = 0, y = 0, z = 0)

as_vector3(v)
```

Arguments

x, y, z	numeric, must have the same length, 'xyz' positions
v	R object to be converted to Vector3 instance

Value

A Vector3 instance

See Also

new_matrix4, new_quaternion

Examples

```
vec3 <- new_vector3(
  x = 1:9,
  y = 9:1,
  z = rep(c(1,2,3), 3)
)

vec3[]

# transform
m <- new_matrix4()

# rotation xy plane by 30 degrees
m$make_rotation_z(pi / 6)

vec3$apply_matrix4(m)

vec3[]

as_vector3(c(1,2,3))
```

---

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

```
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 = window/2,
  nfft = "auto",
  window_family = hamming,
  col = "black",
  xlim = NULL,
  ylim = NULL,
  main = "Welch periodogram",
  plot = 0,
  log = c("xy", "", "x", "y"),
  ...
)

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

## S3 method for class '`ravetools-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,
  window = 64,
  noverlap = window/2,
  nfft = "auto",
  window_family = hamming
)
```

Arguments

x	numerical vector or a row-major vector, signals. If x is a matrix, then each row is a channel. For plot function, x is the 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 half of the window
nfft	number of points in window function; default is automatically determined from input data and window, scaled up to the nearest power of 2
window_family	function generator for generating filter windows, default is hamming. This can be any window function listed in the filter window family, or any window generator function from package gsignal. Default is hamming. For 'iEEG' users, both hamming and blackmanharris are offered by 'EEG-lab'; while blackmanharris offers better attenuation than Hamming windows, it also has lower spectral resolution. hamming has a 42.5 dB side-lobe attenuation. This may mask spectral content below this value (relative to the peak spectral content). Choosing different windows enables you to make trade-off between resolution (e.g., using a rectangular window) and side-lobe attenuation (e.g., using a hanning window)
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",
    "1000000001111111100000000010000000"
  )
} else {
  bitstring <- paste0(
    "0000000100000000111111110000000001",
    "1111111100001010111111110000000000"
```

```
  )
}

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

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

`rcond_filter_ar` *Computer reciprocal condition number of an 'Arma' filter*

Description

Test whether the filter is numerically stable for `filtfilt`.

Usage

```
rcond_filter_ar(a)
```

Arguments

a	auto-regression coefficient, numerical vector; the first element must not be zero

Value

Reciprocal condition number of matrix `z1`, used in `filtfilt`. If the number is less than `.Machine$double.eps`, then `filtfilt` will fail.

See Also

`check_filter`

Examples

```
# Butterworth filter with low-pass at 0.1 Hz (order = 4)
filter <- butter(4, 0.1, "low")

# TRUE
rcond_filter_ar(filter$a) > .Machine$double.eps

diagnose_filter(filter$b, filter$a, 500)

# Bad filter (order is too high)
```

```
filter <- butter(50, 0.1, "low")

rcond_filter_ar(filter$a) > .Machine$double.eps

# filtfilt needs to inverse a singular matrix
diagnose_filter(filter$b, filter$a, 500)
```

`register_volume` *Imaging registration using* 'NiftyReg'

Description

Registers 'CT' to 'MRI', or 'MRI' to another 'MRI'

Usage

```
register_volume(
  source,
  target,
  method = c("rigid", "affine", "nonlinear"),
  interpolation = c("cubic", "trilinear", "nearest"),
  threads = detect_threads(),
  symmetric = TRUE,
  verbose = TRUE,
  ...
)
```

Arguments

`source`	source imaging data, or a `'nifti'` file path; for example, 'CT'
`target`	target imaging data to align to; for example, 'MRI'
`method`	method of transformation, choices are `'rigid'`, `'affine'`, or `'nonlinear'`
`interpolation`	how volumes should be interpolated, choices are `'cubic'`, `'trilinear'`, or `'nearest'`
`threads, symmetric, verbose, ...`	see `niftyreg`

Value

See `niftyreg`

Examples

```
source <- system.file("extdata", "epi_t2.nii.gz", package="RNiftyReg")
target <- system.file("extdata", "flash_t1.nii.gz", package="RNiftyReg")
aligned <- register_volume(source, target, verbose = FALSE)

source_img <- aligned$source[[1]]
target_img <- aligned$target
aligned_img <- aligned$image

oldpar <- par(mfrow = c(2, 2), mar = c(0.1, 0.1, 3.1, 0.1))

pal <- grDevices::grey.colors(256, alpha = 1)
image(source_img[,,30], asp = 1, axes = FALSE,
      col = pal, main = "Source image")
image(target_img[,,64], asp = 1, axes = FALSE,
      col = pal, main = "Target image")
image(aligned_img[,,64], asp = 1, axes = FALSE,
      col = pal, main = "Aligned image")

# bucket fill and calculate differences
aligned_img[is.nan(aligned_img) | aligned_img <= 1] <- 1
target_img[is.nan(target_img) | aligned_img <= 1] <- 1
diff <- abs(aligned_img / target_img - 1)
image(diff[,,64], asp = 1, axes = FALSE,
      col = pal, main = "Percentage Difference")

par(oldpar)
```

`resample_3d_volume` *Sample '3D' volume in the world (anatomical 'RAS') space*

Description

Low-level implementation to sample a '3D' volume into given orientation and shape via a nearest-neighbor sampler.

Usage

```
resample_3d_volume(
  x,
  new_dim,
  vox2ras_old,
  vox2ras_new = vox2ras_old,
  na_fill = NA
)
```

Arguments

x	image (volume) to be sampled: dim(x) must have length of 3
new_dim	target dimension, integers of length 3
vox2ras_old	from volume index (column-row-slice) to 'RAS' (right-anterior-superior) transform: the volume index starts from 0 (C-style) instead of 1 (R-style) to comply with 'NIfTI' transform.
vox2ras_new	the targeting transform from volume index to 'RAS'
na_fill	default numbers to fill if a pixel is out of bound; default is NA or as.raw(0) if input x is raw type

Value

A newly sampled volume that aligns with x in the anatomical 'RAS' coordinate system. The underlying storage mode is the same as x

Examples

```
# up-sample and rotate image
x <- array(0, c(9, 9, 9))
x[4:6, 4:6, 4:6] <- 1
vox2ras <- matrix(nrow = 4, byrow = TRUE, c(
  0.7071, -0.7071, 0, 0,
  0.7071, 0.7071, 0, -5.5,
  0, 0, 1, -4,
  0, 0, 0, 1
))

new_vox2ras <- matrix(nrow = 4, byrow = TRUE, c(
  0, 0.5, 0, -4,
  0, 0, -0.5, 4,
  0.5, 0, 0, -4,
  0, 0, 0, 1
))

y <- resample_3d_volume(
  x,
  c(17, 17, 17),
  vox2ras_old = vox2ras,
  vox2ras_new = new_vox2ras,
  na_fill = 0
)


image(y[9,,])
```

rgl-call *Safe ways to call package 'rgl' without requiring 'x11'*

Description

Internally used for example show-cases. Please install package 'rgl' manually to use these functions.

Usage

```
rgl_call(FUN, ...)

rgl_view(expr, quoted = FALSE, env = parent.frame())

rgl_plot_normals(x, length = 1, lwd = 1, col = 1, ...)
```

Arguments

FUN	'rgl' function name
...	passed to 'rgl' function
expr	expression within which 'rgl' functions are called
quoted	whether expr is quoted
env	environment in which expr is evaluated
x	triangular 'mesh3d' object
length, lwd, col	normal vector length, size, and color

Examples

```
# Make sure the example does not run when compiling
# or check the package
if(FALSE) {

  volume <- array(0, dim = c(8,8,8))
  volume[4:5, 4:5, 4:5] <- 1
  mesh <- mesh_from_volume(volume, verbose = FALSE)

  rgl_view({

    rgl_call("shade3d", mesh, col = 3)
    rgl_plot_normals(mesh)

  })

}
```

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)

oldpar <- 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]))
}
par(oldpar)
```

`vcg_isosurface` *Create surface mesh from 3D-array*

Description

Create surface from 3D-array using marching cubes algorithm

Usage

```
vcg_isosurface(
  volume,
  threshold_lb = 0,
  threshold_ub = NA,
  vox_to_ras = diag(c(-1, -1, 1, 1))
)
```

Arguments

`volume`	a volume or a mask volume
`threshold_lb`	lower-bound threshold for creating the surface; default is `0`
`threshold_ub`	upper-bound threshold for creating the surface; default is `NA` (no upper-bound)
`vox_to_ras`	a `4x4` `'affine'` transform matrix indicating the 'voxel'-to-world transform.

Value

A triangular mesh of class `'mesh3d'`

Examples

```
if(is_not_cran()) {

library(ravetools)
data("left_hippocampus_mask")

mesh <- vcg_isosurface(left_hippocampus_mask)


rgl_view({

  rgl_call("mfrow3d", 1, 2)

  rgl_call("title3d", "Direct ISOSurface")
  rgl_call("shade3d", mesh, col = 2)

  rgl_call("next3d")
  rgl_call("title3d", "ISOSurface + Implicit Smooth")

  rgl_call("shade3d",
           vcg_smooth_implicit(mesh, degree = 2),
           col = 3)
})

}
```

---

vcg_kdtree_nearest *Find nearest* k *points*

Description

For each point in the query, find the nearest k points in target using K-D tree.

Usage

```
vcg_kdtree_nearest(target, query, k = 1, leaf_size = 16, max_depth = 64)
```

Arguments

target	a matrix with n rows (number of points) and 2 or 3 columns, or a mesh3d object. This is the target point cloud where nearest distances will be sought
query	a matrix with n rows (number of points) and 2 or 3 columns, or a mesh3d object. This is the query point cloud where for each point, the nearest k points in target will be sought.
k	positive number of nearest neighbors to look for
leaf_size	the suggested leaf size for the K-D tree; default is 16; larger leaf size will result in smaller depth
max_depth	maximum depth of the K-D tree; default is 64

Value

A list of two matrices: `index` is a matrix of indices of `target` points, whose distances are close to the corresponding `query` point. If no point in `target` is found, then `NA` will be presented. Each `distance` is the corresponding distance from the query point to the target point.

Examples

```
# Find nearest point in B with the smallest distance for each point in A

library(ravetools)

n <- 10
A <- matrix(rnorm(n * 2), nrow = n)
B <- matrix(rnorm(n * 4), nrow = n * 2)
result <- vcg_kdtree_nearest(
  target = B, query = A,
   k = 1
)

plot(
  rbind(A, B),
  pch = 20,
  col = c(rep("red", n), rep("black", n * 2)),
  xlab = "x",
  ylab = "y",
  main = "Black: target; Red: query"
)

nearest_points <- B[result$index, ]
arrows(A[, 1],
       A[, 2],
       nearest_points[, 1],
       nearest_points[, 2],
       col = "red",
       length = 0.1)

# ---- Sanity check ------------------------------------------------
nearest_index <- apply(A, 1, function(pt) {
  which.min(colSums((t(B) - pt) ^ 2))
})

result$index == nearest_index
```

`vcg_mesh_volume` *Compute volume for manifold meshes*

Description

Compute volume for manifold meshes

Usage

```
vcg_mesh_volume(mesh)
```

Arguments

mesh	triangular mesh of class 'mesh3d'

Value

The numeric volume of the mesh

Examples

```
# Initial mesh
mesh <- vcg_sphere()

vcg_mesh_volume(mesh)
```

---

vcg_raycaster *Cast rays to intersect with mesh*

Description

Cast rays to intersect with mesh

Usage

```
vcg_raycaster(
  x,
  ray_origin,
  ray_direction,
  max_distance = Inf,
  both_sides = FALSE
)
```

Arguments

x	surface mesh
ray_origin	a matrix with 3 rows or a vector of length 3, the positions of ray origin
ray_direction	a matrix with 3 rows or a vector of length 3, the direction of the ray, will be normalized to length 1

max_distance	positive maximum distance to cast the normalized ray; default is infinity. Any invalid distances (negative, zero, or NA) will be interpreted as unset.
both_sides	whether to inverse the ray (search both positive and negative ray directions); default is false

Value

A list of ray casting results: whether any intersection is found, position and face normal of the intersection, distance of the ray, and the index of the intersecting face (counted from 1)

Examples

```
library(ravetools)
sphere <- vcg_sphere(normals = FALSE)
sphere$vb[1:3, ] <- sphere$vb[1:3, ] + c(10, 10, 10)
vcg_raycaster(
  x = sphere,
  ray_origin = array(c(0, 0, 0, 1, 0, 0), c(3, 2)),
  ray_direction = c(1, 1, 1)
)
```

---

vcg_smooth *Implicitly smooth a triangular mesh*

Description

Applies smoothing algorithms on a triangular mesh.

Usage

```
vcg_smooth_implicit(
  mesh,
  lambda = 0.2,
  use_mass_matrix = TRUE,
  fix_border = FALSE,
  use_cot_weight = FALSE,
  degree = 1L,
  laplacian_weight = 1
)

vcg_smooth_explicit(
  mesh,
  type = c("taubin", "laplace", "HClaplace", "fujiLaplace", "angWeight",
    "surfPreserveLaplace"),
  iteration = 10,
  lambda = 0.5,
  mu = -0.53,
```

```
  delta = 0.1
)
```

Arguments

mesh	triangular mesh stored as object of class 'mesh3d'.
lambda	In vcg_smooth_implicit, the amount of smoothness, useful only if use_mass_matrix is TRUE; default is 0.2. In vcg_smooth_explicit, parameter for 'taubin' smoothing.
use_mass_matrix	logical: whether to use mass matrix to keep the mesh close to its original position (weighted per area distributed on vertices); default is TRUE
fix_border	logical: whether to fix the border vertices of the mesh; default is FALSE
use_cot_weight	logical: whether to use cotangent weight; default is FALSE (using uniform 'Laplacian')
degree	integer: degrees of 'Laplacian'; default is 1
laplacian_weight	numeric: weight when use_cot_weight is FALSE; default is 1.0
type	method name of explicit smooth, choices are 'taubin', 'laplace', 'HClaplace', 'fujiLaplace', 'angWeight', 'surfPreserveLaplace'.
iteration	number of iterations
mu	parameter for 'taubin' explicit smoothing.
delta	parameter for scale-dependent 'Laplacian' smoothing or maximum allowed angle (in 'Radian') for deviation between surface preserving 'Laplacian'.

Value

An object of class "mesh3d" with:

vb	vertex coordinates
normals	vertex normal vectors
it	triangular face index

Examples

```
if(is_not_cran()) {

# Prepare mesh with no normals
data("left_hippocampus_mask")

# Grow 2mm on each direction to fill holes
volume <- grow_volume(left_hippocampus_mask, 2)

# Initial mesh
mesh <- vcg_isosurface(volume)

# Start: examples
```

```
rgl_view({
  rgl_call("mfrow3d", 2, 4)
  rgl_call("title3d", "Naive ISOSurface")
  rgl_call("shade3d", mesh, col = 2)

  rgl_call("next3d")
  rgl_call("title3d", "Implicit Smooth")
  rgl_call("shade3d", col = 2,
           x = vcg_smooth_implicit(mesh, degree = 2))

  rgl_call("next3d")
  rgl_call("title3d", "Explicit Smooth - taubin")
  rgl_call("shade3d", col = 2,
           x = vcg_smooth_explicit(mesh, "taubin"))

  rgl_call("next3d")
  rgl_call("title3d", "Explicit Smooth - laplace")
  rgl_call("shade3d", col = 2,
           x = vcg_smooth_explicit(mesh, "laplace"))

  rgl_call("next3d")
  rgl_call("title3d", "Explicit Smooth - angWeight")
  rgl_call("shade3d", col = 2,
           x = vcg_smooth_explicit(mesh, "angWeight"))

  rgl_call("next3d")
  rgl_call("title3d", "Explicit Smooth - HClaplace")
  rgl_call("shade3d", col = 2,
           x = vcg_smooth_explicit(mesh, "HClaplace"))

  rgl_call("next3d")
  rgl_call("title3d", "Explicit Smooth - fujiLaplace")
  rgl_call("shade3d", col = 2,
           x = vcg_smooth_explicit(mesh, "fujiLaplace"))

  rgl_call("next3d")
  rgl_call("title3d", "Explicit Smooth - surfPreserveLaplace")
  rgl_call("shade3d", col = 2,
           x = vcg_smooth_explicit(mesh, "surfPreserveLaplace"))
})

}
```

---

vcg_sphere *Simple 3-dimensional sphere mesh*

Description

Simple 3-dimensional sphere mesh

Usage

```
vcg_sphere(sub_division = 3L, normals = TRUE)
```

Arguments

sub_division	density of vertex in the resulting mesh
normals	whether the normal vectors should be calculated

Value

A 'mesh3d' object

Examples

```
vcg_sphere()
```

---

vcg_uniform_remesh *Sample a surface mesh uniformly*

Description

Sample a surface mesh uniformly

Usage

```
vcg_uniform_remesh(
  x,
  voxel_size = NULL,
  offset = 0,
  discretize = FALSE,
  multi_sample = FALSE,
  absolute_distance = FALSE,
  merge_clost = FALSE,
  verbose = TRUE
)
```

Arguments

x	surface
voxel_size	'voxel' size for space 'discretization'
offset	offset position shift of the new surface from the input
discretize	whether to use step function (TRUE) instead of linear interpolation (FALSE) to calculate the position of the intersected edge of the marching cube; default is FALSE

multi_sample	whether to calculate multiple samples for more accurate results (at the expense of more computing time) to remove artifacts; default is FALSE
absolute_distance	whether an unsigned distance field should be computed. When set to TRUE, non-zero offsets is to be set, and double-surfaces will be built around the original surface, like a sandwich.
merge_clost	whether to merge close vertices; default is TRUE
verbose	whether to verbose the progress; default is TRUE

Value

A triangular mesh of class 'mesh3d'

Examples

```
sphere <- vcg_sphere()
mesh <- vcg_uniform_remesh(sphere, voxel_size = 0.45)

if(is_not_cran()) {

rgl_view({

  rgl_call("mfrow3d", 1, 2)

  rgl_call("title3d", "Input")
  rgl_call("wire3d", sphere, col = 2)
  rgl_call("next3d")

  rgl_call("title3d", "Re-meshed to 0.1mm edge distance")
  rgl_call("wire3d", mesh, col = 3)
})

}
```

---

vcg_update_normals *Update vertex normal*

Description

Update vertex normal

Usage

```
vcg_update_normals(
  mesh,
  weight = c("area", "angle"),
  pointcloud = c(10, 0),
  verbose = FALSE
)
```

Arguments

mesh	triangular mesh or a point-cloud (matrix of 3 columns)
weight	method to compute per-vertex normal vectors: "area" weighted average of surrounding face normal, or "angle" weighted vertex normal vectors.
pointcloud	integer vector of length 2: containing optional parameters for normal calculation of point clouds; the first entry specifies the number of neighboring points to consider; the second entry specifies the amount of smoothing iterations to be performed.
verbose	whether to verbose the progress

Value

A 'mesh3d' object with normal vectors.

Examples

```
if(is_not_cran()) {

# Prepare mesh with no normal
data("left_hippocampus_mask")
mesh <- vcg_isosurface(left_hippocampus_mask)
mesh$normals <- NULL

# Start: examples
new_mesh <- vcg_update_normals(mesh, weight = "angle",
                               pointcloud = c(10, 10))

rgl_view({
  rgl_call("mfrow3d", 1, 2)
  rgl_call("shade3d", mesh, col = 2)

  rgl_call("next3d")
  rgl_call("shade3d", new_mesh, col = 2)
})
}
```

---

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

```
# 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