Package ‘trajr’

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Type Package

Title Animal Trajectory Analysis

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Description A toolbox to assist with statistical analysis of animal trajectories.
It provides simple access to algorithms for calculating and assessing a variety of characteristics such as speed and acceleration, as well as multiple measures of straightness or tortuosity. Some support is provided for 3-dimensional trajectories.
McLean & Skowron Volponi (2018) <doi:10.1111/eth.12739>.

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URL `https://github.com/JimMcL/trajr`

BugReports `https://github.com/JimMcL/trajr/issues`

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Imports signal, utils, stats, graphics, plotrix, grDevices

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Contents

`ElapsedTimeProgressBarFn` *A general purpose progress bar that reports elapsed time rather than number of items*

Description

A general purpose progress bar that reports elapsed time rather than number of items

Usage

```
ElapsedTimeProgressBarFn(numItems, reportFn)
```

Arguments

`numItems`	Number of items to be processed
`reportFn`	A function used to report changing progress

Value

A function which should be called for each item as it is processed.

`lines.Trajectory` *Add Trajectory lines to a plot*

Description

The `lines` method for Trajectory objects.

Usage

```
## S3 method for class 'Trajectory'
lines(
  x,
  draw.start.pt = TRUE,
  start.pt.cex = 0.8,
  start.pt.pch = 16,
  start.pt.col = "black",
  turning.angles = NULL,
  ...
)
```

Arguments

`x`	An object of class "Trajectory", the trajectory to be plotted.
`draw.start.pt`	If TRUE, draws a dot at the start point of the trajectory.
`start.pt.cex`	Scale to apply when drawing the start point dot.
`start.pt.pch`	Pch (i.e. plot character, symbol or shape) to apply when drawing the start point dot.
`start.pt.col`	Colour to apply when drawing the start point dot.
`turning.angles`	If `"random"` or `"directed"`, draws step turning angles. `"directed"` assumes errors are relative to the first recorded step angle. `"random"` assumes errors are relative to the previous step.
`...`	Additional arguments are passed to `lines`.

`plot.TrajDirectionAutocorrelations` *Plot method for direction autocorrelation*

Description

The `plot` method for `TrajDirectionAutocorrelations` objects. Plots the direction autocorrelation function as returned by a call to `TrajDirectionAutocorrelations`, with a optional dot at the first local minimum.

Usage

```
## S3 method for class 'TrajDirectionAutocorrelations'
plot(
  x,
  firstMinWindowSize = 10,
  type = "l",
  ylab = expression("C(" * Delta * s * ")"),
  xlab = expression(Delta * s),
  ...
)
```

Arguments

`x`	Trajectory to be plotted.
`firstMinWindowSize`	If not NULL, specifies a window size used to calculate the first local minimum, which is then plotted as a point.
`type`, `xlab`, `ylab`	Defaults for plotting.
`...`	Additional arguments passed to `plot`.

`plot.Trajectory` *Plot method for trajectories*

Description

The `plot` method for Trajectory objects.

Usage

```
## S3 method for class 'Trajectory'
plot(
  x,
  add = FALSE,
  draw.start.pt = TRUE,
  start.pt.cex = 0.8,
  start.pt.pch = 16,
  start.pt.col = "black",
  turning.angles = NULL,
  xlim = grDevices::extendrange(x$x),
  ylim = grDevices::extendrange(x$y),
  xlab = ifelse(is.null(TrajGetUnits(x)), "x", sprintf("x (%s)", TrajGetUnits(x))),
  ylab = ifelse(is.null(TrajGetUnits(x)), "y", sprintf("y (%s)", TrajGetUnits(x))),
  ann = graphics::par("ann"),
  axes = TRUE,
  frame.plot = axes,
  asp = 1,
```

```
  ...
)
```

Arguments

`x`	An object of class "Trajectory", the trajectory to be plotted.
`add`	If TRUE, the trajectory is added to the current plot.
`draw.start.pt`	If TRUE, draws a dot at the start point of the trajectory.
`start.pt.cex`	Scale to apply when drawing the start point dot.
`start.pt.pch`	Pch (i.e. plot character, symbol or shape) to apply when drawing the start point dot.
`start.pt.col`	Colour to apply when drawing the start point dot.
`turning.angles`	If `"random"` or `"directed"`, draws step turning angles. `"directed"` assumes errors are relative to the first recorded step angle. `"random"` assumes errors are relative to the previous step.
`xlim`, `ylim`, `xlab`, `ylab`, `asp`, `ann`, `axes`, `frame.plot`	plotting parameters with useful defaults.
`...`	Additional arguments are passed to both `plot` and `lines`.

See Also

`TrajFromCoords`

Examples

```
set.seed(42)
trj <- TrajGenerate(angularErrorSd = 1.3)
plot(trj)
```

`plot.TrajSpeedIntervals`

Plot method for trajectory speed intervals

Description

Plots speed over time, with intervals of fast and/or slow speed highlighted.

Usage

```
## S3 method for class 'TrajSpeedIntervals'
plot(
  x,
  slowerThanColour = "red",
  fasterThanColour = "green",
```

```
  highlightColor = "#0000FF1E",
  xlab = sprintf("Time (%s)", TrajGetTimeUnits(attr(x, "trajectory"))),
  ylab = sprintf("Speed (%s/%s)", TrajGetUnits(attr(x, "trajectory")),
    TrajGetTimeUnits(attr(x, "trajectory"))),
  type = "l",
  ...
)
```

Arguments

`x`	An object of class "SpeedIntervals", as created by `TrajSpeedIntervals`.
`slowerThanColour`, `fasterThanColour`	The colour of the horizontal line plotted at the "slower than" or "faster than" speed. Specify `NULL` to prevent the line from being plotted.
`highlightColor`	Colour of the highlight rectangles.
`xlab`, `ylab`, `type`	Plotting parameters with useful defaults.
`...`	Additional arguments are passed to `plot`.

See Also

`TrajSpeedIntervals`

Examples

```
# Display speed intervals with custom x-axis labels

# Generate and smooth a trajectory
set.seed(3)
trj <- TrajSmoothSG(TrajGenerate(120, fps = 0.5))
# Get speed intervals to be plotted
si <- TrajSpeedIntervals(trj, slowerThan = 0.9, diff = "central")
# Plot, but don't label x axis
plot(si, xlab = "Time (min:sec)", xaxt = "n")
# Work out where x-axis tick marks should be
speeds <- attr(si, "speed") # data frame containing speed over time
p <- pretty(speeds$time)
# Draw x-sxis ticks and labels with custom formatting
axis(1, p, sprintf("%d:%02d", p %/% 60, p %% 60))
```

`points.Trajectory` *Add Trajectory points to a plot*

Description

The `points` method for Trajectory objects.

Usage

```
## S3 method for class 'Trajectory'
points(x, draw.start.pt = TRUE, turning.angles = NULL, ...)
```

Arguments

`x`	An object of class "Trajectory", the trajectory to be plotted.
`draw.start.pt`	If TRUE, draws a dot at the start point of the trajectory.
`turning.angles`	If `"random"` or `"directed"`, draws step turning angles. `"directed"` assumes errors are relative to the first recorded step angle. `"random"` assumes errors are relative to the previous step.
`...`	Additional arguments are passed to `points`.

`Traj3DDistance` *3D Trajectory distance*

Description

Calculates the distance between the start and end of a 3-dimensional trajectory (or a portion of a trajectory). Also called the diffusion distance, net distance, displacement, or bee-line from start to finish.

Usage

```
Traj3DDistance(trj3d, startIndex = 1, endIndex = nrow(trj3d))
```

Arguments

`trj3d`	3-dimensional trajectory whose distance is to be calculated.
`startIndex`	Index of the starting point.
`endIndex`	Index of the ending point.

Value

Numeric distance from the start to the end of the trajectory.

See Also

`Traj3DFromCoords`

`Traj3DFromCoords` *Create a 3D Trajectory Object*

Description

`Traj3DFromCoords` creates a new 3-dimensional trajectory object from a set of 3-dimensional cartesian coordinates, times and some metadata. A 3D trajectory is a 2D trajectory (see `TrajFromCoords`) with the addition of a `z` coordinate. `trajr` functions that expect a 2D trajectory will work on a 3D trajectory by simply ignoring the `z` dimension, so should only be used with care. A small number of functions operate on 3D trajectories, and are prefixed by `Traj3D`. Existing `trajr` functions that that do not deal with spatial data (e.g. `TrajDuration`, `TrajGetNCoords` etc.) can safely be used.

Usage

```
Traj3DFromCoords(
  track,
  xCol = 1,
  yCol = 2,
  zCol = 3,
  timeCol = NULL,
  fps = 50,
  spatialUnits = "m",
  timeUnits = "s"
)
```

Arguments

`track`	data frame containing cartesian coordinates and optionally times for the points in the trajectory.
`xCol`	Name or index of the `x` column in `track` (default 1).
`yCol`	Name or index of the `y` column in `track` (default 2).
`zCol`	Name or index of the `z` column in `track` (default 3).
`timeCol`	optional name or index of the column which contains coordinate times.
`fps`	Frames per second - used to calculate relative coordinate times if `track` does not contain a `time` column. Time intervals between coordinate are assumed to be constant throught the entire track.
`spatialUnits`	Abbreviation for the x, y and z units.
`timeUnits`	Abbreviation for the units that time is recorded in.

Details

The coordinates are sometimes referred to as "relocations". Rows containing `NA` coordinate or time values at the start or end of the trajectory are discarded. `NA` coordinates or times in the middle of the trajectory generate an error.

If `timeCol` is specified, `track[,timeCol]` is expected to contain the time (in some numeric units) of each coordinate. Otherwise, times are calculated for each point as `(coord - 1) / fps` where `coord` is the index of the point; in other words, sampling at constant time intervals is assumed. Time values require conversion if they are not numeric. It may be possible to use ‘strptime‘ for this purpose, or `TrajConvertTime` can be used to convert multiple field time values.

`x` and `y` must be square units. Longitude and latitude are not suitable for use as `x` and `y` values, since in general, `1° lat != 1° lon`. To create a trajectory from positions in latitude and longitude, it is first necessary to transform the positions to a suitable spatial projection such as UTM (possibly by using `spTransform` from the `rgdal` package).

Leading and trailing rows with `NA` coordinate values are discarded. `NA` coordinate values within a trajectory generate an error.

Value

An object with class "`Trajectory3D`", which is a data.frame with the following components:

`x`	X coordinates of trajectory points.
`y`	Y coordinates of trajectory points.
`time`	Time (in `timeUnits`) for each point. if `timeCol` is specified, values are `track[,timeCol]`, otherwise values are calculated from `fps`.
`displacementTime`	Relative frame/observation times, with frame/observation 1 at time `0`.
`polar`	X and y coordinates represented as complex numbers, to simplify working with 2D segment angles. Note that the z dimension is not represented.
`displacement`	2-dimensional displacement vectors (represented as complex numbers) between each pair of consecutive points. Note that the z dimension is not represented.

See Also

`Traj3DLength`, `Traj3DStepLengths`, `Traj3DDistance`, `Traj3DStraightness`, `Traj3DSmoothSG`, `Traj3DResampleTime`, `Traj3DRediscretize`, `TrajFromCoords` for creating 2-dimensional trajectories

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`Traj3DLength` *3D trajectory length*

Description

Calculates the cumulative length of a 3-dimensional trajectory, or a portion of a trajectory. The length is the total distance travelled along the trajectory.

Usage

```
Traj3DLength(trj3d, startIndex = 1, endIndex = nrow(trj3d))
```

Arguments

`trj3d`	3D trajectory whose length is to be calculated.
`startIndex`	Index of the starting point.
`endIndex`	Index of the ending point.

Value

Numeric length of the trajectory.

See Also

`Traj3DFromCoords`, `Traj3DStepLengths`, `TrajLength`

`Traj3DRediscretize` *Resample a 3D trajectory to a constant step length*

Description

Constructs a new 3-dimensional trajectory by resampling the input 3-dimensional trajectory to a fixed step (or segment) length. By default, timing of frames is lost, so speed and acceleration cannot be calculated on a rediscretized trajectory. However, a constant speed may be applied to the rediscretized trajectory (`simConstantSpeed = TRUE`), in which case the returned trajectory will have (almost) constant speed, with average speed approximately equal to the average speed of `trj3d`.

Usage

```
Traj3DRediscretize(trj3d, R, simConstantSpeed = FALSE)
```

Arguments

`trj3d`	The 3-dimensional trajectory to be resampled.
`R`	rediscretization step length, in the spatial units of `trj`.
`simConstantSpeed`	If TRUE, speeds are interpolated along the new trajectory so that average speed is approximately the same as that of `trj3d`.

Details

Unfortunately this operation is slow for large trajectories.

Based on the appendix in Bovet and Benhamou, (1988), extended to 3 dimensions.

Value

A new 3-dimensional trajectory with a constant segment length which follows `trj3d`.

References

Bovet, P., & Benhamou, S. (1988). Spatial analysis of animals' movements using a correlated random walk model. Journal of Theoretical Biology, 131(4), 419-433. doi:10.1016/S0022-5193(88)80038-9

See Also

`Traj3DFromCoords`, `TrajRediscretize`

`Traj3DResampleTime` *Resample a 3D trajectory to a constant time interval*

Description

Constructs a new 3-dimensional trajectory by resampling the input trajectory to a fixed time interval. Points are linearly interpolated along the trajectory. Spatial and time units are preserved.

Usage

```
Traj3DResampleTime(trj3d, stepTime, newFps = NULL)
```

Arguments

`trj3d`	The 3-dimensional trajectory to be resampled.
`stepTime`	The resampled trajectory step time. Each step in the new trajectory will have this duration.
`newFps`	Value to be stored as the FPS value in the new trajectory (see `TrajGetFPS`). It is not otherwise used by this function.

Value

A new 3-dimensional trajectory with a constant time interval for each step. Points in the new trajectory are calculated by linearly interpolating along `trj3d`.

See Also

`Traj3DFromCoords`, `TrajResampleTime`

`Traj3DSmoothSG` *Smooth a 3D trajectory using a Savitzky-Golay filter*

Description

Smooths a 3-dimensional trajectory using a Savitzky-Golay smoothing filter.

Usage

```
Traj3DSmoothSG(trj3d, p = 3, n = p + 3 - p%%2, ...)
```

Arguments

`trj3d`	The 3=dimensional trajectory to be smoothed.
`p`	polynomial order (passed to `sgolayfilt`).
`n`	Filter length (or window size), must be an odd number. Passed to `sgolayfilt`.
`...`	Additional arguments are passed to `sgolayfilt`.

Details

Consider carefully the effects of smoothing a trajectory with temporal gaps in the data. If the smoothed trajectory is used to derive speed and/or acceleration, it may be advisable to fill in the gaps before smoothing, possibly by calling `Traj3DResampleTime`.

Value

A new trajectory which is a smoothed version of the input trajectory.

See Also

`Traj3DFromCoords`, `sgolayfilt`, `TrajSmoothSG`

`Traj3DStepLengths` *3D trajectory step lengths*

Description

Returns the lengths of each step in a 3-dimensional trajectory (or part of a trajectory).

Usage

```
Traj3DStepLengths(trj3d, startIndex = 1, endIndex = nrow(trj3d))
```

Arguments

`trj3d`	Trajectory to query.
`startIndex`	Index of the starting point.
`endIndex`	Index of the ending point.

Value

Vector of step lengths. The vector will have length `1 - TrajGetNCoords(trj3d)`.

See Also

`Traj3DFromCoords`, `Traj3DLength`, `TrajStepLengths`

`Traj3DStraightness` *Straightness of a 3D Trajectory*

Description

Calculates the straightness index of a 3-dimensional trajectory, D/L, where `D` is the beeline distance between the first and last points in the trajectory,and `L` is the path length travelled (Batschelet, 1981). Benhamou (2004) considers the straightness index to be a reliable measure of the efficiency of a directed walk, but inapplicable to random trajectories. The straightness index of a random walk tends towards zero as the number of steps increases, hence should only be used to compare the tortuosity of random walks consisting of a similar number of steps.

Usage

```
Traj3DStraightness(trj3d)
```

Arguments

`trj3d`	3-dimensional trajectory to calculate straightness of.

Details

The straightness index is also known as the net-to-gross displacement ratio. According to Batschelet (1981), this value (termed *d*) is an approximation of *r*, which is the length of the mean vector of turning angles of a constant step-length trajectory (see `TrajMeanVectorOfTurningAngles` and `TrajRediscretize` for creating a constant step-length trajectory).

Value

The straightness index of `trj`, which is a value between 0 (infinitely tortuous) to 1 (a straight line).

References

Batschelet, E. (1981). Circular statistics in biology. ACADEMIC PRESS, 111 FIFTH AVE., NEW YORK, NY 10003, 1981, 388.

Benhamou, S. (2004). How to reliably estimate the tortuosity of an animal's path. Journal of Theoretical Biology, 229(2), 209-220. doi:10.1016/j.jtbi.2004.03.016

See Also

`Traj3DFromCoords`, `Traj3DDistance` for trajectory distance (or displacement), and `Traj3DLength` for trajectory path length, `Traj3DStraightness` for the straightness of a 2D trajectory.

`TrajAcceleration` *Approximates the acceleration of a trajectory*

Description

Returns an approximation of the acceleration of a trajectory at each point using the second-order central finite differences.

Usage

```
TrajAcceleration(trj)
```

Arguments

`trj`	Trajectory whose acceleration is to be calculated.

Details

'trajr' trajectories, which consist of straight line displacements between sampled locations, do not contain enough information to correctly derive velocity or acceleration. Since we have to assume a constant velocity at each step, the first derivative is discontinuous. Acceleration, therefore, is zero during each step and infinite at each change of velocity. The approximation implemented by this function assumes that acceleration occurs over a period of time: half the duration of the previous step plus half the duration of the next step.

Value

Vector of complex numbers. The modulus (`Mod(a)`) is the magnitude of the acceleration at each point, and the argument (`Arg(a)`) is the direction of the acceleration. The vector has an attribute, `trj`, with the trajectory as its value. The first and last values will always be `NA`, since acceleration cannot be estimated for those points.

See Also

`TrajVelocity` for calculating velocity, `TrajResampleTime` and `TrajRediscretize` to resample a trajectory to fixed time or length steps.

Examples

```
# A function to plot acceleration as arrows (scaled in length)
AccArrows <- function(acc, scale = .001, trj = attr(acc, "trj"), ...) {
  graphics::arrows(trj$x, trj$y, trj$x + Re(acc) * scale, trj$y + Im(acc) * scale, ...)
}

# Generate and plot a random trajectory
set.seed(101)
trj <- TrajGenerate(30)
plot(trj)

# Calculate acceleration
acc <- TrajAcceleration(trj)
# Plot acceleration as red arrows at each point. They need to be scaled down to
# fit in the plot, and the arrowhead lengths need to be shortened to look good
AccArrows(acc, scale = .001, col = "red", length = .1)
```

`TrajAngles` *Turning angles of a Trajectory*

Description

Calculates the step angles (in radians) of each segment, either relative to the previous segment or relative to the specified compass direction.

Usage

```
TrajAngles(trj, lag = 1, compass.direction = NULL)
```

Arguments

`trj`	the trajectory whose angles are to be calculated.
`lag`	Angles between every lag'th segment are calculated. Only applies to non-directed walks, i.e. `compass.direction` is `NULL`.
`compass.direction`	If not `NULL`, step angles are calculated relative to this angle (in radians), otherwise they are calculated relative to the previous step angle.

Details

Note that since turning angles are circular quantities, i.e. 360° == 0°, it is incorrect to treat them as linear quantities. In particular, do not calculate arithmetic means or standard deviations of turning angles. See Batschelet, (1981) for a detailed explanation and techniques for dealing with circular quantities.

The turning angle before and after every zero-length segment will be `NA`, since the angle of a zero-length segment is undefined. This behaviour began in `trajr` version 1.5.0 (or development version

1.4.0.9000). Prior to this fix, the angle of a zero-length segment was assumed to be 0, which led to incorrect turning angles being returned. One approach to dealing with zero-length segments is to simply remove them from the trajectory. See `TrajFromTrjPoints` for a means to achieve this.

Value

Step angles in radians, normalised so that `-pi` < `angle` <= `pi`. If `compass.direction` is `NULL` (the default), the returned vector will have length `nrow(trj) - 2`, i.e. one angle for every pair of adjacent segments. If `compass.direction` is not `NULL`, the returned vector will have length `nrow(trj) - 1`, i.e. one angle for every segment.

References

Batschelet, E. (1981). Circular statistics in biology. ACADEMIC PRESS, 111 FIFTH AVE., NEW YORK, NY 10003, 1981, 388.

See Also

`TrajStepLengths`, `TrajMeanVectorOfTurningAngles`, `TrajFromTrjPoints`

`TrajConvertTime` *Converts a delimited time string to a numeric value*

Description

Time values may be imported in a format which is not immediately usable by ‘trajr‘. This function converts times that are specified as a number of delimited fields to a single numeric value. The default parameter values handle a value with 4 colon-separated values, which are hours, minutes, seconds and milliseconds, eg: "0:01:04:108" represents 1 minute, 4 seconds and 108 milliseconds, or 64.108 seconds.

Usage

```
TrajConvertTime(time, sep = ":", factors = c(60 * 60, 60, 1, 0.001))
```

Arguments

`time`	A character string containing the time value to be converted.
`sep`	Field separator.
`factors`	Vector of numeric factors to be applied to each field, in the order they occur within ‘time‘. The default assumes 4 fields containing numeric hours, minutes, seconds and milliseconds.

Details

Note that the base R strptime can be used to convert time values in more complex date/time formats, but it does not handle millisecond fields.

Value

‘time‘ converted to a numeric value.

See Also

`strptime`

Examples

```
time <- c("0:00:00:029", "0:01:00:216", "0:02:01:062", "1:00:02:195", "1:06:03:949", "1:42:04:087")
seconds <- TrajConvertTime(time)
```

`TrajDAMinMax` *First direction autocorrelation minimum/maximum*

Description

Determines the coordinates of the first local minimum/maximum of `C` in the direction autocorrelation function of a trajectory as returned by `TrajDirectionAutocorrelations`. The end point is excluded from consideration as a minimum, similarly the start point will not be returned as a maximum. If the trajectory does not oscillate in direction, there will not be a local minimum/maximum, and `NULL` is returned.

Usage

```
TrajDAFindFirstMinimum(corr, windowSize = 10)

TrajDAFindFirstMaximum(corr, windowSize = 10)
```

Arguments

`corr`	A `TrajDirectionAutocorrelations` object, i.e. the direction autocorrelation of a trajectory.
`windowSize`	Size of window used to define what constitutes a local mimimum/maximum.

Value

Numeric vector with 2 values, `deltaS` and `C`, or NULL if there is no local minimum/maximum.

See Also

`TrajDirectionAutocorrelations`

Examples

```
set.seed(42)
trj <- TrajGenerate(600, angularErrorSd = 1)
smoothed <- TrajSmoothSG(trj, 3, 11)

# Resample to fixed path length
resampled <- TrajRediscretize(smoothed, 1)
# Calculate direction autocorrelation for resampled trajectory
corr <- TrajDirectionAutocorrelations(resampled, 100)
# Extract first local minimum from autocorrelation
minPt <- TrajDAFindFirstMinimum(corr, 20)

# Plot the autocorrelation function
plot(corr, type ='l')
# Plot a red dot with a black outline at the first minimum
points(minPt["deltaS"], minPt["C"], pch = 16, col = "red", lwd = 2)
points(minPt["deltaS"], minPt["C"], col = "black", lwd = 2)
```

`TrajDerivatives` *Calculates trajectory speed and change of speed*

Description

Calculates speed and change of speed along a trajectory over time. These are the first and second order derivatives of distance travelled over time. Noisy trajectories should be smoothed before being passed to this function, as noise is effectively amplified when taking derivatives.

Usage

```
TrajDerivatives(trj)
```

Arguments

`trj`	Trajectory whose speed and change in speed is to be calculated.

Details

The value returned as `acceleration` is *not* technically acceleration. In mechanics, acceleration is a vector. The returned value is a scalar quantity: change of speed, which is sometimes known informally as acceleration. This value corresponds to the acceleration in a 1-dimensional trajectory, with the sign indicating the direction of acceleration relative to the current direction of velocity. See `TrajAcceleration` for an approximation of (vector) acceleration, and `TrajVelocity` for an approximation of velocity.

Value

A list with components:

`speed`	numeric vector, speed between each pair of trajectory points, i.e. the speed of each step.
`speedTimes`	numeric vector, times corresponding to values in `speed`, i.e. the time from the start of the trajectory to the end of each step.
`acceleration`	numeric vector, change in speed between steps. Despite the name, this is not acceleration as defined by mechanics.
`accelerationTimes`	numeric vector, time from the start of the trajectory to the end of the second step in each pair.

See Also

`TrajSpeedIntervals` for analysing intervals of low or high speed within the trajectory. `TrajSmoothSG` for smoothing a trajectory. `TrajAcceleration` for calculating acceleration, and `TrajVelocity` for calculating velocity.

`TrajDirectionalChange` *Directional change (DC)*

Description

Calculates the time variation of directional change (DC) of a trajectory *sensu* Kitamura & Imafuku (2015). Directional change is defined as the angular change (in degrees) between two steps in the trajectory, divided by the time difference between the two steps.

Usage

```
TrajDirectionalChange(trj, nFrames = 1)
```

Arguments

`trj`	Track to calculate DC for.
`nFrames`	Frame delta to process: if 1, every frame is processed, if 2, every 2nd frame is processed, and so on. Default is 1.

Details

This function returns the DC for each pair of consecutive steps. Kitamura & Imafuku (2015) used the mean and the standard deviation of DC for portions of trajectories as index values of nonlinearity and irregularity respectively.

Value

The directional change (DC) in degrees between every pair of consecutive segments in the trajectory, i.e. if `nFrames` is 1, the returned vector will have length `nrow(trj) - 2`.

References

Kitamura, T., & Imafuku, M. (2015). Behavioural mimicry in flight path of Batesian intraspecific polymorphic butterfly Papilio polytes. Proceedings of the Royal Society B: Biological Sciences, 282(1809). doi:10.1098/rspb.2015.0483

Examples

```
set.seed(42)
trj <- TrajGenerate()
SD = mean(TrajDirectionalChange(trj))
SDDC = sd(TrajDirectionalChange(trj))
```

`TrajDirectionAutocorrelations`

Direction autocorrelation

Description

Calculates the autocorrelation of the track for Δs ranging from 1 to `deltaSMax`, based on Shamble et al. (2017). `trj` must have a constant step length (see `TrajRediscretize`) i.e. all segments in the trajectory must be the same length. deltaS is specified in number of segments. Call `TrajDAFindFirstMinimum` to locate the first local minimum which may be used to characterise directional periodicity in a trajectory (note that the first local minimum may not exist).

Usage

```
TrajDirectionAutocorrelations(trj, deltaSMax = round(nrow(trj)/4))
```

Arguments

`trj`	The trajectory to calculate the directional autocorrelations for.
`deltaSMax`	Maximum delta s to calculate, default is $1/4$ the number of segments in the trajectory.

Value

A data frame with class `TrajDirectionAutocorrelations` and 2 columns, `deltaS` and `C`. Plotting this object displays a graph of the direction autocorrelation function, optionally with the location of the first local minimum marked

References

Shamble, P. S., Hoy, R. R., Cohen, I., & Beatus, T. (2017). Walking like an ant: a quantitative and experimental approach to understanding locomotor mimicry in the jumping spider Myrmarachne formicaria. Proceedings of the Royal Society B: Biological Sciences, 284(1858). doi:10.1098/rspb.2017.0308

See Also

`TrajDAFindFirstMinimum`, `plot.TrajDirectionAutocorrelations`

`TrajDistance` *Trajectory distance*

Description

Calculates the distance between the start and end of a trajectory (or a portion of a trajectory). Also called the diffusion distance, net distance, displacement, or bee-line from start to finish.

Usage

```
TrajDistance(trj, startIndex = 1, endIndex = nrow(trj))
```

Arguments

`trj`	Trajectory whose distance is to be calculated.
`startIndex`	Index of the starting point.
`endIndex`	Index of the ending point.

Value

Numeric distance from the start to the end of the trajectory.

`TrajDuration` *Trajectory duration*

Description

Calculates the temporal duration of a trajectory (or a portion of a trajectory).

Usage

```
TrajDuration(trj, startIndex = 1, endIndex = nrow(trj))
```

Arguments

`trj`	Trajectory whose duration is to be calculated.
`startIndex`	Index of the starting point.
`endIndex`	Index of the ending point.

Value

Numeric duration of the trajectory, in time units.

See Also

`TrajGetTimeUnits`

`TrajEmax` *Trajectory straightness index, E-max*

Description

Emax, the maximum expected displacement, is a single-valued measure of straightness defined by (Cheung, Zhang, Stricker, & Srinivasan, 2007). Emax-a is a dimensionless, scale-independent measure of the maximum possible expected displacement. Emax-b is `Emax-a * mean step length`, and gives the maximum possible expected displacement in spatial units. Values closer to 0 are more sinuous, while larger values (approaching infinity) are straighter.

Usage

```
TrajEmax(trj, eMaxB = FALSE, compass.direction = NULL)
```

Arguments

`trj`	Trajectory to be analysed.
`eMaxB`	If TRUE, calculates and returns Emax-b, otherwise returns Emax-a.
`compass.direction`	if not `NULL`, turning angles are calculated for a directed walk, assuming the specified compass direction (in radians). Otherwise, a random walk is assumed.

Value

Emax (-a or -b) for `trj`.

References

Cheung, A., Zhang, S., Stricker, C., & Srinivasan, M. V. (2007). Animal navigation: the difficulty of moving in a straight line. Biological Cybernetics, 97(1), 47-61. doi:10.1007/s00422-007-0158-0

`TrajExpectedSquareDisplacement` *Trajectory expected square displacement*

Description

Calculates the expected square displacement for a trajectory assuming it is a correlated random walk, using the formula in Kareiva & Shigesada, (1983).

Usage

```
TrajExpectedSquareDisplacement(
  trj,
  n = nrow(trj),
  eqn1 = TRUE,
  compass.direction = NULL
)
```

Arguments

`trj`	A Trajectory.
`n`	Number of steps to calculate.
`eqn1`	If `TRUE`, calculate using equation 1, otherwise using equation 2. Equation 2 applies when the mean of turning angles is 0, i.e.turns are unbiased.
`compass.direction`	If not `NULL`, step angles are calculated relative to this angle (in radians), otherwise they are calculated relative to the previous step angle.

Details

Note that Cheung, Zhang, Stricker, and Srinivasan (2007) define an alternative formulation for expected maximum displacement, Emax (see `TrajEmax`).

References

Cheung, A., Zhang, S., Stricker, C., & Srinivasan, M. V. (2007). Animal navigation: the difficulty of moving in a straight line. Biological Cybernetics, 97(1), 47-61. doi:10.1007/s00422-007-0158-0

Kareiva, P. M., & Shigesada, N. (1983). Analyzing insect movement as a correlated random walk. Oecologia, 56(2), 234-238. doi:10.1007/bf00379695

See Also

`TrajEmax`

Examples

```
set.seed(1)
# A random walk
trj <- TrajGenerate(200)
smoothed <- TrajSmoothSG(trj)

# Calculate actual squared displacement at all points along the trajectory
sd2 <- sapply(2:nrow(smoothed), function(n) TrajDistance(smoothed, 1, n) ^ 2)
# Calculate expected squared displacement
ed2_1 <- sapply(2:nrow(smoothed), function(n) TrajExpectedSquareDisplacement(smoothed, n, TRUE))
ed2_2 <- sapply(2:nrow(smoothed), function(n) TrajExpectedSquareDisplacement(smoothed, n, FALSE))

# Plot expected against actual. According to Kareiva & Shigesada, (1983), if actual
# (approximately) matches expected, the trajectory is probably a correlated random walk
par(mar = c(5, 5, 0.1, 0.1) + .1)
plot(2:nrow(smoothed), sd2, type = 'l', pch = 16, cex = .2, lwd = 2,
     xlab = 'Number of consecutive moves',
     ylab = expression('Squared displacement, ' * R[n]^2))
lines(2:nrow(smoothed), ed2_1, col = "grey", lwd = 2)
lines(2:nrow(smoothed), ed2_2, col = "pink", lwd = 2)

legend("bottomright",
       c(expression("Actual displacement"^2),
         expression("Expected displacement"^2 * " (eqn 1)"),
         expression("Expected displacement"^2 * " (eqn 2)")),
       col = c('black', 'grey', 'pink'), lwd = 2,
       inset = c(0.01, 0.02))
```

`TrajFractalDimension` *Fractal dimension of a trajectory*

Description

Calculates the fractal dimension (`D`) of a trajectory using the 'dividers' method (Sugihara & May, 1990). By default, overestimation of `D` is compensated for as recommended by Nams (2006), by walking the dividers backwards and forwards, and by estimating the remaining path length at the end of the last step.

Usage

```
TrajFractalDimension(trj, stepSizes, adjustD = TRUE, dMean = TRUE)
```

Arguments

`trj`	Trajectory to calculate fractal dimension for.
`stepSizes`	Vector of step sizes (aka divider sizes) used to calculate path lengths.
`adjustD`	If `TRUE`, path length is adjusted for truncation error (Nams, 2006).

`dMean`	If `TRUE`, the fractal dimension is calculated starting from the beginning of the trajectory, then re-calculated starting from the end and moving backwards. The value returned is the mean of the two fractal dimensions (Nams, 2006).

Details

Fractal dimension may be meaningless for animal trajectories as they may not be true fractal curves - see Benhamou (2004) and Turchin (1996), although it may be useful for studies involving differences in behaviour at different spatial scales (Nams, 2006).

You can test whether a trajectory is a fractal curve for a range of step sizes using the `TrajFractalDimensionValues` function. The example code in its documentation demonstrates how to plot path length for a range of step sizes. If the plotted points lie along straight line, then the trajectory is a fractal curve for that range of step sizes. However, typical trajectories result in a curve rather than a straight line.

If you decide to use fractal dimension despite the warnings of Benhamou (2004) and Turchin (1996), try to select a biologically meaningful range of step sizes (and be prepared to justify your choice). If comparing fractal dimensions across trajectories, be consistent in your choice of step sizes.

Value

The fractal dimension of the trajectory for the given step sizes.

References

Benhamou, S. (2004). How to reliably estimate the tortuosity of an animal's path. Journal of Theoretical Biology, 229(2), 209-220. doi:10.1016/j.jtbi.2004.03.016

Nams, V. O. (2006). Improving Accuracy and Precision in Estimating Fractal Dimension of Animal movement paths. Acta Biotheoretica, 54(1), 1-11. doi:10.1007/s10441-006-5954-8

Sugihara, G., & M. May, R. (1990). Applications of fractals in ecology. Trends in Ecology & Evolution, 5(3), 79-86. doi:10.1016/0169-5347(90)90235-6

Turchin, P. (1996). Fractal Analyses of Animal Movement: A Critique. Ecology, 77(7), 2086-2090. doi:10.2307/2265702

See Also

`TrajLogSequence` to create a logarithmically spaced sequence, `TrajFractalDimensionValues` for the function used internally to calculate a range of path lengths for different step sizes, `TrajEmax` and `TrajSinuosity2` for some alternate measures of trajectory tortuosity.

`TrajFractalDimensionValues`

Fractal dimension calculation

Description

Calculates path length ($L(\delta)$) for a range of step sizes (δ). For a fractal (i.e. scale independent) curve, $log(L(\delta))$ grows linearly as $log(\delta)$ grows smaller. In other words, if the points returned by this function lie on a straight line in a log-log plot, `trj` is a fractal curve.

Usage

```
TrajFractalDimensionValues(trj, stepSizes, adjustD = TRUE)
```

Arguments

`trj`	Trajectory to calculate fractal dimension for.
`stepSizes`	Vector of step sizes used to calculate path lengths.
`adjustD`	If TRUE, path length is adjusted to reduce truncation error (Nams, 2006).

Value

Data frame with columns `stepsize` (δ) and `pathlength` (($L(\delta)$).

References

Nams, V. O. (2006). Improving Accuracy and Precision in Estimating Fractal Dimension of Animal movement paths. Acta Biotheoretica, 54(1), 1-11. doi:10.1007/s10441-006-5954-8

See Also

`TrajFractalDimension` for fractal dimension calculation.

Examples

```
set.seed(42)
trj <- TrajGenerate()
muL <- mean(TrajStepLengths(trj))
# Use 20 step sizes from 1/2 mean step length to 5 * mean step length.
# For real use, biologically meaningful step sizes should be used.
stepSizes <- TrajLogSequence(0.5 * muL, 5 * muL, 20)
plot(TrajFractalDimensionValues(trj, stepSizes), log = "xy", pch = 16, cex = .5)
```

`TrajFromCoords` *Create a Trajectory Object*

Description

`TrajFromCoords` creates a new trajectory object from a set of 2-dimensional cartesian coordinates, times and some metadata. The coordinates are sometimes referred to as "relocations". Rows containing `NA` coordinate or time values at the start or end of the trajectory are discarded. `NA` coordinates or times in the middle of the trajectory generate an error.

Usage

```
TrajFromCoords(
  track,
  xCol = 1,
  yCol = 2,
  timeCol = NULL,
  fps = 50,
  spatialUnits = "m",
  timeUnits = "s"
)
```

Arguments

`track`	data frame containing cartesian coordinates and optionally times for the points in the trajectory.
`xCol`	Name or index of the `x` column in `track` (default 1).
`yCol`	Name or index of the `y` column in `track` (default 2).
`timeCol`	optional name or index of the column which contains coordinate times.
`fps`	Frames per second - used to calculate relative coordinate times if `track` does not contain a `time` column. Time intervals between coordinate are assumed to be constant throught the entire track.
`spatialUnits`	Abbreviation for the x and y units.
`timeUnits`	Abbreviation for the units that time is recorded in.

Details

If `timeCol` is specified, `track[,timeCol]` is expected to contain the time (in some numeric units) of each coordinate. Otherwise, times are calculated for each point as `(coord - 1) / fps` where `coord` is the index of the point; in other words, sampling at constant time intervals is assumed. Time values require conversion if they are not numeric. It may be possible to use ‘strptime‘ for this purpose, or `TrajConvertTime` can be used to convert multiple field time values.

`x` and `y` must be square units. Longitude and latitude are not suitable for use as `x` and `y` values, since in general, `1° lat != 1° lon`. To create a trajectory from positions in latitude and longitude, it is first necessary to transform the positions to a suitable spatial projection such as UTM (possibly by using `spTransform` from the `rgdal` package).

Leading and trailing rows with `NA` coordinate values are discarded. `NA` coordinate values within a trajectory generate an error.

Since columns in `coords` are preserved in the returned trajectory, if `coords` contains an `x` or `y` column which is not identified by `xCol` or `yCal` respectively, an error will occur. This is to prevent columns being inadvertently overwritten.

Value

An object with class "`Trajectory`", which is a data.frame with the following components:

`x`	X coordinates of trajectory points.

`y`	Y coordinates of trajectory points.
`time`	Time (in `timeUnits`) for each point. if `timeCol` is specified, values are `track[,timeCol]`, otherwise values are calculated from `fps`.
`displacementTime`	Relative frame/observation times, with frame/observation 1 at time `0`.
`polar`	Coordinates represented as complex numbers, to simplify working with segment angles. Beware when using complex numbers in R; `Arg(0+0i)` should be undefined but actually returns `0`.
`displacement`	Displacement vectors (represented as complex numbers) between each pair of consecutive points.

In addition, any other columns `coords` are include in the data frame.

See Also

`TrajsBuild`, `Traj3DFromCoords`

Examples

```
coords <- data.frame(x = c(1, 1.5, 2, 2.5, 3, 4),
                     y = c(0, 0, 1, 1, 2, 1),
                     times = c(0, 1, 2, 3, 4, 5))
trj <- TrajFromCoords(coords, timeCol = ”times”)

par(mar = c(4, 4, 0.5, 0.5) + 0.1)
plot(trj)
```

`TrajFromTrjPoints` *Create a trajectory from a subset of another*

Description

Creates a trajectory from a subset of the points in another trajectory, preserving metadata and all columns in the original trajectory.

Usage

```
TrajFromTrjPoints(trj, idx)
```

Arguments

`trj`	Trajectory to extract points and metadata from.
`idx`	Indices of the points in `trj` to retain in the new trajectory.

Details

Note that removing points from a trajectory that does not contain a time column will change the timing of the points, and hence change velocity etc.

Value

A new trajectory which is the same as `trj` except with a subset of points.

Examples

```
## Not run:
# Create a trajectory (trj2) by removing all zero-length
# segments from another trajectory (trj). Keep all points
# that are different from their preceding point, and also
# keep the start point
trj2 <- TrajFromTrjPoints(trj, c(1, which(Mod(trj$displacement) != 0)))

## End(Not run)
```

`TrajGenerate` *Generate a random trajectory*

Description

Generates a trajectory. If `random` is `TRUE`, the trajectory will be a correllated random walk/idiothetic directed walk (Kareiva & Shigesada, 1983), corresponding to an animal navigating without a compass (Cheung, Zhang, Stricker, & Srinivasan, 2008). If `random` is `FALSE`, it will be a directed walk/allothetic directed walk/oriented path, corresponding to an animal navigating with a compass (Cheung, Zhang, Stricker, & Srinivasan, 2007, 2008).

Usage

```
TrajGenerate(
  n = 1000,
  random = TRUE,
  stepLength = 2,
  angularErrorSd = 0.5,
  angularErrorDist = function(n) stats::rnorm(n, sd = angularErrorSd),
  linearErrorSd = 0.2,
  linearErrorDist = function(n) stats::rnorm(n, sd = linearErrorSd),
  fps = 50,
  ...
)
```

Arguments

`n`	Number of steps in the trajectory.
`random`	If TRUE, a random search trajectory is returned, otherwise a directed trajectory (with direction = 0 radians) is returned.
`stepLength`	Mean length of each step in the trajectory, in arbitrary length units.
`angularErrorSd`	Standard deviation of angular errors in radians.

`angularErrorDist`	Function which accepts a single argument - the number of values to return, and generates random deviates according to some distribution. The returned values are added to the previous step angle (when `random == TRUE`), or to `0` (is `random == FALSE`) to generate the step angle for each step in the trajectory. If the mean of the returned values is not zero, the walk will be biased.
`linearErrorSd`	Standard deviation of linear step length errors.
`linearErrorDist`	Function which accepts a single argument - the number of values to return, and generates random deviates according to some distribution. The returned values are added to `stepLength` to generate the lengths of each step.
`fps`	Simulated frames-per-second - used to generate times for each point in the trajectory.
`...`	Additional arguments are passed to `TrajFromCoords`.

Details

By default, for both random and directed walks, errors are normally distributed, unbiased, and independent of each other, so are *simple directed walks* in the terminology of Cheung, Zhang, Stricker, & Srinivasan, (2008). This behaviour may be modified by specifying alternative values for the `angularErrorDist` and/or `linearErrorDist` parameters.

The initial angle (for a random walk) or the intended direction (for a directed walk) is `0` radians. To change the initial angle or intended direction, call `TrajRotate` on the new trajectory. The starting position is `(0, 0)`. To change the starting position, call `TrajTranslate` on the new trajectory.

Value

A new Trajectory with `n` segments and `n + 1` coordinate pairs.

References

Kareiva, P. M., & Shigesada, N. (1983). Analyzing insect movement as a correlated random walk. Oecologia, 56(2), 234-238. doi:10.1007/bf00379695

Cheung, A., Zhang, S., Stricker, C., & Srinivasan, M. V. (2007). Animal navigation: the difficulty of moving in a straight line. Biological Cybernetics, 97(1), 47-61. doi:10.1007/s00422-007-0158-0

Cheung, A., Zhang, S., Stricker, C., & Srinivasan, M. V. (2008). Animal navigation: general properties of directed walks. Biological Cybernetics, 99(3), 197-217. doi:10.1007/s00422-008-0251-z

Examples

```
# Generate a 1000 step correlated random walk
trj <- TrajGenerate()
plot(trj, main = "Correlated walk")

# Generate a 1000 step levy flight - paths lengths follow a cauchy distribution
trj <- TrajGenerate(linearErrorDist = rcauchy)
plot(trj, main = "Levy flight")
```

```
# Generate a short directed trajectory
trj <- TrajGenerate(n = 20, random = FALSE)
plot(trj, main = "Directed walk")

# Generate an uncorrelated random walk
trj <- TrajGenerate(500, angularErrorDist = function(n) runif(n, -pi, pi))
plot(trj, main = "Uncorrelated walk")

# Generate a walk directed northwards, starting from (200, 300),
# with a mean step length of 200. The initially generated trajectory
# is directed to angle 0, with starting point (0, 0)
trj <- TrajGenerate(n = 20, stepLength = 200, random = FALSE)
# Rotate 90 degrees about (0, 0) (i.e. from east to north)
trj <- TrajRotate(trj, pi / 2, relative = FALSE)
# Translate to desired starting point
trj <- TrajTranslate(trj, 200, 300)
```

`TrajGetFPS` *Trajectory frames-per-second*

Description

Returns the frames-per-second recorded for this trajectory.

Usage

```
TrajGetFPS(trj)
```

Arguments

`trj`	Trajectory to query

`TrajGetNCoords` *Trajectory number of coordinates*

Description

Returns the number of coordinates recorded for this trajectory, i.e. 1 more than the number of steps.

Usage

```
TrajGetNCoords(trj)
```

Arguments

`trj`	Trajectory to query

`TrajGetTimeUnits` *Trajectory temporal units*

Description

Returns the temporal units specified for a scaled trajectory.

Usage

```
TrajGetTimeUnits(trj)
```

Arguments

`trj`	Trajectory to query

See Also

`TrajFromCoords`, `TrajGetUnits`.

`TrajGetUnits` *Trajectory spatial units*

Description

Returns the spatial units specified for a scaled trajectory.

Usage

```
TrajGetUnits(trj)
```

Arguments

`trj`	Trajectory to query

See Also

`TrajScale`, `TrajGetTimeUnits`.

`TrajInPolygon` *Test whether each of the points in a trajectory lie inside a polygon*

Description

Simply a wrapper around `point.in.polygon`. The `sp` package must be installed for this function to be called. `sp` is not automatically installed as a dependency of trajr.

Usage

```
TrajInPolygon(trj, boundary)
```

Arguments

`trj`	Trajectory to test
`boundary`	A polygon defining the region to be tested against. Can be any structure that `xy.coords` can handle, such as a data frame with `x` and `y` columns.

Value

Integer array with a value for each point in the trajectory. Values are: 0: point is strictly exterior to boundary; 1: point is strictly interior to boundary; 2: point lies on the relative interior of an edge of boundary; 3: point is a vertex of boundary

See Also

`point.in.polygon`, `xy.coords`

Examples

```
# Square arena
boundary <- data.frame(x = c(-10, 10, 10, -10), y = c(-10, -10, 10, 10))

# Generate a random trajectory
set.seed(1)
trj <- TrajGenerate(n = 10, stepLength = 2, angularErrorSd = .15)

# Test which points lie inside the boundary
print(TrajInPolygon(trj, boundary))
## [1] 1 1 1 1 1 1 0 0 0 0 0
```

`TrajLength` *Trajectory length*

Description

Calculates the cumulative length of a trajectory (or a portion of a trajectory), which is the total distance travelled along the trajectory.

Usage

```
TrajLength(trj, startIndex = 1, endIndex = nrow(trj))
```

Arguments

`trj`	Trajectory whose length is to be calculated.
`startIndex`	Index of the starting point.
`endIndex`	Index of the ending point.

Value

Numeric length of the trajectory.

See Also

`TrajStepLengths`

`TrajLogSequence` *Logarithmically spaced sequence*

Description

Convenience function to return a sequence of points which are regularly spaced when plotted on a logarithmic axis.

Usage

```
TrajLogSequence(from, to, length.out)
```

Arguments

`from`	Starting value of the sequence.
`to`	End (maximal) value of the sequence.
`length.out`	Desired length of the sequence (non-negative). Rounded up if fractional.

See Also

`seq`

`TrajMeanVectorOfTurningAngles`
Mean vector of turning angles

Description

Returns the mean vector of the turning angles, as defined by Batschelet, (1981). A unit vector is created for each turning angle in the trajectory, and the centre-of-mass/mean vector is returned.

Usage

```
TrajMeanVectorOfTurningAngles(trj, compass.direction = NULL)
```

Arguments

`trj`	Trajectory object.
`compass.direction`	If not `NULL`, step angles are calculated relative to this angle (in radians), otherwise they are calculated relative to the previous step angle.

Details

According to Batschelet (1981), `r` may serve as a straightness index ranging from 0 to 1, where `r` is the length of the mean vector of turning angles of a trajectory with constant step length. Values of `r` near 1 indicating straighter paths. Hence, `r = Mod(TrajMeanVectorOfTurningAngles(trj))`, assuming that `trj` has a constant step length (e.g. has been rediscretized).

Value

A complex number `r` which represents the mean vector, `Mod(r)` is the length of the mean vector which varies between 0 and 1, `Arg(r)` is the angle.

References

Batschelet, E. (1981). Circular statistics in biology. ACADEMIC PRESS, 111 FIFTH AVE., NEW YORK, NY 10003, 1981, 388.

See Also

`TrajStraightness`, `TrajAngles`, `TrajRediscretize` for resampling a trajectory to a constant step length, `TrajResampleTime` for resampling a trajectory to a constant step time.

`TrajMeanVelocity` *Trajectory mean velocity*

Description

Calculates the mean or net velocity of a trajectory (or a portion of a trajectory). This is the velocity from the start point to the end point, ignoring the path that was taken.

Usage

```
TrajMeanVelocity(trj, startIndex = 1, endIndex = nrow(trj))
```

Arguments

`trj`	Trajectory whose duration is to be calculated.
`startIndex`	Index of the starting point.
`endIndex`	Index of the ending point.

Value

Numeric duration of the trajectory, in time units.

See Also

`TrajGetTimeUnits`

`TrajMerge` *Combine multiple trajectories into a single whole trajectory*

Description

This is the inverse of `TrajSplit`.

Usage

```
TrajMerge(parts)
```

Arguments

`parts`	A list containing one or more trajectories. The trajectories are concatenated together in order.

Value

A single trajectory.

See Also

TrajSplit

Examples

```
trj <- TrajGenerate(n = 20)
ntrj <- TrajMerge(TrajSplit(trj, c(3, 9, 20)))
print(all(trj == ntrj))
## [1] TRUE
```

`TrajRediscretize` *Resample a trajectory to a constant step length*

Description

Constructs a new trajectory by resampling the input trajectory to a fixed step (or segment) length. By default, timing of frames is lost, so speed and acceleration cannot be calculated on a rediscretized trajectory. However, a constant speed may be applied to the rediscretized trajectory (`simConstantSpeed = TRUE`), in which case the returned trajectory will have (almost) constant speed, with average speed approximately equal to the average speed of `trj`.

Usage

```
TrajRediscretize(trj, R, simConstantSpeed = FALSE)
```

Arguments

`trj`	The trajectory to be resampled.
`R`	rediscretization step length, in the spatial units of `trj`.
`simConstantSpeed`	If TRUE, speeds are interpolated along the new trajectory so that average speed is approximately the same as that of `trj`.

Details

Based on the appendix in Bovet and Benhamou, (1988).

Value

A new trajectory with a constant segment length which follows `trj`.

References

Bovet, P., & Benhamou, S. (1988). Spatial analysis of animals' movements using a correlated random walk model. Journal of Theoretical Biology, 131(4), 419-433. doi:10.1016/S0022-5193(88)80038-9

`TrajResampleTime` *Resample a trajectory to a constant time interval.*

Description

Constructs a new trajectory by resampling the input trajectory to a fixed time interval. Points are linearly interpolated along the trajectory. Spatial and time units are preserved.

Usage

```
TrajResampleTime(trj, stepTime, newFps = NULL)
```

Arguments

`trj`	The trajectory to be resampled.
`stepTime`	The resampled trajectory step time. Each step in the new trajectory will have this duration.
`newFps`	Value to be stored as the FPS value in the new trajectory (see `TrajGetFPS`). It is not otherwise used by this function.

Value

A new trajectory with a constant time interval for each step. Points in the new trajectory are calculated by linearly interpolating along `trj`.

Examples

```
# Simulate a trajectory with steps every 5 hours
set.seed(46)
trj <- TrajGenerate(10, stepLength = 5, fps = 1/5, timeUnits = "hours", linearErrorSd = .8)

# Resample to 1 hour steps
resampled <- TrajResampleTime(trj, 1)

par(mar = c(5, 4, .5, .5))
plot(trj, lwd = 2)
points(trj, pch = 16)
points(resampled, col = "red", draw.start.pt = FALSE)
```

`TrajReverse` *Reverse a trajectory*

Description

Reverses the direction of a trajectory, so that the starting point becomes the last point and vice versa.

Usage

```
TrajReverse(trj)
```

Arguments

`trj`	The Trajectory to be reversed.

Value

A copy of `trj` with direction reversed.

`TrajRotate` *Rotate a trajectory*

Description

Rotates a trajectory by `angle` (when `relative` is `FALSE`), or so that `angle(finish - start) == angle` (when `relative` is `TRUE`).

Usage

```
TrajRotate(trj, angle = 0, origin = c(0, 0), relative = TRUE)
```

Arguments

`trj`	The trajectory to be rotated.
`angle`	The angle of rotation in radians. Either the first and last points in the rotated trajectory (when `relative = TRUE`), or else the angle be rotated (when `relative = FALSE`).
`origin`	Trajectory is rotated about this point.
`relative`	If TRUE, `angle` is the angle (after rotation) from the start to the end point of the trajectory. If FALSE, the trajectory is rotated about its start point by `angle`. You probably want to use `relative = TRUE`.

Value

A new trajectory which is a rotated version of the input trajectory.

`TrajsBuild` *Construct multiple trajectories*

Description

Reads multiple trajectories from files, performs some basic sanity checks on them, and optionally smooths and scales them. Attempts to collect and report errors for multiple trajectories in a single call.

Usage

```
TrajsBuild(
  fileNames,
  fps = NULL,
  scale = NULL,
  spatialUnits = NULL,
  timeUnits = NULL,
  csvStruct = list(x = 1, y = 2, time = NULL),
  smoothP = 3,
  smoothN = 41,
  translateToOrigin = FALSE,
  rootDir = NULL,
 csvReadFn = function(filename, ...) utils::read.csv(filename, stringsAsFactors = FALSE,
    ...),
  ...
)
```

Arguments

`fileNames`	Vector of the names of CSV files containing trajectory coordinates. All of the files must have the same columns. All file names must be unique. If `rootDir` is not `NULL`, then the file names are treated as regular expressions.
`fps`	Vector of frames-per-second values corresponding to the trajectories in `fileNames`. If length is 1, it is repeated to length(fileNames).
`scale`	Vector of scale values corresponding to the trajectories in `fileNames`. May be specified as character expressions (e.g. "1 / 1200") rather than numeric values. If NULL, the trajectories will not be scaled. If length is 1, it is repeated to length(fileNames).
`spatialUnits`	Abbreviated name of spatial coordinate units after scaling, e.g. "m".
`timeUnits`	Abbreviated name of temporal units, e.g. "s".
`csvStruct`	A list which identifies the columns in each CSV file which contain x-, y-, and optionally time-values.
`smoothP`	Filter order to be used for Savitzky-Golay smoothing (see `TrajSmoothSG`). If `NA`, no smoothing is performed.

`smoothN`	Filter length to be used for Savitzky-Golay smoothing (must be odd, see `TrajSmoothSG`). If `NA`, no smoothing is performed.
`translateToOrigin`	If TRUE, each trajectory is translated so that its starting point is at (0, 0).
`rootDir`	Optional name of a top level directory which contains the CSV files. If `rootDir` is not NULL, the CSV files may be located anywhere within `rootDir` or its sub-directories.
`csvReadFn`	Function used to read the CSV files. Required to accept arguments `filename`, `...`, and return a data frame of coordinates, or a list of multiple data frames (see `read.csv`, `read.csv2`). The default function calls `read.csv` with argument `stringsAsFactors = FALSE`.
`...`	Additional arguments passed to `csvReadFn`.

Details

If `rootDir` is not null, it should be the name of a directory which is searched for the files in `fileNames`. The found files are then used as the list of files to be read in. This may be useful when the names of the files are known, but their exact location within a directory structure is not known.

For each file name in `fileNames`, reads the file by calling `csvReadFn` to obtain a set of coordinates and optionally times. A Trajectory is then constructed by passing the coordinates to `TrajFromCoords`, passing in the appropriate `fps` value, and x, y and time column names/indices from `csvStruct`. If `scale` is not `NULL`, the trajectory is scaled by calling `TrajScale`. If `smoothP` and `smoothN` are not `NULL`, the trajectory is smoothed by calling `TrajSmoothSG`.

Value

A list of trajectories.

See Also

`read.csv`, `TrajFromCoords`, `TrajScale`, `TrajSmoothSG`, `TrajTranslate`

Examples

```
## Not run:
# Names of CSV files containing trajectory coordinates
fileNames <- c('xy001.csv', 'xy003.csv', 'xy004.csv')
# The files are all located somewhere under this directory
rootDir <- '.'
# Scale for these files is 1 / pixels per metre
scale <- c('1/1200', '1/1350', '1/1300')
# Files have columns y, x
csvStruct <- list(x = 2, y = 1)
# Apply default smoothing, and the files are formatted as conventional CSV,
# so there's no need to specify csvReadFn
trjs <- TrajsBuild(fileNames, fps = 50, scale = scale, units = "m",
                   csvStruct = csvStruct, rootDir = rootDir)
```

```
## End(Not run)
```

`TrajScale` *Scale a trajectory*

Description

Scales the cartesian coordinates in a trajectory, for example, to convert units from pixels to metres.

Usage

```
TrajScale(trj, scale, units, yScale = scale)
```

Arguments

`trj`	The trajectory to be scaled.
`scale`	Scaling factor to be applied to the trajectory coordinates.
`units`	Character specifying the spatial units after scaling, e.g. "m" or "metres"
`yScale`	Optional scaling factor to be applied to the y-axis, which may be specified if the original coordinates are not square. Defaults to `scale`.

Value

new scaled trajectory.

Examples

```
set.seed(42)
trj <- TrajGenerate()
# original trajectory units are pixels, measured as having
# 47 pixels in 10 mm, so to convert to metres, scale the
# trajectory by the approriate factor, i.e. (size in metres) / (size in pixels).
scale <- .01 / 47
scaled <- TrajScale(trj, scale, "m")
```

`TrajSinuosity` *Sinuosity of a trajectory*

Description

Calculates the sinuosity of a (constant step length) trajectory as defined by Bovet & Benhamou (1988), which is: $S = 1.18\sigma/\sqrt{q}$ where σ is the standard deviation of the step turning angles and q is the mean step length. A corrected sinuosity index is available as the function `TrajSinuosity2` which handles a wider range of variations in step angles.

Usage

```
TrajSinuosity(trj, compass.direction = NULL)
```

Arguments

`trj`	Trajectory to calculate sinuosity of.
`compass.direction`	if not `NULL`, turning angles are calculated for a directed walk, assuming the specified compass direction (in radians). Otherwise, a random walk is assumed.

Details

If your trajectory does not have a constant step length, it should be _rediscretized_ by calling `TrajRediscretize` before calling this function.

Value

The sinuosity of `trj`.

References

Bovet, P., & Benhamou, S. (1988). Spatial analysis of animals' movements using a correlated random walk model. Journal of Theoretical Biology, 131(4), 419-433. doi:10.1016/S0022-5193(88)80038-9

See Also

`TrajAngles` for the turning angles in a trajectory, `TrajStepLengths` for the step lengths, `TrajSinuosity2` for a corrected version of sinuosity, and `TrajRediscretize` for resampling to a constant step length.

`TrajSinuosity2` *Sinuosity of a trajectory*

Description

Calculates the sinuosity of a trajectory as defined by Benhamou (2004), equation 8. This is a corrected version of the sinuosity index defined in Bovet & Benhamou (1988), which is suitable for a wider range of turning angle distributions, and does not require a constant step length.

Usage

```
TrajSinuosity2(trj, compass.direction = NULL)
```

Arguments

`trj`	A Trajectory object.
`compass.direction`	if not `NULL`, turning angles are calculated for a directed walk, assuming the specified compass direction (in radians). Otherwise, a random walk is assumed.

Details

This function implements the formula

$$S = 2[p(((1 + c)/(1 - c)) + b^2)]^{-0.5}$$

where p is the mean step length, c is the mean cosine of turning angles, and b is the coefficient of variation of the step length.

References

Benhamou, S. (2004). How to reliably estimate the tortuosity of an animal's path. Journal of Theoretical Biology, 229(2), 209-220. doi:10.1016/j.jtbi.2004.03.016

See Also

`TrajSinuosity` for the uncorrected sinuosity index.

`TrajsMergeStats` *Merge trajectory characteristics*

Description

Builds a data frame by combining rows of statistical values for multiple trajectories. The statistics for each trajectory are defined by the caller in a user defined function - see the example for one way to achieve this.

Usage

```
TrajsMergeStats(
  trjs,
  statsFn,
  progressBar = c("none", "text", "win", "tk"),
  check.names = TRUE,
  ...
)
```

Arguments

`trjs`	List of trajectories to be characterised.
`statsFn`	Function to calculate statistics of interest for a single trajectory.
`progressBar`	Displays an optional progressbar, which may be helpful if processing is very slow. The progressbar is displayed by printing to the console, by using `winProgressBar` or `tkProgressBar`, if `progressBar` is `"text"`, `"win"` or `"tk"` respectively. The default is no progressbar (value `"none"`). The `"win"` progressbar is only available on Windows.
`check.names`	Passed to `as.data.frame`. Set to `FALSE` if statistic names are not syntactically valid variable names.
`...`	Additional arguments passed to `statsFn`.

Note

Any NULL valued statistics are converted to NAs.

Examples

```
## Not run:

# Define a function which calculates some statistics
# of interest for a single trajectory
characteriseTrajectory <- function(trj) {
  # Measures of speed
  derivs <- TrajDerivatives(trj)
  mean_speed <- mean(derivs$speed)
  sd_speed <- sd(derivs$speed)
```

```
    # Resample to constant step length.
    # Step length must be appropriate for the trajectory
    resampled <- TrajRediscretize(trj, 2)

    # Measures of straightness
    sinuosity <- TrajSinuosity2(resampled)
    Emax <- TrajEmax(resampled)

    # Periodicity
    resampled <- TrajRediscretize(trj, .001)
    corr <- TrajDirectionAutocorrelations(resampled, round(nrow(resampled) / 4))
    first_min <- TrajDAFindFirstMinimum(corr)

    # Return a list with all of the statistics for this trajectory
    list(mean_speed = mean_speed,
         sd_speed = sd_speed,
         sinuosity = sinuosity,
         Emax = Emax,
         first_min_deltaS = first_min[1],
         first_min_C = first_min[2])
  }

  trjs <- TrajsBuild(filenames)
  stats <- TrajsMergeStats(trjs, characteriseTrajectory)

  ## End(Not run)
```

`TrajSmoothSG` *Smooth a trajectory using a Savitzky-Golay filter*

Description

Smooths a trajectory using a Savitzky-Golay smoothing filter.

Usage

```
TrajSmoothSG(trj, p = 3, n = p + 3 - p%%2, ...)
```

Arguments

`trj`	The trajectory to be smoothed.
`p`	polynomial order (passed to `sgolayfilt`).
`n`	Filter length (or window size), must be an odd number. Passed to `sgolayfilt`.
`...`	Additional arguments are passed to `sgolayfilt`.

Details

Consider carefully the effects of smoothing a trajectory with temporal gaps in the data. If the smoothed trajectory is used to derive speed and/or acceleration, it may be advisable to fill in the gaps before smoothing, possibly by calling `TrajResampleTime`.

Value

A new trajectory which is a smoothed version of the input trajectory.

See Also

`sgolayfilt`

Examples

```
set.seed(3)
trj <- TrajGenerate(500, random = TRUE, angularErrorSd = .25)
smoothed <- TrajSmoothSG(trj, 3, 31)
plot(trj)
plot(smoothed, col = "red", add = TRUE)
```

`TrajSpeedIntervals` *Calculate speed time intervals*

Description

Calculates and returns a list of time intervals during which speed is slower and/or faster than specified values. Speed is calculated by taking the modulus of velocity (`TrajVelocity`).

Usage

```
TrajSpeedIntervals(
  trj,
  fasterThan = NULL,
  slowerThan = NULL,
  interpolateTimes = TRUE,
  diff = c("backward", "central", "forward")
)
```

Arguments

`trj`	Trajectory to be analysed.
`fasterThan, slowerThan`	If not `NULL`, intervals will cover time periods where speed exceeds/is lower than this value. At least one of `fasterThan`, or `slowerThan` must be specified.
`interpolateTimes`	If `TRUE`, times will be linearly interpolated between frames.

`diff`	Method used to calculate speed, see `TrajVelocity` for details. The default is `"backward"` to maintain backwards compatibility; in general, `"central"` provides a more accurate estimate of velocity.

Value

A data frame of class "TrajSpeedIntervals", each row is an interval, columns are:

`startFrame`	Indices of frames at the start of each interval.
`stopFrame`	Indices of frames at the end of each interval.
`startTime`	Time since start of trajectory at the start of each interval.
`stopTime`	Time since start of trajectory at the end of each interval
`duration`	Duration of each interval.

The data frame will also have non-standard attributes:

`trajectory`	Value of the `trj` argument.
`slowerThan`	Value of the `slowerThan` argument.
`fasterThan`	Value of the `fasterThan` argument.
`speed`	Data frame with columns `speed` and `time`.
`derivs`	Value returned by calling `TrajDerivatives(trj)`. Provided for backwards-compatibility; use of the `speed` attribute is now preferred to the `derivs` attribute.

See Also

`TrajVelocity` for calculating trajectory velocity, `plot.TrajSpeedIntervals` for plotting speed over time with intervals highlighted.

Examples

```
# Plot speed, highlighting intervals where speed drops below 50 units/sec
set.seed(4)
trj <- TrajGenerate(200, random = TRUE)
smoothed <- TrajSmoothSG(trj, 3, 101)
intervals <- TrajSpeedIntervals(smoothed, diff = "central", slowerThan = 50, fasterThan = NULL)
plot(intervals)

# Report the duration of the longest period of low speed
cat(sprintf("Duration of the longest low-speed interval was %g secs\n", max(intervals$duration)))
```

`TrajSplit` *Split a trajectory into multiple sections*

Description

Every point in `trj` will belong to exactly one of the returned sections. Note that this function will happily create single point trajectories.

Usage

```
TrajSplit(trj, idx)
```

Arguments

`trj`	The trajectory to be split
`idx`	Indices of splits. Each new section starts at one of these indices.

Value

A list containing one or more trajectories. The first trajectory in the list contains the first points from `trj`. Remaining trajectories contain the points starting from each of the `idx` values, in ascending order.

See Also

`TrajMerge`, `TrajSplitAtFirstCrossing`

`TrajSplitAtFirstCrossing` *Split a trajectory into two parts, separated at the first boundary crossing*

Description

This is basically a wrapper around `TrajInPolygon` and `TrajSplit`.

Usage

```
TrajSplitAtFirstCrossing(trj, boundary)
```

Arguments

`trj`	The trajectory to split.
`boundary`	A polygon defining the boundary. Can be any structure that `xy.coords` can handle, such as a data frame with `x` and `y` columns.

Value

A list with 1 or 2 elements. If `trj` lies entirely inside or outside `boundary`, then the list simply contains `trj`. If `trj` crosses the boundary, then the list contains 2 trajectories. The first is the longest part of `trj` that lies entirely inside or outside `boundary`, and the second is the remainder of `trj`.

See Also

`TrajInPolygon`, `TrajSplit`

Examples

```
# Square arena
boundary <- data.frame(x = c(-10, 10, 10, -10), y = c(-10, -10, 10, 10))

# Generate a random trajectory
set.seed(1)
trj <- TrajGenerate(n = 8, stepLength = 3, angularErrorSd = .4)
# Split the trajectory where it crosses the boundary
l <- TrajSplitAtFirstCrossing(trj, boundary)

# Plot the boundary and the two trajectories
plot(NULL, xlim = range(c(boundary$x, trj$x)), ylim = range(c(boundary$y, trj$y)), asp = 1)
polygon(boundary, border = "brown", lwd = 2)
lines(l[[1]], col = "#2040ff80", lwd = 3)
lines(l[[2]], col = "#ff204080", lwd = 3)
```

`TrajsStatsReplaceNAs` *Replace NAs in a data frame*

Description

Replaces NAs in a single column of a data frame with an imputed uninformative numeric replacement value, so that a principal component analysis can be applied without discarding data. Optionally adds a new "flag" column which contains 1 for each row which originally contained NA, otherwise `0`.

Usage

```
TrajsStatsReplaceNAs(
  df,
  column,
  replacementValue = mean(df[, column], na.rm = TRUE),
  flagColumn = NULL
)
```

Arguments

`df`	Data frame to be adjusted.
`column`	Name or index of the column to be adjusted.
`replacementValue`	Numeric value to use instead of NA.
`flagColumn`	If not NULL, specifies the name of a new column to be added to the data frame, with value 0 for non-NA rows, 1 for NA rows. The column is added regardless of whether there are any NAs in the data.

Value

A copy of `df` with NAs replaced in `column`.

See Also

`prcomp`

Examples

```
df <- data.frame(x = c(1, 2, 3), y = c(NA, 5, 6), z = c(NA, NA, 9))
# Eliminate NAs in y, add a flag column, ignore other NAs
df <- TrajsStatsReplaceNAs(df, "y", flagColumn = "y.was.NA")
print(df)
```

`TrajsStepLengths` *Step lengths of multiple trajectories*

Description

Returns the lengths of all of the steps in a list of trajectories

Usage

```
TrajsStepLengths(trjs)
```

Arguments

`trjs`	A list of `Trajectory` objects.

Value

A numeric vector containing the lengths of every step in every trajectory.

Examples

```
## Not run:
trjs <- TrajsBuild(fileNames, scale = scale, units = "m")
# Print a summary about the step sizes across all trajectories
print(summary(TrajsStepLengths(trjs)))

## End(Not run)
```

`TrajStepLengths` *Trajectory step lengths*

Description

Returns the lengths of each step in a trajectory.

Usage

```
TrajStepLengths(trj)
```

Arguments

`trj`	Trajectory to query.

See Also

`TrajLength`

`TrajStraightness` *Straightness of a Trajectory*

Description

Calculates the straightness index of a trajectory, D/L, where `D` is the beeline distance between the first and last points in the trajectory,and `L` is the path length travelled (Batschelet, 1981). Benhamou (2004) considers the straightness index to be a reliable measure of the efficiency of a directed walk, but inapplicable to random trajectories. The straightness index of a random walk tends towards zero as the number of steps increases, hence should only be used to compare the tortuosity of random walks consisting of a similar number of steps.

Usage

```
TrajStraightness(trj)
```

Arguments

`trj`	Trajectory to calculate straightness of.

Details

The straightness index is also known as the net-to-gross displacement ratio. According to Batschelet (1981), this value (termed *d*) is an approximation of *r*, which is the length of the mean vector of turning angles of a constant step-length trajectory (see `TrajMeanVectorOfTurningAngles` and `TrajRediscretize` for creating a constant step-length trajectory).

Value

The straightness index of `trj`, which is a value between 0 (infinitely tortuous) to 1 (a straight line).

References

Batschelet, E. (1981). Circular statistics in biology. ACADEMIC PRESS, 111 FIFTH AVE., NEW YORK, NY 10003, 1981, 388.

Benhamou, S. (2004). How to reliably estimate the tortuosity of an animal's path. Journal of Theoretical Biology, 229(2), 209-220. doi:10.1016/j.jtbi.2004.03.016

See Also

`TrajDistance` for trajectory distance (or displacement), and `TrajLength` for trajectory path length.

`TrajTranslate` *Translate a trajectory*

Description

Shifts an entire trajectory by the specified delta x and y.

Usage

```
TrajTranslate(trj, dx, dy, dt = 0)
```

Arguments

`trj`	The Trajectory to be translated.
`dx`	Delta x.
`dy`	Delta y.
`dt`	Delta time.

Value

A new trajectory which is a translated version of the input trajectory.

Examples

```
# Shift a trajectory so that its origin is (10, 15).
# Note that trajectories created by TrajGenerate always start at (0, 0)
set.seed(42)
trj <- TrajGenerate()
trj <- TrajTranslate(trj, 10, 15)

# Translate a trajectory so its origin (0, 0) and it starts at time 0
trj <- TrajTranslate(trj, -trj$x[1], -trj$y[1], -trj$time[1])
```

`TrajVelocity` *Velocity of a trajectory*

Description

The velocity is approximated at each point of the trajectory using first-order finite differences. Central, forward or backward differences can be used. Central differences yield a more accurate approximation if the velocity is smooth. As a practical guide, if velocity doesn't change much between steps, use central differences. If it changes substantially (and not just as an artifact of recording noise), then use either forward or backward differences.

Usage

```
TrajVelocity(trj, diff = c("central", "forward", "backward"))
```

Arguments

`trj`	Trajectory whose velocity is to be calculated.
`diff`	Type of difference to be calculated, one of "central" (the default), "forward" or "backward".

Details

Intuitively, think of the central difference velocity at a point as the mean of the velocities of the two adjacent steps. Forward difference velocity is the velocity of the step starting at the point. Backward difference is the velocity of the step ending at the point.

Value

A vector of complex numbers representing the velocity at each point along the trajectory. The modulus (`Mod(v)`) is the magnitude of the velocity, i.e. the speed; the argument (`Arg(v)`) is the direction of the velocity; the real part (`Re(v)`) is velocity in the X direction; and the imaginary part (`Im(v)`) is velocity in the Y direction. The vector has an attribute, `trj`, with the trajectory as its value. If `diff` is `"central"`, the first and last velocity values are `NA` since velocity cannot be calculated for them. If `diff` is `"forward"`, the last value will be NA, and if `diff` is `"backward"`, the first value will be NA.

See Also

`TrajAcceleration` for calculating acceleration; `TrajResampleTime` and `TrajRediscretize` to resample a trajectory to fixed time or length steps; `TrajSpeedIntervals` for calculating when speed crosses some threshold; Finite differences on Wikipedia.

Examples

```
set.seed(11)
trj <- TrajGenerate(100)
# calculate velocity
vel <- TrajVelocity(trj)

# Obtain speed over time, with NAs removed
speed <- na.omit(data.frame(speed = Mod(vel), time = trj$time))

plot(speed ~ time, speed, type = 'l')
```

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