Package 'moveHMM'

October 13, 2022

Type Package

Title Animal Movement Modelling using Hidden Markov Models

Version 1.8

Date 2022-05-11

Author Theo Michelot, Roland Langrock, Toby Patterson, Brett McClintock, Eric Rexstad (ctb)

Maintainer Theo Michelot <tm75@st-andrews.ac.uk>

Description Provides tools for animal movement modelling using hidden Markov models. These include processing of tracking data, fitting hidden Markov models to movement data, visualization of data and fitted model, decoding of the state process...

URL https://github.com/TheoMichelot/moveHMM,

https://cran.r-project.org/package=moveHMM

License GPL-3

LazyData TRUE

Depends CircStats

Imports Rcpp, boot, MASS, sp, geosphere, ggplot2, ggmap, numDeriv

LinkingTo Rcpp, RcppArmadillo

Suggests testthat, knitr

VignetteBuilder knitr

RoxygenNote 7.1.2

Encoding UTF-8

NeedsCompilation yes

Repository CRAN

Date/Publication 2022-05-13 20:20:16 UTC

R topics documented:

AIC.moveHMM *AIC*

Description

Akaike information criterion of a moveHMM model.

Usage

```
## S3 method for class 'moveHMM'
AIC(object, ..., k = 2)
```

Arguments

object	A moveHMM object.
...	Optional additional moveHMM objects, to compare AICs of the different models.
k	Penalty per parameter. Default: 2; for classical AIC.

Value

The AIC of the model(s) provided. If several models are provided, the AICs are output in ascending order.

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m
AIC(m)
```

angleCI *Confidence intervals for angle parameters*

Description

Simulation-based computation of confidence intervals for the parameters of the angle distribution. Used in CI.

Usage

```
angleCI(m, alpha, nbSims = 10^6)
```

Arguments

m	A moveHMM object
alpha	Range of the confidence intervals. Default: 0.95 (i.e. 95% CIs).
nbSims	Number of simulations. Default: 10^6.

Value

A list of the following objects:

lower	Lower bound of the confidence interval for the parameters of the angle distribution
upper	Upper bound of the confidence interval for the parameters of the angle distribution

---

CI *Confidence intervals*

Description

Computes the confidence intervals of the step length and turning angle parameters, as well as for the transition probabilities regression parameters.

Usage

```
CI(m, alpha = 0.95, nbSims = 10^6)
```

Arguments

m	A moveHMM object
alpha	Range of the confidence intervals. Default: 0.95 (i.e. 95% CIs).
nbSims	Number of simulations in the computation of the CIs for the angle parameters. Default: 10^6.

Value

A list of the following objects:

stepPar	Confidence intervals for the parameters of the step lengths distribution
anglePar	Confidence intervals for the parameters of the turning angles distribution
beta	Confidence intervals for the regression coefficients of the transition probabilities.

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

CI(m)
```

dexp_rcpp *Exponential density function*

Description

Probability density function of the exponential distribution (written in C++)

Usage

```
dexp_rcpp(x, rate, foo = 0)
```

Arguments

x	Vector of quantiles
rate	Rate
foo	Unused (for compatibility with template)

Value

Vector of densities

dgamma_rcpp *Gamma density function*

Description

Probability density function of the gamma distribution (written in C++)

Usage

```
dgamma_rcpp(x, mu, sigma)
```

Arguments

x	Vector of quantiles
mu	Mean
sigma	Standard deviation

Value

Vector of densities

dlnorm_rcpp *Log-normal density function*

Description

Probability density function of the log-normal distribution (written in C++)

Usage

```
dlnorm_rcpp(x, meanlog, sdlog)
```

Arguments

x	Vector of quantiles
meanlog	Mean of the distribution on the log-scale
sdlog	Standard deviation of the distribution on the log-scale

Value

Vector of densities

dvm_rcpp *Von Mises density function*

Description

Probability density function of the Von Mises distribution, defined as a function of the modified Bessel function of order 0 (written in C++)

Usage

```
dvm_rcpp(x, mu, kappa)
```

Arguments

x	Vector of quantiles
mu	Mean
kappa	Concentration

Value

Vector of densities

dweibull_rcpp *Weibull density function*

Description

Probability density function of the Weibull distribution (written in C++)

Usage

```
dweibull_rcpp(x, shape, scale)
```

Arguments

x	Vector of quantiles
shape	Shape
scale	Scale

Value

Vector of densities

dwrpcauchy_rcpp *Wrapped Cauchy density function*

Description

Probability density function of the wrapped Cauchy distribution (written in C++)

Usage

```
dwrpcauchy_rcpp(x, mu, rho)
```

Arguments

x	Vector of quantiles
mu	Mean
rho	Concentration

Value

Vector of densities

elk_data *Elk data set from Morales et al. (2004, Ecology)*

Description

It is a data frame with the following columns:

- `ID` Track identifier
- `Easting` Easting coordinate of locations
- `Northing` Northing coordinate of locations
- `dist_water` Distance of elk to water (in metres)

Usage

```
elk_data
```

example *Example dataset*

Description

This data is generated by the function `exGen`, and used in the examples and tests of other functions to keep them as short as possible.

Usage

```
example
```

Details

It is a list of the following objects:

- `data` A `moveData` object
- `m` A `moveHMM` object
- `simPar` The parameters used to simulate `data`
- `par0` The initial parameters in the optimization to fit `m`

exGen *Example data simulation*

Description

Generate the file `data/example.RData`, used in other functions' examples and unit tests.

Usage

```
exGen()
```

fitHMM *Fit an HMM to the data*

Description

Fit an hidden Markov model to the data provided, using numerical optimization of the log-likelihood function.

Usage

```
fitHMM(
  data,
  nbStates,
  stepPar0,
  anglePar0 = NULL,
  beta0 = NULL,
  delta0 = NULL,
  formula = ~1,
  stepDist = c("gamma", "weibull", "lnorm", "exp"),
  angleDist = c("vm", "wrpcauchy", "none"),
  angleMean = NULL,
  stationary = FALSE,
  knownStates = NULL,
  verbose = 0,
  nlmPar = NULL,
  fit = TRUE
)
```

Arguments

`data`	An object `moveData`.
`nbStates`	Number of states of the HMM.

stepPar0	Vector of initial state-dependent step length distribution parameters. The parameters should be in the order expected by the pdf of stepDist, and the zero-mass parameter should be the last. Note that zero-mass parameters are mandatory if there are steps of length zero in the data. For example, for a 2-state model using the gamma distribution and including zero-inflation, the vector of initial parameters would be something like: c(mu1,mu2,sigma1,sigma2,zeromass1,zeromass2).
anglePar0	Vector of initial state-dependent turning angle distribution parameters. The parameters should be in the order expected by the pdf of angleDist. For example, for a 2-state model using the Von Mises (vm) distribution, the vector of initial parameters would be something like: c(mu1,mu2,kappa1,kappa2).
beta0	Initial matrix of regression coefficients for the transition probabilities (more information in "Details"). Default: NULL. If not specified, beta0 is initialized such that the diagonal elements of the transition probability matrix are dominant.
delta0	Initial value for the initial distribution of the HMM. Default: rep(1/nbStates,nbStates).
formula	Regression formula for the covariates. Default: ~1 (no covariate effect).
stepDist	Name of the distribution of the step lengths (as a character string). Supported distributions are: gamma, weibull, lnorm, exp. Default: gamma.
angleDist	Name of the distribution of the turning angles (as a character string). Supported distributions are: vm, wrpcauchy. Set to "none" if the angle distribution should not be estimated. Default: vm.
angleMean	Vector of means of turning angles if not estimated (one for each state). Default: NULL (the angle mean is estimated).
stationary	FALSE if there are covariates. If TRUE, the initial distribution is considered equal to the stationary distribution. Default: FALSE.
knownStates	Vector of values of the state process which are known prior to fitting the model (if any). Default: NULL (states are not known). This should be a vector with length the number of rows of 'data'; each element should either be an integer (the value of the known states) or NA if the state is not known.
verbose	Determines the print level of the optimizer. The default value of 0 means that no printing occurs, a value of 1 means that the first and last iterations of the optimization are detailed, and a value of 2 means that each iteration of the optimization is detailed.
nlmPar	List of parameters to pass to the optimization function nlm (which should be either 'gradtol', 'stepmax', 'steptol', or 'iterlim' – see nlm's documentation for more detail)
fit	TRUE if an HMM should be fitted to the data, FALSE otherwise. If fit=FALSE, a model is returned with the MLE replaced by the initial parameters given in input. This option can be used to assess the initial parameters. Default: TRUE.

Details

- The matrix beta of regression coefficients for the transition probabilities has one row for the intercept, plus one row for each covariate, and one column for each non-diagonal element of the transition probability matrix. For example, in a 3-state HMM with 2 covariates, the matrix beta has three rows (intercept + two covariates) and six columns (six non-diagonal elements in

the 3x3 transition probability matrix - filled in row-wise). In a covariate-free model (default), beta has one row, for the intercept.

- The choice of initial parameters is crucial to fit a model. The algorithm might not find the global optimum of the likelihood function if the initial parameters are poorly chosen.

Value

A moveHMM object, i.e. a list of:

mle	The maximum likelihood estimates of the parameters of the model (if the numerical algorithm has indeed identified the global maximum of the likelihood function), which is a list of: stepPar (step distribution parameters), anglePar (angle distribution parameters), beta (transition probabilities regression coefficients - more information in "Details"), and delta (initial distribution).
data	The movement data
mod	The object returned by the numerical optimizer nlm
conditions	A few conditions used to fit the model (stepDist, angleDist, zeroInflation, estAngleMean, stationary, and formula)
rawCovs	Raw covariate values, as found in the data (if any). Used in plot.moveHMM.
knownStates	Vector of states known a priori, as provided in input (if any, NULL otherwise). Used in viterbi,logAlpha, and logBeta
nlmTime	Computing time for optimisation, obtained with system.time

References

Patterson T.A., Basson M., Bravington M.V., Gunn J.S. 2009. Classifying movement behaviour in relation to environmental conditions using hidden Markov models. Journal of Animal Ecology, 78 (6), 1113-1123.

Langrock R., King R., Matthiopoulos J., Thomas L., Fortin D., Morales J.M. 2012. Flexible and practical modeling of animal telemetry data: hidden Markov models and extensions. Ecology, 93 (11), 2336-2342.

Examples

```
### 1. simulate data
# define all the arguments of simData
nbAnimals <- 2
nbStates <- 2
nbCovs <- 2
mu<-c(15,50)
sigma<-c(10,20)
angleMean <- c(pi,0)
kappa <- c(0.7,1.5)
stepPar <- c(mu,sigma)
anglePar <- c(angleMean,kappa)
stepDist <- "gamma"
angleDist <- "vm"
zeroInflation <- FALSE
```

```
obsPerAnimal <- c(50,100)

data <- simData(nbAnimals=nbAnimals,nbStates=nbStates,stepDist=stepDist,angleDist=angleDist,
            stepPar=stepPar,anglePar=anglePar,nbCovs=nbCovs,zeroInflation=zeroInflation,
                 obsPerAnimal=obsPerAnimal)

### 2. fit the model to the simulated data
# define initial values for the parameters
mu0 <- c(20,70)
sigma0 <- c(10,30)
kappa0 <- c(1,1)
stepPar0 <- c(mu0,sigma0) # no zero-inflation, so no zero-mass included
anglePar0 <- kappa0 # the angle mean is not estimated, so only the concentration parameter is needed
formula <- ~cov1+cos(cov2)

m <- fitHMM(data=data,nbStates=nbStates,stepPar0=stepPar0,anglePar0=anglePar0,formula=formula,
              stepDist=stepDist,angleDist=angleDist,angleMean=angleMean)

print(m)
```

`getPalette` *Discrete colour palette for states*

Description

Discrete colour palette for states

Usage

```
getPalette(nbStates)
```

Arguments

`nbStates`	Number of states

Value

Vector of colours, of length nbStates.

getPlotData *Data to produce plots of fitted model*

Description

Data to produce plots of fitted model

Usage

```
getPlotData(m, type, format = "wide", alpha = 0.95)
```

Arguments

m	Fitted HMM object, as output by fitHMM.
type	Type of plot, one of: "dist", "tpm", "stat"
format	Format of data, either "wide" (for base graphics) or "long" (for ggplot)
alpha	Level of confidence intervals. Default: 0.95, i.e., 95% confidence intervals

Details

- If type = "dist", the function evaluates each state-dependent distribution over the range of observed variable (step length or turning angle), and weighs them by the proportion of time spent in each state (obtained from Viterbi state sequence).
- If type = "tpm", the function returns transition probabilities estimated over a range of covariate values. Other covariates are fixed to their mean values.

Value

Data frame (or list of data frames) containing data in a format that can easily be plotted. If type = "dist", the output is a list with two elements, "step" and "angle". If type = "tpm" or "stat", the output is a list with one element for each covariate. See details for more extensive description of output.

haggis_data *Wild haggis data set from Michelot et al. (2016, Methods Eco Evol)*

Description

Data frame of the first three tracks from Michelot et al. (2016), with columns:

- ID Track identifier
- x Easting coordinate of locations
- y Northing coordinate of locations
- slope Terrain slope (in degrees)
- temp Air temperature (in degrees Celsius)

Usage

```
haggis_data
```

`is.moveData` *Is moveData*

Description

Check that an object is of class `moveData`. Used in `fitHMM`.

Usage

```
is.moveData(x)
```

Arguments

`x`	An R object

Value

`TRUE` if `x` is of class `moveData`, `FALSE` otherwise.

`is.moveHMM` *Is moveHMM*

Description

Check that an object is of class `moveHMM`. Used in `CI`, `plotPR`, `plotStates`, `pseudoRes`, `stateProbs`, and `viterbi`.

Usage

```
is.moveHMM(x)
```

Arguments

`x`	An R object

Value

`TRUE` if `x` is of class `moveHMM`, `FALSE` otherwise.

logAlpha *Forward log-probabilities*

Description

Used in stateProbs and pseudoRes.

Usage

```
logAlpha(m)
```

Arguments

m	A moveHMM object.

Value

The matrix of forward log-probabilities.

Examples

```
## Not run:
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

la <- logAlpha(m)

## End(Not run)
```

logBeta *Backward log-probabilities*

Description

Used in stateProbs.

Usage

```
logBeta(m)
```

Arguments

m	A moveHMM object.

Value

The matrix of backward log-probabilities.

Examples

```
## Not run:
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

lb <- logBeta(m)

## End(Not run)
```

`moveData` *Constructor of* `moveData` *objects*

Description

Constructor of `moveData` objects

Usage

```
moveData(data)
```

Arguments

`data`	A dataframe containing: `ID` (the ID(s) of the observed animal(s)), `step` (the step lengths), `angle` (the turning angles, if any), `x` (either easting or longitude), `y` (either norting or latitude), and covariates, if any.

Value

An object `moveData`.

`moveHMM` *Constructor of* `moveHMM` *objects*

Description

Constructor of `moveHMM` objects

Usage

```
moveHMM(m)
```

Arguments

`m`	A list of attributes of the fitted model: `mle` (the maximum likelihood estimates of the parameters of the model), `data` (the movement data), `mod` (the object returned by the numerical optimizer `nlm`), `conditions` (a few conditions used to fit the model: `stepDist`, `angleDist`, `zeroInflation`, `estAngleMean`, `stationary`, and `formula`), `rawCovs` (optional – only if there are covariates in the data).

Value

An object moveHMM.

---

n2w *Scaling function: natural to working parameters.*

Description

Scales each parameter from its natural interval to the set of real numbers, to allow for unconstrained optimization. Used during the optimization of the log-likelihood.

Usage

```
n2w(par, bounds, beta, delta = NULL, nbStates, estAngleMean)
```

Arguments

par	Vector of state-dependent distributions parameters.
bounds	Matrix with 2 columns and as many rows as there are elements in par. Each row contains the lower and upper bound for the correponding parameter.
beta	Matrix of regression coefficients for the transition probabilities.
delta	Initial distribution. Default: NULL ; if the initial distribution is not estimated.
nbStates	The number of states of the HMM.
estAngleMean	TRUE if the angle mean is estimated, FALSE otherwise.

Value

A vector of unconstrained parameters.

Examples

```
## Not run:
nbStates <- 3
par <- c(0.001,0.999,0.5,0.001,1500.3,7.1)
bounds <- matrix(c(0,1, # bounds for first parameter
                   0,1, # bounds for second parameter
                   0,1, # ...
                   0,Inf,
                   0,Inf,
                   0,Inf),
                 byrow=TRUE,ncol=2)
beta <- matrix(rnorm(18),ncol=6,nrow=3)
delta <- c(0.6,0.3,0.1)

# vector of working parameters
wpar <- n2w(par=par,bounds=bounds,beta=beta,delta=delta,nbStates=nbStates,
           estAngleMean=FALSE)
```

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

---

nLogLike *Negative log-likelihood function*

Description

Negative log-likelihood function

Usage

```
nLogLike(
  wpar,
  nbStates,
  bounds,
  parSize,
  data,
  stepDist = c("gamma", "weibull", "lnorm", "exp"),
  angleDist = c("vm", "wrpcauchy", "none"),
  angleMean = NULL,
  zeroInflation = FALSE,
  stationary = FALSE,
  knownStates = NULL
)
```

Arguments

wpar	Vector of working parameters.
nbStates	Number of states of the HMM.
bounds	Matrix with 2 columns and as many rows as there are elements in wpar. Each row contains the lower and upper bound for the correponding parameter.
parSize	Vector of two values: number of parameters of the step length distribution, number of parameters of the turning angle distribution.
data	An object moveData.
stepDist	Name of the distribution of the step lengths (as a character string). Supported distributions are: gamma, weibull, lnorm, exp. Default: gamma.
angleDist	Name of the distribution of the turning angles (as a character string). Supported distributions are: vm, wrpcauchy. Set to "none" if the angle distribution should not be estimated. Default: vm.
angleMean	Vector of means of turning angles if not estimated (one for each state). Default: NULL (the angle mean is estimated).
zeroInflation	TRUE if the step length distribution is inflated in zero. Default: FALSE. If TRUE, initial values for the zero-mass parameters should be included in stepPar0.

stationary	FALSE if there are covariates. If TRUE, the initial distribution is considered equal to the stationary distribution. Default: FALSE.
knownStates	Vector of values of the state process which are known prior to fitting the model (if any). Default: NULL (states are not known). This should be a vector with length the number of rows of 'data'; each element should either be an integer (the value of the known states) or NA if the state is not known.

Value

The negative log-likelihood of the parameters given the data.

Examples

```
## Not run:
# data is a moveData object (as returned by prepData), automatically loaded with the package
data <- example$data
simPar <- example$simPar
par0 <- example$par0

estAngleMean <- is.null(simPar$angleMean)
bounds <- parDef(simPar$stepDist,simPar$angleDist,simPar$nbStates,
                 estAngleMean,simPar$zeroInflation)$bounds
parSize <- parDef(simPar$stepDist,simPar$angleDist,simPar$nbStates,
                  estAngleMean,simPar$zeroInflation)$parSize

par <- c(par0$stepPar0,par0$anglePar0)
wpar <- n2w(par,bounds,par0$beta0,par0$delta0,simPar$nbStates,FALSE)

l <- nLogLike(wpar=wpar,nbStates=simPar$nbStates,bounds=bounds,parSize=parSize,data=data,
         stepDist=simPar$stepDist,angleDist=simPar$angleDist,angleMean=simPar$angleMean,
             zeroInflation=simPar$zeroInflation)

## End(Not run)
```

---

nLogLike_rcpp *Negative log-likelihood*

Description

Computation of the negative log-likelihood (forward algorithm - written in C++)

Usage

```
nLogLike_rcpp(
  nbStates,
  beta,
  covs,
  data,
```

```
  stepDist,
  angleDist,
  stepPar,
  anglePar,
  delta,
  aInd,
  zeroInflation,
  stationary,
  knownStates
)
```

Arguments

nbStates	Number of states
beta	Matrix of regression coefficients for the transition probabilities
covs	Covariates
data	A moveData object of the observations
stepDist	The name of the step length distribution
angleDist	The name of the turning angle distribution
stepPar	State-dependent parameters of the step length distribution
anglePar	State-dependent parameters of the turning angle distribution
delta	Stationary distribution
aInd	Vector of indices of the rows at which the data switches to another animal
zeroInflation	true if zero-inflation is included in the step length distribution, false otherwise.
stationary	false if there are covariates. If true, the initial distribution is considered equal to the stationary distribution.
knownStates	Vector of values of the state process which are known prior to fitting the model (if any). Default: NULL (states are not known). This should be a vector with length the number of rows of 'data'; each element should either be an integer (the value of the known states) or NA if the state is not known.

Value

Negative log-likelihood

---

parDef *Parameters definition*

Description

Parameters definition

Usage

```
parDef(stepDist, angleDist, nbStates, estAngleMean, zeroInflation)
```

Arguments

stepDist	Name of the distribution of the step lengths.
angleDist	Name of the distribution of the turning angles. Set to "none" if the angle distribution should not be estimated.
nbStates	Number of states of the HMM.
estAngleMean	TRUE if the mean of the turning angles distribution is estimated, FALSE otherwise.
zeroInflation	TRUE if the step length distribution is inflated in zero.

Value

A list of:

parSize	Vector of two values: number of parameters of the step length distribution, number of parameters of the turning angle distribution
bounds	Matrix with 2 columns and sum(parSize) rows - each row contains the lower and upper bound for the correponding parameter)
parNames	Names of parameters of step distribution (the names of the parameters of the angle distribution are always the same).

---

plot.moveData *Plot* moveData

Description

Plot moveData

Usage

```
## S3 method for class 'moveData'
plot(x, animals = NULL, compact = FALSE, ask = TRUE, breaks = "Sturges", ...)
```

Arguments

x	An object moveData
animals	Vector of indices or IDs of animals for which information will be plotted. Default: NULL ; all animals are plotted.
compact	TRUE for a compact plot (all individuals at once), FALSE otherwise (default – one individual at a time).
ask	If TRUE, the execution pauses between each plot.
breaks	Histogram parameter. See hist documentation.
...	Currently unused. For compatibility with generic method.

Examples

```
# data is a moveData object (as returned by prepData), automatically loaded with the package
data <- example$data

plot(data,compact=TRUE,breaks=20,ask=FALSE)
```

`plot.moveHMM` *Plot* `moveHMM`

Description

Plot the fitted step and angle densities over histograms of the data, transition probabilities as functions of the covariates, and maps of the animals' tracks colored by the decoded states.

Usage

```
## S3 method for class 'moveHMM'
plot(
  x,
  animals = NULL,
  ask = TRUE,
  breaks = "Sturges",
  col = NULL,
  plotTracks = TRUE,
  plotCI = FALSE,
  alpha = 0.95,
  ...
)
```

Arguments

`x`	Object `moveHMM`
`animals`	Vector of indices or IDs of animals for which information will be plotted. Default: `NULL`; all animals are plotted.
`ask`	If `TRUE`, the execution pauses between each plot.
`breaks`	Histogram parameter. See `hist` documentation. See `hist` documentation. Default: `NULL` ; the function sets default values.
`col`	Vector or colors for the states (one color per state).
`plotTracks`	If `TRUE`, the Viterbi-decoded tracks are plotted (default).
`plotCI`	If `TRUE`, confidence intervals are plotted on the transition probabilities (default: FALSE).
`alpha`	Significance level of the confidence intervals if plotCI=TRUE. Default: 0.95 (i.e. 95% CIs).
`...`	Currently unused. For compatibility with generic method.

Details

The state-dependent densities are weighted by the frequency of each state in the most probable state sequence (decoded with the function viterbi). For example, if the most probable state sequence indicates that one third of observations correspond to the first state, and two thirds to the second state, the plots of the densities in the first state are weighted by a factor 1/3, and in the second state by a factor 2/3.

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

plot(m,ask=TRUE,animals=1,breaks=20)
```

---

plotPR *Plot pseudo-residuals*

Description

Plots time series, qq-plots (against the standard normal distribution), and sample ACF functions of the pseudo-residuals

Usage

```
plotPR(m)
```

Arguments

m	A moveHMM object

Details

- If some turning angles in the data are equal to pi, the corresponding pseudo-residuals will not be included. Indeed, given that the turning angles are defined on (-pi,pi], an angle of pi results in a pseudo-residual of +Inf (check Section 6.2 of reference for more information on the computation of pseudo-residuals).
- If some steps are of length zero (i.e. if there is zero-inflation), the corresponding pseudo-residuals are shown as segments, because pseudo-residuals for discrete data are defined as segments (see Zucchini and MacDonald, 2009, Section 6.2).

References

Zucchini, W. and MacDonald, I.L. 2009. Hidden Markov Models for Time Series: An Introduction Using R. Chapman & Hall (London).

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

plotPR(m)
```

---

plotSat *Plot observations on satellite image*

Description

Plot tracking data on a satellite map. This function only works with longitude and latitude values (not with UTM coordinates), and uses the package ggmap to fetch a satellite image from Google. An Internet connection is required to use this function.

Usage

```
plotSat(
  data,
  zoom = NULL,
  location = NULL,
  segments = TRUE,
  compact = TRUE,
  col = NULL,
  alpha = 1,
  size = 1,
  states = NULL,
  animals = NULL,
  ask = TRUE,
  return = FALSE
)
```

Arguments

data	Data frame of the data, with necessary fields 'x' (longitude values) and 'y' (latitude values).
zoom	The zoom level, as defined for get_map. Integer value between 3 (continent) and 21 (building).
location	Location of the center of the map to be plotted.
segments	TRUE if segments should be plotted between the observations (default), FALSE otherwise.
compact	FALSE if tracks should be plotted separately, TRUE otherwise (default).
col	Palette of colours to use for the dots and segments. If not specified, uses default palette.

alpha	Transparency argument for geom_point.
size	Size argument for geom_point.
states	A sequence of integers, corresponding to the decoded states for these data (such that the observations are colored by states).
animals	Vector of indices or IDs of animals/tracks to be plotted. Default: NULL; all animals are plotted.
ask	If TRUE, the execution pauses between each plot.
return	If TRUE, the function returns a ggplot object (which can be edited and plotted manually). If FALSE, the function automatically plots the map (default).

Details

If the plot displays the message "Sorry, we have no imagery here", try a lower level of zoom.

References

D. Kahle and H. Wickham. ggmap: Spatial Visualization with ggplot2. The R Journal, 5(1), 144-161. URL: http://journal.r-project.org/archive/2013-1/kahle-wickham.pdf

---

plotStates *Plot states*

Description

Plot the states and states probabilities.

Usage

```
plotStates(m, animals = NULL, ask = TRUE)
```

Arguments

m	A moveHMM object
animals	Vector of indices or IDs of animals for which states will be plotted.
ask	If TRUE, the execution pauses between each plot.

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

# plot states for first and second animals
plotStates(m,animals=c(1,2))
```

plotStationary *Plot stationary state probabilities*

Description

Plot stationary state probabilities

Usage

```
plotStationary(m, col = NULL, plotCI = FALSE, alpha = 0.95)
```

Arguments

m	An object moveHMM
col	Vector or colors for the states (one color per state).
plotCI	Logical. Should 95% confidence intervals be plotted? (Default: FALSE)
alpha	Significance level of the confidence intervals if plotCI=TRUE. Default: 0.95 (i.e. 95% CIs).

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

plotStationary(m)
```

predictStationary *Predict stationary state probabilities*

Description

Predict stationary state probabilities

Usage

```
predictStationary(
  m,
  newData,
  beta = m$mle$beta,
  returnCI = FALSE,
  alpha = 0.95
)
```

Arguments

m	Fitted moveHMM object, as returned by fitHMM
newData	Data frame with columns for the covariates
beta	Optional matrix of regression coefficients for the transition probability model. By default, uses estimates in m.
returnCI	Logical indicating whether confidence intervals should be returned. Default: FALSE.
alpha	Confidence level if returnCI = TRUE. Default: 0.95, i.e., 95% confidence intervals.

Value

List with elements 'mle', 'lci', and 'uci' (the last two only if returnCI = TRUE). Each element is a matrix of stationary state probabilities with one row for each row of newData and one column for each state.

---

predictTPM *Predict transition probabilities for new covariate values*

Description

Predict transition probabilities for new covariate values

Usage

```
predictTPM(m, newData, beta = m$mle$beta, returnCI = FALSE, alpha = 0.95)
```

Arguments

m	Fitted moveHMM object, as returned by fitHMM
newData	Data frame with columns for the covariates
beta	Optional matrix of regression coefficients for the transition probability model. By default, uses estimates in m.
returnCI	Logical indicating whether confidence intervals should be returned. Default: FALSE.
alpha	Confidence level if returnCI = TRUE. Default: 0.95, i.e., 95% confidence intervals.

Value

List with elements 'mle', 'lci', and 'uci' (the last two only if returnCI = TRUE). Each element is an array, where each layer is a transition probability matrix corresponding to a row of newData.

prepData *Preprocessing of the tracking data*

Description

Preprocessing of the tracking data

Usage

```
prepData(
  trackData,
  type = c("LL", "UTM"),
  coordNames = c("x", "y"),
  LLangle = NULL
)
```

Arguments

trackData	A dataframe of the tracking data, including at least coordinates (either longitude/latitude values or cartesian coordinates), and optionnaly a field ID (identifiers for the observed individuals). Additionnal fields are considered as covariates. Note that, if the names of the coordinates are not "x" and "y", the coordNames argument should specified. Tracking data should be structured so that the rows for each track (or each animal) are grouped together, and ordered by date, in the data frame.
type	'LL' if longitude/latitude provided (default), 'UTM' if easting/northing.
coordNames	Names of the columns of coordinates in the data frame. Default: c("x","y").
LLangle	Logical. If TRUE, the turning angle is calculated with geosphere::bearing (default), else calculated with atan2.

Value

An object moveData, i.e. a dataframe of:

ID	The ID(s) of the observed animal(s)
step	The step lengths - in kilometers if longitude/latitude provided, and in the metrics of the data otherwise
angle	The turning angles (if any) - in radians
x	Either Easting or longitude (or e.g. depth for 1D data)
y	Either Northing or latitude (all zero if 1D data)
...	Covariates (if any)

Examples

```
coord1 <- c(1,2,3,4,5,6,7,8,9,10)
coord2 <- c(1,1,1,2,2,2,1,1,1,2)
trackData <- data.frame(coord1=coord1,coord2=coord2)
d <- prepData(trackData,type='UTM',coordNames=c("coord1","coord2"))
```

---

print.moveHMM *Print* moveHMM

Description

Print moveHMM

Usage

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

Arguments

x	A moveHMM object.
...	Currently unused. For compatibility with generic method.

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

print(m)
```

---

pseudoRes *Pseudo-residuals*

Description

The pseudo-residuals of a moveHMM model, as described in Zucchini and McDonad (2009).

Usage

```
pseudoRes(m)
```

Arguments

m	A moveHMM object.

Details

If some turning angles in the data are equal to pi, the corresponding pseudo-residuals will not be included. Indeed, given that the turning angles are defined on (-pi,pi], an angle of pi results in a pseudo-residual of +Inf (check Section 6.2 of reference for more information on the computation of pseudo-residuals).

Value

A list of:

`stepRes`	The pseudo-residuals for the step lengths
`angleRes`	The pseudo-residuals for the turning angles

References

Zucchini, W. and MacDonald, I.L. 2009. Hidden Markov Models for Time Series: An Introduction Using R. Chapman & Hall (London).

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m
res <- pseudoRes(m)
qqnorm(res$stepRes)
qqnorm(res$angleRes)
```

---

simData *Simulation tool*

Description

Simulates movement data from an HMM.

Usage

```
simData(
  nbAnimals = 1,
  nbStates = 2,
  stepDist = c("gamma", "weibull", "lnorm", "exp"),
  angleDist = c("vm", "wrpcauchy", "none"),
  stepPar = NULL,
  anglePar = NULL,
  beta = NULL,
  covs = NULL,
  nbCovs = 0,
  zeroInflation = FALSE,
  obsPerAnimal = c(500, 1500),
```

```
  model = NULL,
  states = FALSE
)
```

Arguments

nbAnimals	Number of observed individuals to simulate.
nbStates	Number of behavioural states to simulate.
stepDist	Name of the distribution of the step lengths (as a character string). Supported distributions are: gamma, weibull, lnorm, exp. Default: gamma.
angleDist	Name of the distribution of the turning angles (as a character string). Supported distributions are: vm, wrpcauchy. Set to "none" if the angle distribution should not be estimated. Default: vm.
stepPar	Parameters of the step length distribution.
anglePar	Parameters of the turning angle distribution.
beta	Matrix of regression parameters for the transition probabilities (more information in "Details").
covs	Covariate values to include in the model, as a dataframe. Default: NULL. Covariates can also be simulated according to a standard normal distribution, by setting covs to NULL, and specifying nbCovs>0.
nbCovs	Number of covariates to simulate (0 by default). Does not need to be specified of covs is specified.
zeroInflation	TRUE if the step length distribution is inflated in zero. Default: FALSE. If TRUE, values for the zero-mass parameters should be included in stepPar.
obsPerAnimal	Either the number of the number of observations per animal (if single value), or the bounds of the number of observations per animal (if vector of two values). In the latter case, the numbers of obervations generated for each animal are uniformously picked from this interval. Default: c(500,1500).
model	A moveHMM object. This option can be used to simulate from a fitted model. Default: NULL. Note that, if this argument is specified, most other arguments will be ignored – except for nbAnimals, obsPerAnimal, covs (if covariate values different from those in the data should be specified), and states.
states	TRUE if the simulated states should be returned, FALSE otherwise (default).

Details

- The matrix beta of regression coefficients for the transition probabilities has one row for the intercept, plus one row for each covariate, and one column for each non-diagonal element of the transition probability matrix. For example, in a 3-state HMM with 2 covariates, the matrix beta has three rows (intercept + two covariates) and six columns (six non-diagonal elements in the 3x3 transition probability matrix - filled in row-wise). In a covariate-free model (default), beta has one row, for the intercept.
- If the length of covariate values passed (either through 'covs', or 'model') is not the same as the number of observations suggested by 'nbAnimals' and 'obsPerAnimal', then the series of covariates is either shortened (removing last values - if too long) or extended (starting over from the first values - if too short).

Value

An object moveData, i.e. a dataframe of:

ID	The ID(s) of the observed animal(s)
step	The step lengths
angle	The turning angles (if any)
x	Either easting or longitude
y	Either northing or latitude
...	Covariates (if any)

Examples

```
# 1. Pass a fitted model to simulate from
# (m is a moveHMM object - as returned by fitHMM - automatically loaded with the package)
# We keep the default nbAnimals=1.
m <- example$m
obsPerAnimal=c(50,100)
data <- simData(model=m,obsPerAnimal=obsPerAnimal)

# 2. Pass the parameters of the model to simulate from
stepPar <- c(1,10,1,5,0.2,0.3) # mean1, mean2, sd1, sd2, z1, z2
anglePar <- c(pi,0,0.5,2) # mean1, mean2, k1, k2
stepDist <- "gamma"
angleDist <- "vm"
data <- simData(nbAnimals=5,nbStates=2,stepDist=stepDist,angleDist=angleDist,stepPar=stepPar,
               anglePar=anglePar,nbCovs=2,zeroInflation=TRUE,obsPerAnimal=obsPerAnimal)

stepPar <- c(1,10,1,5) # mean1, mean2, sd1, sd2
anglePar <- c(pi,0,0.5,0.7) # mean1, mean2, k1, k2
stepDist <- "weibull"
angleDist <- "wrpcauchy"
data <- simData(nbAnimals=5,nbStates=2,stepDist=stepDist,angleDist=angleDist,stepPar=stepPar,
               anglePar=anglePar,obsPerAnimal=obsPerAnimal)

# step length only and zero-inflation
stepPar <- c(1,10,1,5,0.2,0.3) # mean1, mean2, sd1, sd2, z1, z2
stepDist <- "gamma"
data <- simData(nbAnimals=5,nbStates=2,stepDist=stepDist,angleDist="none",stepPar=stepPar,
               nbCovs=2,zeroInflation=TRUE,obsPerAnimal=obsPerAnimal)

# include covariates
# (note that it is useless to specify "nbCovs", which is determined
# by the number of columns of "cov")
cov <- data.frame(temp=rnorm(500,20,5))
stepPar <- c(1,10,1,5) # mean1, mean2, sd1, sd2
anglePar <- c(pi,0,0.5,2) # mean1, mean2, k1, k2
stepDist <- "gamma"
angleDist <- "vm"
data <- simData(nbAnimals=5,nbStates=2,stepDist=stepDist,angleDist=angleDist,stepPar=stepPar,
                anglePar=anglePar,covs=cov)
```

stateProbs *State probabilities*

Description

For a given model, computes the probability of the process being in the different states at each time point.

Usage

```
stateProbs(m)
```

Arguments

m	A moveHMM object.

Value

The matrix of state probabilities, with element [i,j] the probability of being in state j in observation i.

References

Zucchini, W. and MacDonald, I.L. 2009. Hidden Markov Models for Time Series: An Introduction Using R. Chapman & Hall (London).

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

sp <- stateProbs(m)
```

stationary *Stationary state probabilities*

Description

Calculates the stationary probabilities of each state, for given covariate values.

Usage

```
stationary(m, covs, beta = m$mle$beta)
```

Arguments

m	Fitted model (as output by fitHMM).
covs	Either a data frame or a design matrix of covariates.
beta	Optional matrix of regression coefficients for the transition probability model. By default, uses estimates in m.

Value

Matrix of stationary state probabilities. Each row corresponds to a row of covs, and each column corresponds to a state.

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

# data frame of covariates
stationary(m, covs = data.frame(cov1 = 0, cov2 = 0))

# design matrix (each column corresponds to row of m$mle$beta)
stationary(m, covs = matrix(c(1,0,cos(0)),1,3))
```

---

summary.moveData *Summary* moveData

Description

Summary moveData

Usage

```
## S3 method for class 'moveData'
summary(object, details = TRUE, ...)
```

Arguments

object	A moveData object.
details	TRUE if quantiles of the covariate values should be printed (default), FALSE otherwise.
...	Currently unused. For compatibility with generic method.

Examples

```
# m is a moveData object (as returned by prepData), automatically loaded with the package
data <- example$data

summary(data)
```

trMatrix_rcpp *Transition probability matrix*

Description

Computation of the transition probability matrix, as a function of the covariates and the regression parameters. Written in C++. Used in `fitHMM`, `logAlpha`, `logBeta`, `plot.moveHMM`, `pseudoRes`, and `viterbi`.

Usage

```
trMatrix_rcpp(nbStates, beta, covs)
```

Arguments

`nbStates`	Number of states
`beta`	Matrix of regression parameters
`covs`	Matrix of covariate values

Value

Three dimensional array `trMat`, such that `trMat[,,t]` is the transition matrix at time t.

turnAngle *Turning angle*

Description

Used in `prepData`.

Usage

```
turnAngle(x, y, z, LLangle)
```

Arguments

`x`	First point
`y`	Second point
`z`	Third point
`LLangle`	Logical. If TRUE, the turning angle is calculated with `geosphere::bearing`, else calculated with `atan2`.

Value

The angle between vectors (x,y) and (y,z)

Examples

```
## Not run:
x <- c(0,0)
y <- c(4,6)
z <- c(10,7)
turnAngle(x,y,z,LLangle=FALSE)

## End(Not run)
```

`viterbi` *Viterbi algorithm*

Description

For a given model, reconstructs the most probable states sequence, using the Viterbi algorithm.

Usage

```
viterbi(m, newdata = NULL)
```

Arguments

`m`	An object `moveHMM`
`newdata`	An object `moveData` (optional)

Value

The sequence of most probable states.

References

Zucchini, W. and MacDonald, I.L. 2009. Hidden Markov Models for Time Series: An Introduction Using R. Chapman & Hall (London).

Examples

```
# m is a moveHMM object (as returned by fitHMM), automatically loaded with the package
m <- example$m

# reconstruction of states sequence
states <- viterbi(m)
```

w2n *Scaling function: working to natural parameters*

Description

Scales each parameter from the set of real numbers, back to its natural interval. Used during the optimization of the log-likelihood.

Usage

```
w2n(wpar, bounds, parSize, nbStates, nbCovs, estAngleMean, stationary)
```

Arguments

wpar	Vector of state-dependent distributions unconstrained parameters.
bounds	Matrix with 2 columns and as many rows as there are elements in wpar. Each row contains the lower and upper bound for the correponding parameter.
parSize	Vector of two values: number of parameters of the step length distribution, number of parameters of the turning angle distribution.
nbStates	The number of states of the HMM.
nbCovs	The number of covariates.
estAngleMean	TRUE if the angle mean is estimated, FALSE otherwise.
stationary	FALSE if there are covariates. If TRUE, the initial distribution is considered equal to the stationary distribution. Default: FALSE.

Value

A list of:

stepPar	Matrix of natural parameters of the step length distribution
anglePar	Matrix of natural parameters of the turning angle distribution
beta	Matrix of regression coefficients of the transition probabilities
delta	Initial distribution

Examples

```
## Not run:
nbStates <- 3
nbCovs <- 2
par <- c(0.001,0.999,0.5,0.001,1500.3,7.1)
parSize <- c(1,1)
bounds <- matrix(c(0,1,0,1,0,1,
                   0,Inf,0,Inf,0,Inf),
                 byrow=TRUE,ncol=2)
beta <- matrix(rnorm(18),ncol=6,nrow=3)
delta <- c(0.6,0.3,0.1)
```

```
wpar <- n2w(par,bounds,beta,delta,nbStates,FALSE)
print(w2n(wpar,bounds,parSize,nbStates,nbCovs,estAngleMean=FALSE,stationary=FALSE))

## End(Not run)
```

Index