Package: womblR (via r-universe)

October 29, 2026

Type Package

Title Spatiotemporal Boundary Detection Model for Areal Unit Data

Version 1.0.6

Description Implements a spatiotemporal boundary detection model with a dissimilarity metric for areal data with inference in a Bayesian setting using Markov chain Monte Carlo (MCMC). The response variable can be modeled as Gaussian (no nugget), probit or Tobit link and spatial correlation is introduced at each time point through a conditional autoregressive (CAR) prior. Temporal correlation is introduced through a hierarchical structure and can be specified as exponential or first-order autoregressive. Full details of the package can be found in the accompanying vignette. Furthermore, the details of the package can be found in ``Diagnosing Glaucoma Progression with Visual Field Data Using a Spatiotemporal Boundary Detection Method'', by Berchuck et al (2019) <doi:10.1080/01621459.2018.1537911>.

Date 2025-09-26

License GPL (>= 2)

Encoding UTF-8

LazyData true

RoxygenNote 7.3.2

NeedsCompilation yes

Depends R (>= 3.0.2)

Imports graphics, grDevices, msm (>= 1.0.0), mvtnorm (>= 1.0-0), Rcpp (>= 0.12.9), stats, utils

Suggests coda, classInt, knitr, rmarkdown

LinkingTo Rcpp, RcppArmadillo (>= 0.7.500.0.0)

VignetteBuilder knitr

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Repository https://cran.r-universe.dev

Date/Publication 2025-09-26 21:28:26 UTC

RemoteUrl https://github.com/cran/womblR

RemoteRef HEAD

RemoteSha 06d9fc60dbe714482e09f24686cfc70804962425

Contents

diagnostics . . . 2
GarwayHeath . . . 4
HFAII_Queen . . . 4
HFAII_QueenHF . . . 5
HFAII_Rook . . . 5
is.PosteriorAdj . . . 6
is.STBDwDM . . . 6
PlotAdjacency . . . 7
PlotSensitivity . . . 8
PlotVfTimeSeries . . . 9
PosteriorAdj . . . 11
predict.STBDwDM . . . 12
STBDwDM . . . 13
VFSeries . . . 16
womblR . . . 17

Index **18**

`diagnostics` *diagnostics*

Description

Calculates diagnostic metrics using output from the `STBDwDM` model.

Usage

```
diagnostics(
  obj,
  diags = c("dic", "dinf", "waic"),
  keepDeviance = FALSE,
  keepPPD = FALSE
)
```

Arguments

obj	A STBDwDM model object for which diagnostics are desired from.
diags	A vector of character strings indicating the diagnostics to compute. Options include: Deviance Information Criterion ("dic"), d-infinity ("dinf") and Watanabe-Akaike information criterion ("waic"). At least one option must be included. Note: The probit model cannot compute the DIC or WAIC diagnostics due to computational issues with computing the multivariate normal CDF.
keepDeviance	A logical indicating whether the posterior deviance distribution is returned (default = FALSE).
keepPPD	A logical indicating whether the posterior predictive distribution at each observed location is returned (default = FALSE).

Details

To assess model fit, DIC, d-infinity and WAIC are used. DIC is based on the deviance statistic and penalizes for the complexity of a model with an effective number of parameters estimate pD (Spiegelhalter et al 2002). The d-infinity posterior predictive measure is an alternative diagnostic tool to DIC, where d-infinity=P+G. The G term decreases as goodness of fit increases, and P, the penalty term, inflates as the model becomes over-fit, so small values of both of these terms and, thus, small values of d-infinity are desirable (Gelfand and Ghosh 1998). WAIC is invariant to parametrization and is asymptotically equal to Bayesian cross-validation (Watanabe 2010). WAIC = -2 * (lppd - p_waic_2). Where lppd is the log pointwise predictive density and p_waic_2 is the estimated effective number of parameters based on the variance estimator from Vehtari et al. 2016. (p_waic_1 is the mean estimator).

Value

diagnostics returns a list containing the diagnostics requested and possibly the deviance and/or posterior predictive distribution objects.

Author(s)

Samuel I. Berchuck

References

Gelfand, A. E., & Ghosh, S. K. (1998). Model choice: a minimum posterior predictive loss approach. Biometrika, 1-11.

Spiegelhalter, D. J., Best, N. G., Carlin, B. P., & Van Der Linde, A. (2002). Bayesian measures of model complexity and fit. Journal of the Royal Statistical Society: Series B (Statistical Methodology), 64(4), 583-639.

Vehtari, A., Gelman, A., & Gabry, J. (2016). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Statistics and Computing, 1-20.

Watanabe, S. (2010). Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory. Journal of Machine Learning Research, 11(Dec), 3571-3594.

GarwayHeath *Garway-Heath angles for the HFA-II*

Description

These Garway-Heath angles are used as the dissimilarity metric when implementing the boundary detection model for a longitudinal series of visual fields.

Usage

```
data(GarwayHeath)
```

Format

A vector with length 54, where each entry represents the angle (in degrees) that the underlying retinal nerve fiber enters the optic nerve head. The measure ranges from 0-360, where 0 is designated at the 9-o'clock position (right eye) and angles are counted counter clockwise. These angles are estimates for the Humphrey Field Analyzer-II (Carl Zeiss Meditec Inc., Dublin, CA). The 26th and 35th entries are missing as they correspond to a natural blind spot.

References

Garway-Heath, et al. (2000). Ophthalmology 107:10:1809–1815. (PubMed)

HFAII_Queen *HFAII Queen Adjacency Matrix*

Description

Binary adjacency matrix for the Humphrey Field Analyzer-II (Carl Zeiss Meditec Inc., Dublin, CA)

Usage

```
data(HFAII_Queen)
```

Format

This adjacency matrix is formated using queen neighbor criteria, meaning two locations on the visual field are only considered neighbors if they share an edge or corner. The adjacency matrix is a 54 x 54 dimensional binary object with zeros on the diagonal and the column and row sums are equal to the number of neighbors.

HFAII_QueenHF *HFAII Queen Hemisphere Adjacency Matrix*

Description

Binary adjacency matrix for the Humphrey Field Analyzer-II (Carl Zeiss Meditec Inc., Dublin, CA)

Usage

```
data(HFAII_QueenHF)
```

Format

This adjacency matrix is formated using queen neighbor criteria, meaning two locations on the visual field are only considered neighbors if they share an edge or corner. An additional criterion is included that locations are not considered neighbors if they fall within different hemispheres on the visual field. The adjacency matrix is a 54 x 54 dimensional binary object with zeros on the diagonal and the column and row sums are equal to the number of neighbors.

HFAII_Rook *HFAII Rook Adjacency Matrix*

Description

Binary adjacency matrix for the Humphrey Field Analyzer-II (Carl Zeiss Meditec Inc., Dublin, CA)

Usage

```
data(HFAII_Rook)
```

Format

This adjacency matrix is formated using rook neighbor criteria, meaning two locations on the visual field are only considered neighbors if they share an edge. The adjacency matrix is a 54 x 54 dimensional binary object with zeros on the diagonal and the column and row sums are equal to the number of neighbors.

is.PosteriorAdj *is.PosteriorAdj*

Description

is.PosteriorAdj is a general test of an object being interpretable as a PosteriorAdj object.

Usage

```
is.PosteriorAdj(x)
```

Arguments

x	object to be tested.

Details

The PosteriorAdj class is defined as the posterior adjacency object that results from the PosteriorAdj function.

is.STBDwDM *is.STBDwDM*

Description

is.STBDwDM is a general test of an object being interpretable as a STBDwDM object.

Usage

```
is.STBDwDM(x)
```

Arguments

x	object to be tested.

Details

The STBDwDM class is defined as the regression object that results from the STBDwDM regression function.

PlotAdjacency *PlotAdjacency*

Description

Plots a heat map of the differential light sensitivity on the Humphrey Field Analyzer-II visual field.

Usage

```
PlotAdjacency(
  Wij,
  Visit = 1,
  stat = "mean",
  main = "Estimated Adjacencies",
  color.scheme = c("Black", "White"),
  edgewidth = 2,
  cornerwidth = 1/4,
  lwd.border = 3,
  color.bs = "gray",
  zlim = c(0, 1),
  legend = TRUE,
  DM = NULL,
  W = NULL
)
```

Arguments

Wij	a PosteriorAdj object.
Visit	either an integer (1,...,Nu) indicating the visit number for which you want to get the adjacencies to plot or NA. If NA, then the plot will produce the dissimilarity metric at each adjacency.
stat	either "mean" or "sd" (only used for Visit != NA).
main	an overall title for the plot.
color.scheme	a vector of colors to be used to show the adjacencies changing.
edgewidth	a scalar indicating the width of the edges.
cornerwidth	a scalar indicating the width of the corners.
lwd.border	a scalar indicating width of the visual field border.
color.bs	one color specifying the blind spot.
zlim	the limits used for the legend (default are c(0,1)).
legend	logical, indicating whether the legend should be present (default = TRUE).
DM	a dissimilarity metric to be plotted at each location on the visual field (default = NULL).
W	an adjacency matrix that specifies the visual field, required if Wij is not provided (default = NULL).

Details

PlotAdjacency is used in the application of glaucoma progression to plot the posterior mean and standard deviation neighborhood adjacencies across the visual field.

Author(s)

Samuel I. Berchuck

Examples

```
###Define blind spot locations on the HFA-II
blind_spot <- c(26, 35)

###Load visual field adjacency matrix
W <- HFAII_Queen[ -blind_spot, -blind_spot]

###Load Garway-Heath angles for dissimiliarity metric
DM <- GarwayHeath[-blind_spot] #Uses Garway-Heath angles object "GarwayHeath"

###Adjacency plots
PlotAdjacency(W = W, DM = DM, zlim = c(0, 180), Visit = NA,
              main = "Garway-Heath dissimilarity metric\n across the visual field")
```

PlotSensitivity *PlotSensitivity*

Description

Plots a heat map of the differential light sensitivity on the Humphrey Field Analyzer-II visual field.

Usage

```
PlotSensitivity(
  Y = Y,
  main = "Sensitivity Estimate (dB) at each \nlocation on visual field",
  legend.lab = "DLS (dB)",
  zlim = c(10, 35),
  bins = 200,
  border = TRUE,
  legend = TRUE,
  color = c("yellow", "orange", "red"),
  col.bs = "grey",
  legend.round = 0,
  legend.vals = 5
)
```

Arguments

Y	variable to be plotted on the visual field (e.g. differential light sensitivity).
main	an overall title for the plot.
legend.lab	a label for the legend (default = "DLS (dB)").
zlim	the limits used for the legend (default are the minimum and maximum of Y).
bins	the number of bins used to refine the color palette for the figure and legend.
border	logical, indicating whether there should be a border around the visual field (default = TRUE).
legend	logical, indicating whether the legend should be present (default = TRUE).
color	a vector of character strings representing the color palette.
col.bs	color of the blind spot locations (default = "grey").
legend.round	integer, indicating the digits that the legend labels are rounded to (default = 0).
legend.vals	integer, indicating the number of labels values to be included on the legend (default = 5).

Details

PlotSensitivity is used in the application of glaucoma progression to plot a variable across the visual field in the form of a heat map.

Author(s)

Samuel I. Berchuck

Examples

```
data(VFSeries)
PlotSensitivity(Y = VFSeries$DLS[VFSeries$Visit == 1],
                main = "Sensitivity estimate (dB) at each \n location on visual field",
                 legend.lab = "DLS (dB)",
                 zlim = c(10, 35),
                 bins = 250)
```

PlotVfTimeSeries *PlotVfTimeSeries*

Description

Plots a time series at each location of the Humphrey Field Analyzer-II visual field .

Usage

```
PlotVfTimeSeries(
  Y,
  Location,
  Time,
  main = "Visual field sensitivity time series \n at each location",
  xlab = "Time from first visit (days)",
  ylab = "Sensitivity (dB)",
  line.col = "red",
  line.reg = TRUE,
  line.type = 1
)
```

Arguments

Y	a time series variable to be plotted.
Location	a variable corresponding to the location on the visual field that the time series variable was observed.
Time	a variable corresponding to the time that the time series variable was observed.
main	an overall title for the plot.
xlab	a title for the x axis.
ylab	a title for the y axis.
line.col	color for the regression line, either character string corresponding to a color or a integer (default = "red").
line.reg	logical, determines if there are regression lines printed (default = TRUE).
line.type	integer, specifies the type of regression line printed (default = 1).

Details

PlotVfTimeSeries is used in the application of glaucoma progression. In each cell is the observed DLS at each location over visits, with the red line representing a linear regression trend.

Author(s)

Samuel I. Berchuck

Examples

```
data(VFSeries)
PlotVfTimeSeries(Y = VFSeries$DLS,
                 Location = VFSeries$Location,
                 Time = VFSeries$Time,
                 main = "Visual field sensitivity time series \n at each location",
                 xlab = "Days from baseline visit",
                 ylab = "Differential light sensitivity (dB)")
```

PosteriorAdj *PosteriorAdj*

Description

Calculates the posterior mean and standard deviation for the neighborhood adjacencies from the STBDwDM model.

Usage

```
PosteriorAdj(object)
```

Arguments

object	a STBDwDM model object for which predictions are desired from.

Details

The function PosteriorAdj calculates the posterior mean and standard deviation of the neighborhood adjacencies for each pairwise location. The neighborhood structure used to do this comes from Berchuck et al. 2017.

Value

PosteriorAdj returns a matrix containing the following columns.

- i Location i (i.e. which row/column on the adjacency matrix W).
- j Location j (i.e. which row/column on the adjacency matrix W).
- DM The dissimilarity metric between locations i and j.
- meant The posterior mean of the neighborhood adjacency between location i and j at time t, t = 1, ... , Nu.
- sdt The posterior mean of the neighborhood adjacency between location i and j at time t, t = 1, ... , Nu.

Author(s)

Samuel I. Berchuck

predict.STBDwDM *predict.STBDwDM*

Description

Predicts future observations from the STBDwDM model.

Usage

```
## S3 method for class 'STBDwDM'
predict(object, NewTimes, ...)
```

Arguments

object	a STBDwDM model object for which predictions are desired from.
NewTimes	a numeric vector including desired time(s) points for prediction.
...	other arguments.

Details

predict.STBDwDM uses Bayesian krigging to predict vectors at future time points. The function returns the krigged observed outcomes along with the observational level parameters (mu, tau, and alpha).

Value

predict.STBDwDM returns a list containing the following objects.

MuTauAlpha A list containing three matrices, mu, tau and alpha. Each matrix is dimension NKeep x s, where s is the number of new time points. Each matrix contains posterior samples obtained by Bayesian krigging.

Y A list containing s posterior predictive distribution matrices. Each matrix is dimension NKeep x s, where s is the number of new time points. Each matrix is obtained through Bayesian krigging.

Author(s)

Samuel I. Berchuck

STBDwDM *MCMC sampler for spatiotemporal boundary detection with dissimilarity metric.*

Description

STBDwDM is a Markov chain Monte Carlo (MCMC) sampler for a spatiotemporal boundary detection model using the Bayesian hierarchical framework.

Usage

```
STBDwDM(
  Y,
  DM,
  W,
  Time,
  Starting = NULL,
  Hypers = NULL,
  Tuning = NULL,
  MCMC = NULL,
  Family = "tobit",
  TemporalStructure = "exponential",
  Distance = "circumference",
  Weights = "continuous",
  Rho = 0.99,
  ScaleY = 10,
  ScaleDM = 100,
  Seed = 54
)
```

Arguments

Y	An N dimensional vector containing the observed outcome data. Here, N = M * Nu, where M represents the number of spatial locations and Nu the number of temporal visits. The observations in Y must be first ordered spatially and then temporally, meaning the first M observations in Y should come from the initial time point.
DM	An M dimensional vector containing a dissimilarity metric for each spatial location. The order of the spatial locations must match the order from Y.
W	An M x M dimensional binary adjacency matrix for dictating the spatial neigborhood structure.
Time	A Nu dimensional vector containing the observed time points for each vector of outcomes in increasing order.
Starting	Either NULL or a list containing starting values to be specified for the MCMC sampler. If NULL is not chosen then none, some or all of the starting values may be specified.

When NULL is chosen then default starting values are automatically generated. Otherwise a list must be provided with names Delta, T or Phi containing appropriate objects. Delta must be a 3 dimensional vector, T a 3 x 3 dimensional matrix and Phi a scalar.

Hypers

Either NULL or a list containing hyperparameter values to be specified for the MCMC sampler. If NULL is not chosen then none, some or all of the hyperparameter values may be specified.

When NULL is chosen then default hyperparameter values are automatically generated. These default hyperparameters are described in detail in (Berchuck et al.). Otherwise a list must be provided with names Delta, T or Phi containing further hyperparameter information. These objects are themselves lists and may be constructed as follows.

Delta is a list with two objects, MuDelta and OmegaDelta. MuDelta represents the mean component of the multivariate normal hyperprior and must be a 3 dimensional vector, while OmegaDelta represents the covariance and must be a 3 x 3 dimensional matrix.

T is a list with two objects, Xi and Psi. Xi represents the degrees of freedom parameter for the inverse-Wishart hyperprior and must be a real number scalar, while Psi represents the scale matrix and must be a 3 x 3 dimensional positive definite matrix.

Phi is a list with two objects, APhi and BPhi. APhi represents the lower bound for the uniform hyperprior, while BPhi represents the upper bound. The bounds must be specified carefully. For example, if the exponential temporal correlation structure is chosen both bounds must be restricted to be non-negative.

Tuning

Either NULL or a list containing tuning values to be specified for the MCMC Metropolis steps. If NULL is not chosen then all of the tuning values must be specified.

When NULL is chosen then default tuning values are automatically generated to 1. Otherwise a list must be provided with names Theta2, Theta3 and Phi. Theta2 and Theta3 must be Nu dimensional vectors and Phi a scalar. Each containing tuning variances for their corresponding Metropolis updates.

MCMC

Either NULL or a list containing input values to be used for implementing the MCMC sampler. If NULL is not chosen then all of the MCMC input values must be specified.

NBurn: The number of sampler scans included in the burn-in phase. (default = 10,000)

NSims: The number of post-burn-in scans for which to perform the sampler. (default = 100,000)

NThin: Value such that during the post-burn-in phase, only every NThin-th scan is recorded for use in posterior inference (For return values we define, NKeep = NSims / NThin (default = 10).

NPilot: The number of times during the burn-in phase that pilot adaptation is performed (default = 20)

Family

Character string indicating the distribution of the observed data. Options include: "normal", "probit", "tobit".

`TemporalStructure`
: Character string indicating the temporal structure of the time observations. Options include: `"exponential"` and `"ar1"`.

`Distance`
: Character string indicating the distance metric for computing the dissimilarity metric. Options include: `"euclidean"` and `"circumference"`.

`Weights`
: Character string indicating the type of weight used. Options include: `"continuous"` and `"binary"`.

`Rho`
: A scalar in `(0,1)` that dictates the magnitude of local spatial sharing. By default it is fixed at `0.99` as suggested by Lee and Mitchell (2012).

`ScaleY`
: A positive scalar used for scaling the observed data, `Y`. This is used to aid numerically for MCMC convergence, as scaling large observations often stabilizes chains. By default it is fixed at `10`.

`ScaleDM`
: A positive scalar used for scaling the dissimilarity metric distances, `DM`. This is used to aid numerically for MCMC convergence. as scaling spatial distances is often used for improved MCMC convergence. By default it is fixed at `100`.

`Seed`
: An integer value used to set the seed for the random number generator (default = 54).

Details

Details of the underlying statistical model can be found in the article by Berchuck et al. (2018), "Diagnosing Glaucoma Progression with Visual Field Data Using a Spatiotemporal Boundary Detection Method", <arXiv:1805.11636>.

Value

`STBDwDM` returns a list containing the following objects

`mu` `NKeep` x `Nu` `matrix` of posterior samples for `mu`. The t-th column contains posterior samples from the the t-th time point.

`tau2` `NKeep` x `Nu` `matrix` of posterior samples for `tau2`. The t-th column contains posterior samples from the the t-th time point.

`alpha` `NKeep` x `Nu` `matrix` of posterior samples for `alpha`. The t-th column contains posterior samples from the the t-th time point.

`delta` `NKeep` x `3` `matrix` of posterior samples for `delta`. The columns have names that describe the samples within them.

`T` `NKeep` x `6` `matrix` of posterior samples for `T`. The columns have names that describe the samples within them. The row is listed first, e.g., `t32` refers to the entry in row `3`, column `2`.

`phi` `NKeep` x `1` `matrix` of posterior samples for `phi`.

`metropolis` `(2 * Nu + 1)` x `2` `matrix` of metropolis acceptance rates and tuners that result from the pilot adaptation. The first `Nu` correspond to the `Theta2` (i.e. `tau2`) parameters, the next `Nu` correspond to the `Theta3` (i.e. `alpha`) parameters and the last row give the `phi` values.

`runtime` A `character` string giving the runtime of the MCMC sampler.

`datobj` A `list` of data objects that are used in future `STBDwDM` functions and should be ignored by the user.

`dataug` A `list` of data augmentation objects that are used in future `STBDwDM` functions and should be ignored by the user.

Author(s)

Samuel I. Berchuck

References

Berchuck et al. (2018), "Diagnosing Glaucoma Progression with Visual Field Data Using a Spatiotemporal Boundary Detection Method", <arXiv:1805.11636>.

`VFSeries` *Visual field series for one patient.*

Description

A dataset containing 9 visual field series from a patient of the Vein Pulsation Study Trial in Glaucoma and the Lions Eye Institute trial registry, Perth, Western Australia.

Usage

```
data(VFSeries)
```

Format

A data frame with 486 rows and 4 variables:

Visit The visual field test visit number, (1, 2, ... , 9).

DLS The observed outcome variable, differential light sensitivity (DLS).

Time The time of the visual field test (in days from baseline).

Location The location on the visual field of a Humphrey Field Analyzer-II (Carl Zeiss Meditec Inc., Dublin, CA) (1, 2, ... , 54).

Source

https://anzctr.org.au/Trial/Registration/TrialReview.aspx?ACTRN=12608000274370

womblR *womblR*

Description

This package implements a spatiotemporal boundary detection with a dissimilarity metric for areal data with inference in a Bayesian setting using Markov chain Monte Carlo (MCMC). The response variable can be modeled as Gaussian (no nugget), probit or Tobit link and spatial correlation is introduced at each time point through a conditional autoregressive (CAR) prior. Temporal correlation is introduced through a hierarchical structure and can be specified as exponential or first-order autoregressive. Full details of the the package can be found in the accompanying vignette. Furthermore, the details of the package can be found in "Diagnosing Glaucoma Progression with Visual Field Data Using a Spatiotemporal Boundary Detection Method", by Berchuck et al (2018), <arXiv:1805.11636>. The paper is in press at the Journal of the American Statistical Association.

Author(s)

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Index

∗ **datasets**
GarwayHeath, 4
HFAII_Queen, 4
HFAII_QueenHF, 5
HFAII_Rook, 5
VFSeries, 16

diagnostics, 2

GarwayHeath, 4

HFAII_Queen, 4
HFAII_QueenHF, 5
HFAII_Rook, 5

is.PosteriorAdj, 6
is.STBDwDM, 6

PlotAdjacency, 7
PlotSensitivity, 8
PlotVfTimeSeries, 9
PosteriorAdj, *6, 7*, 11
predict.STBDwDM, 12

STBDwDM, *2, 3*, *6*, *11, 12*, 13

VFSeries, 16

womblR, 17
womblR-package *(*womblR*)*, 17