Package ‘BoltzMM’

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Type Package

Title Boltzmann Machines with MM Algorithms

Version 0.1.4

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Description Provides probability computation, data generation,
and model estimation for fully-visible Boltzmann machines. It follows the methods
described in Nguyen and Wood (2016a) <doi:10.1162/NECO_a_00813>
and Nguyen and Wood (2016b) <doi:10.1109/TNNLS.2015.2425898>.

License GPL-3

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R topics documented:

`allpfvbm` *Probability mass function of a fully-visible Boltzmann machine evaluated for all possible vectors.*

Description

Compute the probability of all 2^n strings of n>1 binary spin variables (i.e. each element is -1 or 1) arising from a fully-visible Boltzmann machine with some specified bias vector and interaction matrix.

Usage

```
allpfvbm(bvec, Mmat)
```

Arguments

`bvec`	Vector of length n containing real valued bias parameters.
`Mmat`	Symmetric n by n matrix, with zeros along the diagonal, containing the interaction parameters.

Value

A vector of the probabilities of all 2^n binary spin vectors under a fully-visible Boltzmann machine with bias vector bvec and interaction matrix `Mmat`. Probabilities are reported in ascending order of the binary strings; i.e for n=2 the reporting order is (-1,1), (-1,1), (1,-1), and (1,1).

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Compute the probability of every length n=3 binary spin vector under bvec and Mmat.
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
allpfvbm(bvec,Mmat)
```

`BoltzMM` *BoltzMM: A package for probability computation, data generation, and model estimation of fully-visible Boltzmann machines.*

Description

The BoltzMM package allows for computation of probability mass functions of fully-visible Boltzmann machines via `pfvbm` and `allpfvbm`. Random data can be generated using `rfvbm`. Maximum pseudolikelihood estimation of parameters via the MM algorithm can be conducted using `fitfvbm`. Computation of partial derivatives and Hessians can be performed via `fvbmpartiald` and `fvbmHessian`. Covariance estimation and normal standard errors can be computed using `fvbmcov` and `fvbmstderr`.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

H.D. Nguyen and I.A. Wood (2016), A block successive lower-bound maximization algorithm for the maximum pseudolikelihood estimation of fully visible Boltzmann machines, Neural Computation, vol 28, pp. 485-492.

`fitfvbm` *Maximum pseudolikelihood estimation of a fully-visible Boltzmann machine.*

Description

Estimates the bias vector and interaction matrix of a fully-visible Boltzmann machine via maximum pseudolikelihood estimation using an MM algorithm.

Usage

```
fitfvbm(data, bvec, Mmat, delta_crit = 0.001, max_it = 1000L)
```

Arguments

data	An N by n matrix, where each of the N rows contains a length n string of spin variables (i.e. each element is -1 or 1).
bvec	Initial estimate for a vector of length n containing real valued bias parameters.
Mmat	Initial estimate for a symmetric n by n matrix, with zeros along the diagonal, containing the interaction parameters.
delta_crit	Real threshold value for the convergence criterion, based on the relative change in the Euclidean distance of parameter estimates from consecutive iterations.
max_it	Integer value indicating the maximum number of iterations that the algorithm is to run for.

Value

A list containing 4 objects: the final log-pseudolikelihood value `pll`, a vector containing the estimate of the bias parameters `bvec`, a matrix containing the estimate of the interaction parameters `Mmat`, and the number of algorithm iterations `itt`.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), A block successive lower-bound maximization algorithm for the maximum pseudolikelihood estimation of fully visible Boltzmann machines, Neural Computation, vol 28, pp. 485-492

Examples

```
# Generate num=1000 random strings of n=3 binary spin variables under bvec and Mmat.
num <- 1000
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
data <- rfvbm(num,bvec,Mmat)
# Fit a fully visible Boltzmann machine to data, starting from parameters bvec and Mmat.
fitfvbm(data,bvec,Mmat)
```

fvbmcov — *Sandwich estimator of the covariance matrix for a fitted fully-visible Boltzmann machine.*

Description

Computes the sandwich estimator of the covariance matrix for a maximum pseudolikelihood estimated fully-visible Boltzmann machine.

Usage

```
fvbmcov(data, model, fvbmHess)
```

Arguments

`data`	An N by n matrix, where each of the N rows contains a length n string of spin variables (i.e. each element is -1 or 1).
`model`	List generated from `fitfvbm`.
`fvbmHess`	A function that computes the Hessian of the parameter elements. Currently, the only implemented method is the default `fvbmHess` function.

Value

The n+choose(n,2) by n+choose(n,2) sandwich covariance matrix, estimated using `data` and evaluated at the fitted parameter values provided in `model`. Each row (column) is a unique element of the bias vector and interaction matrix. The rows are arranged in lexicographical order with the bias elements first, followed by the interaction elements. For example, if n=3, the order would be bias[1], bias[2] bias[3], interaction[1,2], interaction[1,3], and interaction[2,3].

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Generate num=1000 random strings of n=3 binary spin variables under bvec and Mmat.
num <- 1000
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
data <- rfvbm(num,bvec,Mmat)
# Fit a fully visible Boltzmann machine to data, starting from parameters bvec and Mmat.
model <- fitfvbm(data,bvec,Mmat)
# Compute the sandwich covariance matrix using the data and the model.
fvbmcov(data,model,fvbmHess)
```

fvbmHess — *Hessian of the log-pseudolikelihood function for a fitted fully-visible Boltzmann machine.*

Description

Computes the Hessian with respect to all unique parameter elements of the bias vector and interaction matrix of a fully-visible Boltzmann machine, for some random length n string of spin variables (i.e. each element is -1 or 1) and some fitted parameter values.

Usage

```
fvbmHess(data, model)
```

Arguments

`data`	An N by n matrix, where each of the N rows contains a length n string of spin variables (i.e. each element is -1 or 1).
`model`	List generated from `fitfvbm`.

Value

The n+choose(n,2) by n+choose(n,2) Hessian matrix, summed over the N rows of `data` and evaluated at the fitted parameter values provided in `model`. Each row (column) is a unique element of the bias vector and interaction matrix. The rows are arranged in lexicographical order with the bias elements first, followed by the interaction elements. For example, if n=3, the order would be bias[1], bias[2] bias[3], interaction[1,2], interaction[1,3], and interaction[2,3].

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Generate num=1000 random strings of n=3 binary spin variables under bvec and Mmat.
num <- 1000
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
data <- rfvbm(num,bvec,Mmat)
# Fit a fully visible Boltzmann machine to data, starting from parameters bvec and Mmat.
model <- fitfvbm(data,bvec,Mmat)
# Compute the Hessian matrix summed over all num rows of data.
fvbmHess(data,model)
```

`fvbmpartiald` *Partial derivatives of the log-pseudolikelihood function for a fitted fully-visible Boltzmann machine.*

Description

Computes the partial derivatives for all unique parameter elements of the bias vector and interaction matrix of a fully-visible Boltzmann machine, for some random length n string of spin variables (i.e. each element is -1 or 1) and some fitted parameter values.

Usage

```
fvbmpartiald(data, model)
```

Arguments

`data`	Vector of length n containing binary spin variables.
`model`	List generated from `fitfvbm`.

Value

A list containing 2 objects: a vector containing the partial derivatives corresponding to the bias parameters `bvec`, and a matrix containing the partial derivatives corresponding to the interaction parameters `Mmat`.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Generate num=1000 random strings of n=3 binary spin variables under bvec and Mmat.
num <- 1000
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
data <- rfvbm(num,bvec,Mmat)
# Fit a fully visible Boltzmann machine to data, starting from parameters bvec and Mmat.
model <- fitfvbm(data,bvec,Mmat)
# Compute the partial derivatives evaluated at the first observation of data.
fvbmpartiald(data,model)
```

fvbmstderr — *Standard errors for the parameter elements of a fitted fully-visible Boltzmann machine.*

Description

Computes the normal approximation standard errors from the sandwich estimator of the covariance matrix for a maximum pseudolikelihood estimated fully-visible Boltzmann machine.

Usage

```
fvbmstderr(data, covarmat)
```

Arguments

`data`	An N by n matrix, where each of the N rows contains a length n string of spin variables (i.e. each element is -1 or 1).
`covarmat`	A covariance matrix generated from `fvbmcov`.

Value

A list containing 2 objects: a vector containing the standard errors corresponding to the bias parameters `bvec_se`, and a matrix containing the standard errors corresponding to the interaction parameters `Mmat_se`.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Generate num=1000 random strings of n=3 binary spin variables under bvec and Mmat.
num <- 1000
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
data <- rfvbm(num,bvec,Mmat)
# Fit a fully visible Boltzmann machine to data, starting from parameters bvec and Mmat.
model <- fitfvbm(data,bvec,Mmat)
# Compute the sandwich covariance matrix using the data and the model.
covarmat <- fvbmcov(data,model,fvbmHess)
# Compute the standard errors of the parameter elements according to a normal approximation.
fvbmstderr(data,covarmat)
```

fvbmtests *Hypothesis testing for a fully-visible Boltzmann machine.*

Description

Tests the hypothesis that the true bias and interaction parameter values are those in `nullmodel`, given `data` and `model`.

Usage

```
fvbmtests(data, model, nullmodel)
```

Arguments

`data`	An N by n matrix, where each of the N rows contains a length n string of spin variables (i.e. each element is -1 or 1).
`model`	List generated from `fitfvbm`.
`nullmodel`	A list containing two elements: a vector of length n `bvec`, and an n by n matrix `Mmat`. A list generated by `fitfvbm` is also sufficient.

Value

A list containing 4 objects: a vector containing the z-scores corresponding to the bias parameters `bvec_z`,a vector containing the p-values corresponding to the bias parameters `bvec_p`,a matrix containing the z-scores corresponding to the interaction parameters `Mmat_z`, and a matrix containing the standard errors corresponding to the interaction parameters `Mmat_p`.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Generate num=1000 random strings of n=3 binary spin variables under bvec and Mmat.
num <- 1000; bvec <- c(0,0.5,0.25); Mmat <- matrix(0.1,3,3) - diag(0.1,3,3);
data <- rfvbm(num,bvec,Mmat)
# Fit a fully visible Boltzmann machine to data, starting from parameters bvec and Mmat.
model <- fitfvbm(data,bvec,Mmat)

#Propose a null hypothesis model
nullmodel <- list(bvec = c(0,0,0), Mmat = matrix(0,3,3))
```

```
# Compute z-scores
fvbmtests(data,model,nullmodel)
```

---

marginpfvbm *Marginal probability function for a fully-visible Boltzmann machine.*

Description

Computes the marginal probabilities (for values = +1 in each coordinate) under under some specified bias vector and interaction matrix, specified by `bvec` and `Mmat`, respectively.

Usage

```
marginpfvbm(bvec, Mmat)
```

Arguments

`bvec`	Vector of length n containing real valued bias parameters.
`Mmat`	Symmetric n by n matrix, with zeros along the diagonal, containing the interaction parameters.

Value

Vector of length n containing the marginal probabilities of +1 in each coordinate.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
#Compute the marginal probabilities under bvec and Mmat.
# Set the parameter values
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
marginpfvbm(bvec,Mmat)
```

pfvbm *Probability mass function of a fully-visible Boltzmann machine evaluated for an individual vector.*

Description

Compute the probability of a string of n>1 binary spin variables (i.e. each element is -1 or 1) arising from a fully-visible Boltzmann machine with some specified bias vector and interaction matrix.

Usage

```
pfvbm(xval, bvec, Mmat)
```

Arguments

xval	Vector of length n containing binary spin variables.
bvec	Vector of length n containing real valued bias parameters.
Mmat	Symmetric n by n matrix, with zeros along the diagonal, containing the interaction parameters.

Value

The probability of the random string `xval` under a fully-visible Boltzmann machine with bias vector `bvec` and interaction matrix `Mmat`.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Compute the probability of the vector xval=(-1,1,-1), under bvec and Mmat.
xval <- c(-1,1,-1)
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
pfvbm(xval,bvec,Mmat)
```

`rfvbm` *Random data generation from a fully-visible Boltzmann machine.*

Description

Generate N random strings of n>1 binary spin variables (i.e. each element is -1 or 1) arising from a fully-visible Boltzmann machine with some specified bias vector and interaction matrix.

Usage

```
rfvbm(num, bvec, Mmat)
```

Arguments

`num`	Number N of random strings to be generated.
`bvec`	Vector of length n containing real valued bias parameters.
`Mmat`	Symmetric n by n matrix, with zeros along the diagonal, containing the interaction parameters.

Value

An N by n matrix, where each row contains a random spin variable string from a fully-visible Boltzmann machine with bias vector `bvec` and interaction matrix `Mmat`.

Note

The function `allpfvbm` must be called each time this function is run. Thus, it is much more efficient to generate N strings all at once, than to generate strings one at a time.

Author(s)

Andrew T. Jones and Hien D. Nguyen

References

H.D. Nguyen and I.A. Wood (2016), Asymptotic normality of the maximum pseudolikelihood estimator for fully-visible Boltzmann machines, IEEE Transactions on Neural Networks and Learning Systems, vol. 27, pp. 897-902.

Examples

```
# Generate num=10 random strings of n=3 binary spin variables under bvec and Mmat.
num <- 10
bvec <- c(0,0.5,0.25)
Mmat <- matrix(0.1,3,3) - diag(0.1,3,3)
rfvbm(num,bvec,Mmat)
```

senate *Senate voting data from the 45th Australian Parliament.*

Description

A dataset he data from the first sitting of the Senate of the 45th Australian Parliament, until the final sitting of the year 2016. The first division during this period was conducted on the 31st of August 2016, and the last division was performed on the 1st of December 2016. In total, 147 divisions were performed during this period.

Each row represents a division(vote), each column is a party or independent. Data is either "Yes" or "No" depending on the vote. Absences and abstentions are left as NA. See https://hal.archives-ouvertes.fr/hal-01927188v1 for details of data preparation.

Usage

```
data(senate)
```

Format

A data frame with 147 rows (votes) and 9 variables (parties).

Author(s)

Jessica J. Bagnall

Source

www.aph.gov.au/Parliamentary_Business/Statistics/Senate_StatsNet/General/divisions

Examples

```
dim(senate)
```

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