Package 'Bergm'

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Title Bayesian Exponential Random Graph Models

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Description Bayesian analysis for exponential random graph models using advanced computational algorithms. More information can be found at: <https://acaimo.github.io/Bergm/>.

License GPL (>= 2)

Depends ergm, R (>= 2.10)

Imports network, coda, MCMCpack, Matrix, mvtnorm, matrixcalc, statnet.common

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`Bergm-package` *Bayesian exponential random graph models*

Description

`Bergm` provides a range of tools to analyse Bayesian exponential random graph models using advanced computational methods.

`bergm` *Parameter estimation for Bayesian ERGMs*

Description

Function to fit Bayesian exponential random graphs models using the approximate exchange algorithm.

Usage

```
bergm(
  formula,
  prior.mean = NULL,
  prior.sigma = NULL,
  burn.in = 100,
  main.iters = 1000,
  aux.iters = 1000,
  nchains = NULL,
  gamma = 0.5,
  V.proposal = 0.0025,
  startVals = NULL,
  offset.coef = NULL,
  ...
)
```

Arguments

formula	formula; an ergm formula object, of the form <network> ~ <model terms> where <network> is a network object and <model terms> are ergm-terms.
prior.mean	vector; mean vector of the multivariate Normal prior. By default set to a vector of 0's.
prior.sigma	square matrix; variance/covariance matrix for the multivariate Normal prior. By default set to a diagonal matrix with every diagonal entry equal to 100.
burn.in	count; number of burn-in iterations for every chain of the population.
main.iters	count; number of iterations for every chain of the population.
aux.iters	count; number of auxiliary iterations used for network simulation.
nchains	count; number of chains of the population MCMC. By default set to twice the model dimension (number of model terms).
gamma	scalar; parallel adaptive direction sampling move factor.
V.proposal	count; diagonal entry for the multivariate Normal proposal. By default set to 0.0025.
startVals	vector; optional starting values for the parameter estimation.
offset.coef	vector; A vector of coefficients for the offset terms.
...	additional arguments, to be passed to lower-level functions.

References

Caimo, A. and Friel, N. (2011), "Bayesian Inference for Exponential Random Graph Models," Social Networks, 33(1), 41-55. https://arxiv.org/abs/1007.5192

Caimo, A. and Friel, N. (2014), "Bergm: Bayesian Exponential Random Graphs in R," Journal of Statistical Software, 61(2), 1-25. https://www.jstatsoft.org/article/view/v061i02

Examples

```
## Not run:
# Load the florentine marriage network
data(florentine)

# Posterior parameter estimation:
p.flo <- bergm(flomarriage ~ edges + kstar(2),
               burn.in    = 50,
               aux.iters  = 500,
               main.iters = 1000,
               gamma      = 1.2)

# Posterior summaries:
summary(p.flo)

## End(Not run)
```

bergmC *Calibrating misspecified Bayesian ERGMs*

Description

Function to transform a sample from the pseudo-posterior to one that is approximately sampled from the intractable posterior distribution.

Usage

```
bergmC(
  formula,
  prior.mean = NULL,
  prior.sigma = NULL,
  burn.in = 10000,
  main.iters = 40000,
  aux.iters = 3000,
  V.proposal = 1.5,
  thin = 1,
  rm.iters = 500,
  rm.a = 0.001,
  rm.alpha = 0,
  n.aux.draws = 400,
  aux.thin = 50,
  estimate = c("MLE", "CD"),
  seed = 1,
  ...
)
```

Arguments

formula	formula; an ergm formula object, of the form <network> ~ <model terms> where <network> is a network object and <model terms> are ergm-terms.
prior.mean	vector; mean vector of the multivariate Normal prior. By default set to a vector of 0's.
prior.sigma	square matrix; variance/covariance matrix for the multivariate Normal prior. By default set to a diagonal matrix with every diagonal entry equal to 100.
burn.in	count; number of burn-in iterations at the beginning of an MCMC run for the pseudo-posterior estimation.
main.iters	count; number of MCMC iterations after burn-in for the pseudo-posterior estimation.
aux.iters	count; number of auxiliary iterations used for drawing the first network from the ERGM likelihood (Robbins-Monro). See control.simulate.formula.
V.proposal	count; diagonal entry for the multivariate Normal proposal. By default set to 1.5.

thin	count; thinning interval used in the simulation for the pseudo-posterior estimation. The number of MCMC iterations must be divisible by this value.
rm.iters	count; number of iterations for the Robbins-Monro stochastic approximation algorithm.
rm.a	scalar; constant for sequence alpha_n (Robbins-Monro).
rm.alpha	scalar; noise added to gradient (Robbins-Monro).
n.aux.draws	count; number of auxiliary networks drawn from the ERGM likelihood (Robbins-Monro). See control.simulate.formula.
aux.thin	count; number of auxiliary iterations between network draws after the first network is drawn (Robbins-Monro). See control.simulate.formula.
estimate	If "MLE" (the default), then an approximate maximum likelihood estimator is used as a starting point in the Robbins-Monro algorithm. If "CD" , the Monte-Carlo contrastive divergence estimate is returned. See ergm.
seed	integer; seed for the random number generator. See set.seed.
...	Additional arguments, to be passed to the ergm function. See ergm.

References

Bouranis, L., Friel, N., & Maire, F. (2017). Efficient Bayesian inference for exponential random graph models by correcting the pseudo-posterior distribution. Social Networks, 50, 98-108. https://arxiv.org/abs/1510.00934

Examples

```
## Not run:
# Load the florentine marriage network
data(florentine)

# Calibrated pseudo-posterior:
cpp.flo <- bergmC(flomarriage ~ edges + kstar(2),
                  aux.iters  = 500,
                  burn.in    = 500,
                  main.iters = 10000,
                  V.proposal = 2.5)

# Posterior summaries:
summary(cpp.flo)

## End(Not run)
```

bergmM *Parameter estimation for Bayesian ERGMs under missing data*

Description

Function to fit Bayesian exponential random graphs models under missing data using the approximate exchange algorithm.

Usage

```
bergmM(
  formula,
  burn.in = 100,
  main.iters = 1000,
  aux.iters = 1000,
  prior.mean = NULL,
  prior.sigma = NULL,
  nchains = NULL,
  gamma = 0.5,
  V.proposal = 0.0025,
  seed = NULL,
  startVals = NULL,
  offset.coef = NULL,
  nImp = NULL,
  missingUpdate = NULL,
  ...
)
```

Arguments

formula	formula; an ergm formula object, of the form <network> ~ <model terms> where <network> is a network object and <model terms> are ergm-terms.
burn.in	count; number of burn-in iterations for every chain of the population.
main.iters	count; number of iterations for every chain of the population.
aux.iters	count; number of auxiliary iterations used for network simulation.
prior.mean	vector; mean vector of the multivariate Normal prior. By default set to a vector of 0's.
prior.sigma	square matrix; variance/covariance matrix for the multivariate Normal prior. By default set to a diagonal matrix with every diagonal entry equal to 100.
nchains	count; number of chains of the population MCMC. By default set to twice the model dimension (number of model terms).
gamma	scalar; parallel adaptive direction sampling move factor.
V.proposal	count; diagonal entry for the multivariate Normal proposal. By default set to 0.0025.

seed	count; random number seed for the Bergm estimation.
startVals	vector; optional starting values for the parameter estimation.
offset.coef	vector; A vector of coefficients for the offset terms.
nImp	count; number of imputed networks to be returned. If null, no imputed network will be returned.
missingUpdate	count; number of tie updates in each imputation step. By default equal to number of missing ties. Smaller numbers increase speed. Larger numbers lead to better sampling.
...	additional arguments, to be passed to lower-level functions.

References

Caimo, A. and Friel, N. (2011), "Bayesian Inference for Exponential Random Graph Models," Social Networks, 33(1), 41-55. https://arxiv.org/abs/1007.5192

Caimo, A. and Friel, N. (2014), "Bergm: Bayesian Exponential Random Graphs in R," Journal of Statistical Software, 61(2), 1-25. https://www.jstatsoft.org/v61/i02

Koskinen, J.H., Robins, G.L., Pattison, P.E. (2010), "Analysing exponential random graph (p-star) models with missing data using Bayesian data augmentation," Statistical Methodology 7(3), 366-384.

Krause, R.W., Huisman, M., Steglich, C., Snijders, T.A. (2020), "Missing data in cross-sectional networks-An extensive comparison of missing data treatment methods", Social Networks 62: 99-112.

Examples

```
## Not run:
# Load the florentine marriage network
data(florentine)

# Create missing data
set.seed(14021994)
n <- dim(flomarriage[, ])[1]
missNode <- sample(1:n, 1)
flomarriage[missNode, ] <- NA
flomarriage[, missNode] <- NA

# Posterior parameter estimation:
m.flo <- bergmM(flomarriage ~ edges + kstar(2),
                burn.in    = 50,
                aux.iters  = 500,
                main.iters = 1000,
                gamma      = 1.2,
                nImp       = 5)

# Posterior summaries:
summary(m.flo)

## End(Not run)
```

bgof *Bayesian goodness-of-fit diagnostics for ERGMs*

Description

Function to calculate summaries for degree, minimum geodesic distances, and edge-wise shared partner distributions to diagnose the Bayesian goodness-of-fit of exponential random graph models.

Usage

```
bgof(
  x,
  sample.size = 100,
  aux.iters = 10000,
  n.deg = NULL,
  n.dist = NULL,
  n.esp = NULL,
  n.ideg = NULL,
  n.odeg = NULL,
  ...
)
```

Arguments

x	an R object of class bergm.
sample.size	count; number of networks to be simulated and compared to the observed network.
aux.iters	count; number of iterations used for network simulation.
n.deg	count; used to plot only the first n.deg-1 degree distributions. By default no restrictions on the number of degree distributions is applied.
n.dist	count; used to plot only the first n.dist-1 geodesic distances distributions. By default no restrictions on the number of geodesic distances distributions is applied.
n.esp	count; used to plot only the first n.esp-1 edge-wise shared partner distributions. By default no restrictions on the number of edge-wise shared partner distributions is applied.
n.ideg	count; used to plot only the first n.ideg-1 in-degree distributions. By default no restrictions on the number of in-degree distributions is applied.
n.odeg	count; used to plot only the first n.odeg-1 out-degree distributions. By default no restrictions on the number of out-degree distributions is applied.
...	additional arguments, to be passed to lower-level functions.

References

Caimo, A. and Friel, N. (2011), "Bayesian Inference for Exponential Random Graph Models," Social Networks, 33(1), 41-55. https://arxiv.org/abs/1007.5192

Caimo, A. and Friel, N. (2014), "Bergm: Bayesian Exponential Random Graphs in R," Journal of Statistical Software, 61(2), 1-25. https://www.jstatsoft.org/v61/i02

Examples

```
## Not run:
# Load the florentine marriage network
data(florentine)

# Posterior parameter estimation:
p.flo <- bergm(flomarriage ~ edges + kstar(2),
               burn.in    = 50,
               aux.iters  = 500,
               main.iters = 1000,
               gamma      = 1.2)

# Bayesian goodness-of-fit test:
bgof(p.flo,
     aux.iters   = 500,
     sample.size = 30,
     n.deg       = 10,
     n.dist      = 9,
     n.esp       = 6)

## End(Not run)
```

`ergmAPL` *Adjustment of ERGM pseudolikelihood*

Description

Function to estimate the transformation parameters for adjusting the pseudolikelihood function.

Usage

```
ergmAPL(
  formula,
  aux.iters = NULL,
  n.aux.draws = NULL,
  aux.thin = NULL,
  ladder = NULL,
  estimate = c("MLE", "CD"),
  seed = 1,
  ...
)
```

Arguments

formula	formula; an ergm formula object, of the form <network> ~ <model terms> where <network> is a network object and <model terms> are ergm-terms.
aux.iters	count; number of auxiliary iterations used for drawing the first network from the ERGM likelihood. See control.simulate.formula.
n.aux.draws	count; Number of auxiliary networks drawn from the ERGM likelihood. See control.simulate.formula.
aux.thin	count; Number of auxiliary iterations between network draws after the first network is drawn. See control.simulate.formula.
ladder	count; Length of temperature ladder (>=3).
estimate	If "MLE" (the default), then an approximate maximum likelihood estimator is returned. If "CD" , the Monte-Carlo contrastive divergence estimate is returned. See ergm.
seed	integer; seed for the random number generator. See set.seed.
...	Additional arguments, to be passed to the ergm function. See ergm.

References

Bouranis, L., Friel, N., & Maire, F. (2018). Bayesian model selection for exponential random graph models via adjusted pseudolikelihoods. Journal of Computational and Graphical Statistics, 27(3), 516-528. https://arxiv.org/abs/1706.06344

---

evidence *Wrapper function for evidence estimation*

Description

Function to estimate the evidence (marginal likelihood) with Chib and Jeliazkov's method or Power posteriors, based on the adjusted pseudolikelihood function.

Usage

```
evidence(evidence.method = c("CJ", "PP"), ...)
```

Arguments

evidence.method	vector Method to estimate the marginal likelihood. Options are: "CJ", in which case the marginal likelihood is estimated with Chib and Jeliazkov's method; "PP", in which case the marginal likelihood is estimated with Power posteriors.
...	further arguments to be passed. See evidenceCJ and evidencePP.

References

Bouranis, L., Friel, N., & Maire, F. (2018). Bayesian model selection for exponential random graph models via adjusted pseudolikelihoods. Journal of Computational and Graphical Statistics, 27(3), 516-528. https://arxiv.org/abs/1706.06344

Examples

```
## Not run:
# Load the florentine marriage network:
data(florentine)

# MCMC sampling and evidence estimation:
CJE <- evidence(evidence.method = "CJ",
                formula     = flomarriage ~ edges + kstar(2),
                main.iters  = 30000,
                burn.in     = 2000,
                aux.iters   = 1000,
                num.samples = 25000,
                V.proposal  = 2.5,
                ladder      = 100,
                seed        = 1)

# Posterior summaries:
summary(CJE)

# MCMC diagnostics plots:
plot(CJE)

# Log-evidence (marginal likelihood) estimate:
CJE$log.evidence

## End(Not run)
```

`evidenceCJ` *Evidence estimation via Chib and Jeliazkov's method*

Description

Function to estimate the evidence (marginal likelihood) with Chib and Jeliazkov's method, based on the adjusted pseudolikelihood function.

Usage

```
evidenceCJ(
  formula,
  prior.mean = NULL,
  prior.sigma = NULL,
  aux.iters = 1000,
```

```
  n.aux.draws = 5,
  aux.thin = 50,
  ladder = 30,
  main.iters = 30000,
  burn.in = 5000,
  thin = 1,
  V.proposal = 1.5,
  num.samples = 25000,
  seed = 1,
  estimate = c("MLE", "CD"),
  ...
)
```

Arguments

formula	formula; an ergm formula object, of the form <network> ~ <model terms> where <network> is a network object and <model terms> are ergm-terms.
prior.mean	vector; mean vector of the multivariate Normal prior. By default set to a vector of 0's.
prior.sigma	square matrix; variance/covariance matrix for the multivariate Normal prior. By default set to a diagonal matrix with every diagonal entry equal to 100.
aux.iters	count; number of auxiliary iterations used for drawing the first network from the ERGM likelihood. See control.simulate.formula and ergmAPL.
n.aux.draws	count; number of auxiliary networks drawn from the ERGM likelihood. See control.simulate.formula and ergmAPL.
aux.thin	count; number of auxiliary iterations between network draws after the first network is drawn. See control.simulate.formula and ergmAPL.
ladder	count; length of temperature ladder (>=3). See ergmAPL.
main.iters	count; number of MCMC iterations after burn-in for the adjusted pseudo-posterior estimation.
burn.in	count; number of burn-in iterations at the beginning of an MCMC run for the adjusted pseudo-posterior estimation.
thin	count; thinning interval used in the simulation for the adjusted pseudo-posterior estimation. The number of MCMC iterations must be divisible by this value.
V.proposal	count; diagonal entry for the multivariate Normal proposal. By default set to 1.5.
num.samples	integer; number of samples used in the marginal likelihood estimate. Must be lower than main.iters - burnin.
seed	integer; seed for the random number generator. See set.seed and MCMCmetrop1R.
estimate	If "MLE" (the default), then an approximate maximum likelihood estimator is returned. If "CD" , the Monte-Carlo contrastive divergence estimate is returned. See ergm.
...	additional arguments, to be passed to the ergm function. See ergm and ergmAPL.

References

Caimo, A., & Friel, N. (2013). Bayesian model selection for exponential random graph models. Social Networks, 35(1), 11-24. https://arxiv.org/abs/1201.2337

Bouranis, L., Friel, N., & Maire, F. (2018). Bayesian model selection for exponential random graph models via adjusted pseudolikelihoods. Journal of Computational and Graphical Statistics, 27(3), 516-528. https://arxiv.org/abs/1706.06344

Examples

```
## Not run:
# Load the florentine marriage network:
data(florentine)

# MCMC sampling and evidence estimation:
CJE <- evidenceCJ(flomarriage ~ edges + kstar(2),
                  main.iters  = 2000,
                  burn.in     = 200,
                  aux.iters   = 500,
                  num.samples = 25000,
                  V.proposal  = 2.5)

# Posterior summaries:
summary(CJE)

# MCMC diagnostics plots:
plot(CJE)

# Log-evidence (marginal likelihood) estimate:
CJE$log.evidence

## End(Not run)
```

`evidencePP` *Evidence estimation via power posteriors*

Description

Function to estimate the evidence (marginal likelihood) with Power posteriors, based on the adjusted pseudolikelihood function.

Usage

```
evidencePP(
  formula,
  prior.mean = NULL,
  prior.sigma = NULL,
  aux.iters = 1000,
```

```
  n.aux.draws = 50,
  aux.thin = 50,
  ladder = 30,
  main.iters = 20000,
  burn.in = 5000,
  thin = 1,
  V.proposal = 1.5,
  seed = 1,
  temps = NULL,
  estimate = c("MLE", "CD"),
  ...
)
```

Arguments

formula	formula; an ergm formula object, of the form <network> ~ <model terms> where <network> is a network object and <model terms> are ergm-terms.
prior.mean	vector; mean vector of the multivariate Normal prior. By default set to a vector of 0's.
prior.sigma	square matrix; variance/covariance matrix for the multivariate Normal prior. By default set to a diagonal matrix with every diagonal entry equal to 100.
aux.iters	count; number of auxiliary iterations used for drawing the first network from the ERGM likelihood. See control.simulate.formula and ergmAPL.
n.aux.draws	count; number of auxiliary networks drawn from the ERGM likelihood. See control.simulate.formula and ergmAPL.
aux.thin	count; number of auxiliary iterations between network draws after the first network is drawn. See control.simulate.formula and ergmAPL.
ladder	count; length of temperature ladder (>=3). See ergmAPL.
main.iters	count; number of MCMC iterations after burn-in for the adjusted pseudo-posterior estimation.
burn.in	count; number of burn-in iterations at the beginning of an MCMC run for the adjusted pseudo-posterior estimation.
thin	count; thinning interval used in the simulation for the adjusted pseudo-posterior estimation. The number of MCMC iterations must be divisible by this value.
V.proposal	count; diagonal entry for the multivariate Normal proposal. By default set to 1.5.
seed	integer; seed for the random number generator. See set.seed and MCMCmetrop1R.
temps	numeric vector; inverse temperature ladder, $t \in [0, 1]$.
estimate	If "MLE" (the default), then an approximate maximum likelihood estimator is returned. If "CD" , the Monte-Carlo contrastive divergence estimate is returned. See ergm.
...	additional arguments, to be passed to the ergm function. See ergm and ergmAPL.

References

Bouranis, L., Friel, N., & Maire, F. (2018). Bayesian model selection for exponential random graph models via adjusted pseudolikelihoods. Journal of Computational and Graphical Statistics, 27(3), 516-528. https://arxiv.org/abs/1706.06344

Examples

```
## Not run:
# Load the florentine marriage network:
data(florentine)

PPE <- evidencePP(flomarriage ~ edges + kstar(2),
                  aux.iters   = 500,
                  noisy.nsim  = 50,
                  aux.thin    = 50,
                  main.iters  = 2000,
                  burn.in     = 100,
                  V.proposal  = 2.5)

# Posterior summaries:
summary(PPE)

# MCMC diagnostics plots:
plot(PPE)

# Log-evidence (marginal likelihood) estimate:
PPE$log.evidence

## End(Not run)
```

---

lazega *Lazega lawyers network data*

Description

Lazega lawyers network data

Usage

```
lazega
```

Format

An oject of class `network`.

Source

This network dataset comes from a network study of corporate law partnership that was carried out in a Northeastern US corporate law firm in New England from 1988 to 1991. It represents collaborative relations among the 36 attorneys (partners and associates) of this firm. Nodal attributes include: Age, Gender, Office, Practice, School, and Years.

References

Lazega, E. (2001), "The Collegial Phenomenon: The Social Mechanisms of Cooperation Among Peers in a Corporate Law Partnership," Oxford University Press.

Examples

```
## Not run:
 par(mfrow = c(1, 2), oma = rep(0, 4))
 CC <- hcl.colors(3, "Teal")
 set.seed(22)
 plot(lazega,
      vertex.col = CC[lazega %v% "Office"],
     vertex.cex = 2)
 legend("topright",
        pch    = 21,
        pt.bg  = CC,
        legend = c("Boston", "Hartford", "Providence"),
        title  = "OFFICE")

## End(Not run)
```

---

plot.bergm *Plot BERGM posterior output*

Description

This function creates MCMC diagnostic plots for `bergm` objects.

Usage

```
## S3 method for class 'bergm'
plot(x, ...)
```

Arguments

`x`	an `R` object of class `bergm`.
`...`	additional arguments, to be passed to lower-level functions.

Examples

```
## Not run:
# Load the florentine marriage network
data(florentine)

# Posterior parameter estimation:
p.flo <- bergm(flomarriage ~ edges + kstar(2),
               burn.in    = 50,
               aux.iters  = 500,
               main.iters = 1000,
               gamma      = 1.2)

# MCMC diagnostics plots:
plot(p.flo)

## End(Not run)
```

---

summary.bergm *Summary of BERGM posterior output*

Description

This function summarises MCMC output for bergm objects.

Usage

```
## S3 method for class 'bergm'
summary(object, ...)
```

Arguments

object	an R object of class bergm.
...	additional arguments, to be passed to lower-level functions.

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