Package 'ctmcd'

July 22, 2025

Type Package

Title Estimating the Parameters of a Continuous-Time Markov Chain from Discrete-Time Data

Version 1.4.4

Date 2024-02-07

Description
Estimation of Markov generator matrices from discrete-time observations. The implemented approaches comprise diagonal and weighted adjustment of matrix logarithm based candidate solutions as in Israel (2001) <doi:10.1111/1467-9965.00114> as well as a quasi-optimization approach. Moreover, the expectation-maximization algorithm and the Gibbs sampling approach of Bladt and Sorensen (2005) <doi:10.1111/j.1467-9868.2005.00508.x> are included.

License GPL-3

Imports Rcpp (>= 1.0.12), coda, expm, numDeriv

Suggests knitr, rmarkdown, R.rsp

LinkingTo Rcpp, RcppArmadillo

VignetteBuilder knitr, R.rsp

NeedsCompilation yes

Author Marius Pfeuffer [aut, cre],
Greig Smith [ctb],
Goncalo dos Reis [ctb],
Linda Moestel [ctb],
Matthias Fischer [ctb]

Maintainer Marius Pfeuffer <marius.pfeuffer@fau.de>

Repository CRAN

Date/Publication 2024-02-09 09:40:02 UTC

Contents

`ctmcd-package` *Estimating the Parameters of a Continuous-Time Markov Chain from Discrete-Time Data*

Description

Functions for estimating Markov generator matrices from discrete-time observations.

Author(s)

Marius Pfeuffer [aut, cre], Greig Smith [ctb], Goncalo dos Reis [ctb], Linda Moestel [ctb], Matthias Fischer [ctb]

Maintainer: Marius Pfeuffer <marius.pfeuffer@fau.de>

References

M. Pfeuffer: ctmcd: An R Package for Estimating the Parameters of a Continuous-Time Markov Chain from Discrete-Time Data. The R Journal 9(2):127-141, 2017

M. Pfeuffer. Generator Matrix Approximation Based on Discrete-Time Rating Migration Data. Master Thesis, Ludwig Maximilian University of Munich, 2016

R. B. Israel et al.: Finding Generators for Markov Chains via Empirical Transition Matrices, with Applications to Credit Ratings. Mathematical Finance 11(2):245-265, 2001

E. Kreinin and M. Sidelnikova: Regularization Algorithms for Transition Matrices. Algo Research Quarterly 4(1):23-40, 2001

M. Bladt and M. Soerensen: Statistical Inference for Discretely Observed Markov Jump Processes. Journal of the Royal Statistical Society B 67(3):395-410, 2005

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)
plot(gmem)

## Confidence Interval
ciem=gmci(gmem,alpha=0.05)
plot(ciem)
```

---

ctmcdlogLik *Discrete-Time Data Log-Likelihood Function*

Description

Function for evaluating the likelihood function of a continuous-time Markov chain given discrete-time data.

Usage

```
ctmcdlogLik(gm, tmabs, te)
```

Arguments

gm	generator matrix of continuous-time Markov chain
tmabs	matrix of absolute transition frequencies
te	time elapsed in transition process

Value

log-likelihood value

Author(s)

Marius Pfeuffer

Examples

```
data(tm_abs)

## Initial guess for generator matrix (absorbing default state)
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

## Log-likelihood of initial guess
ctmcdlogLik(gm0,tm_abs,1)
```

`gm` *Generator Matrix Estimation*

Description

Generic function to estimate the parameters of a continuous Markov chain

Usage

```
gm(tm, te, method, ...)
```

Arguments

`tm`	matrix of either absolute transition frequencies (if method is "EM" or "GS") or relative transition frequencies (if method is "DA", "WA" of "QO")
`te`	time elapsed in transition process
`method`	method to derive generator matrix: "DA" - Diagonal Adjustment, "WA" - Weighted Adjustment, "QO" - Quasi-Optimization, "EM" - Expectation-Maximization Algorithm, "GS" - Gibbs Sampler
`...`	Additional Arguments: • gmguess: initial guess for generator matrix estimation procedure (if method is "EM") • prior: prior parametrization (if method is "GS") • burnin: burn-in period (if method is "GS") • eps: convergence criterion (if method is "EM") • conv_pvalue,conv_freq: convergence criterion (if method is "GS") • niter: maximum number of iterations (if method is "EM" or "GS") • sampl_func: optional self-written path sampling function for endpoint-conditioned Markov processes (if method is "GS") • combmat: matrix stating combined use of modified rejection sampling / uniformization sampling algorithms (if method is "GS") • sampl_method: sampling method for deriving endpoint-conditioned Markov process path: "Unif" - Uniformization Sampling, "ModRej" - Modified Rejection Sampling (if method is "GS")

- logmethod: method to compute matrix logarithm (if method is "DA", "WA" or "QO", see `?logm` from `expm` package for more information)
- expmethod: method to compute matrix exponential (if method is "EM" or "GS", see `?expm` from `expm` package for more information)
- verbose: verbose mode (if method is "EM" or "GS")

Details

The methods "DA", "WA" and "QO" provide adjustments of a matrix logarithm based candidate solution, "EM" gives the maximum likelihood estimate and "GS" a posterior mean estimate in a Bayesian setting with conjugate Gamma priors.

Value

generator matrix estimate

Author(s)

Marius Pfeuffer

References

G. dos Reis, M. Pfeuffer, G. Smith: Capturing Rating Momentum in the Estimation of Probabilities of Default, With Application to Credit Rating Migrations (In Preparation), 2018

M. Pfeuffer: Generator Matrix Approximation Based on Discrete Time Rating Migration Data. Master Thesis, University of Munich, 2016

Y. Inamura: Estimating Continuous Time Transition Matrices from Discretely Observed Data. Bank of Japan Working Paper Series, 2006

R. B. Israel et al.: Finding Generators for Markov Chains via Empirical Transition Matrices, with Applications to Credit Ratings. Mathematical Finance 11(2):245-265, 2001

E. Kreinin and M. Sidelnikova: Regularization Algorithms for Transition Matrices. Algo Research Quarterly 4(1):23-40, 2001

M. Bladt and M. Soerensen: Statistical Inference for Discretely Observed Markov Jump Processes. Journal of the Royal Statistical Society B 67(3):395-410, 2005

See Also

gmDA, gmWA, gmQO, gmEM, gmGS

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0
```

```
gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)
gmem

## Quasi Optimization Estimate
tm_rel=rbind((tm_abs/rowSums(tm_abs))[1:7,],c(rep(0,7),1))

gmqo=gm(tm_rel,te=1,method="QO")
gmqo
```

`gm.default` *Generator Matrix Estimation*

Description

Default function to estimate the parameters of a continuous Markov chain

Usage

```
## Default S3 method:
gm(tm, te, method, gmguess = NULL, prior = NULL, burnin = NULL,
eps = 1e-06, conv_pvalue = 0.05, conv_freq = 10, niter = 10000, sampl_func = NULL,
combmat = NULL, sampl_method = "Unif", logmethod = "Eigen", expmethod = "PadeRBS",
verbose = FALSE, ...)
```

Arguments

`tm`	matrix of either absolute transition frequencies (if method is "EM" or "GS") or relative transition frequencies (if method is "DA", "WA" of "QO")
`te`	time elapsed in transition process
`method`	method to derive generator matrix: "DA" - Diagonal Adjustment, "WA" - Weighted Adjustment, "QO" - Quasi-Optimization, "EM" - Expectation-Maximization Algorithm, "GS" - Gibbs Sampler
`gmguess`	initial guess for generator matrix estimation procedure (if method is "EM")
`prior`	prior parametrization (if method is "GS")
`burnin`	burn-in period (if method is "GS")
`eps`	convergence criterion (if method is "EM" or "GS")
`conv_pvalue`	convergence criterion: stop, if Heidelberger and Welch's diagnostic assumes convergence (see coda package)
`conv_freq`	convergence criterion: absolute frequency of convergence evaluations
`niter`	maximum number of iterations (if method is "EM" or "GS")
`sampl_func`	optional self-written path sampling function for endpoint-conditioned Markov processes (if method is "GS")
`combmat`	matrix stating combined use of modified rejection sampling / uniformization sampling algorithms (if method is "GS")

sampl_method	sampling method for deriving endpoint-conditioned Markov process path: "Unif" - Uniformization Sampling, "ModRej" - Modified Rejection Sampling (if method is "GS")
logmethod	method to compute matrix logarithm (if method is "DA", "WA" or "QO", see ?logm from expm package for more information)
expmethod	method to compute matrix exponential (if method is "EM" or "GS", see ?expm from expm package for more information)
verbose	verbose mode (if method is "EM" or "GS")
...	additional arguments

Details

The methods "DA", "WA" and "QO" provide adjustments of a matrix logarithm based candidate solution, "EM" gives the maximum likelihood estimate and "GS" a posterior mean estimate in a Bayesian setting with conjugate Gamma priors.

Value

generator matrix estimate

Author(s)

Marius Pfeuffer

References

M. Pfeuffer: Generator Matrix Approximation Based on Discrete Time Rating Migration Data. Master Thesis, University of Munich, 2016

Y. Inamura: Estimating Continuous Time Transition Matrices from Discretely Observed Data. Bank of Japan Working Paper Series, 2006

R. B. Israel et al.: Finding Generators for Markov Chains via Empirical Transition Matrices, with Applications to Credit Ratings. Mathematical Finance 11(2):245-265, 2001

E. Kreinin and M. Sidelnikova: Regularization Algorithms for Transition Matrices. Algo Research Quarterly 4(1):23-40, 2001

M. Bladt and M. Soerensen: Statistical Inference for Discretely Observed Markov Jump Processes. Journal of the Royal Statistical Society B 67(3):395-410, 2005

See Also

gmDA, gmWA, gmQO, gmEM, gmGS

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
```

```
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)
gmem

## Quasi Optimization Estimate
tm_rel=rbind((tm_abs/rowSums(tm_abs))[1:7,],c(rep(0,7),1))

gmqo=gm(tm_rel,te=1,method="QO")
gmqo
```

---

gmci *Confidence / Credibility Intervals for Generator Matrix Objects*

Description

Generic function to derive confidence / credibility intervals for "EM" or "GS" based generator matrix objects

Usage

```
gmci(gm, alpha, ...)
```

Arguments

gm	a "EM" or "GS" generator matrix object
alpha	significance level
...	additional arguments:

- eps: threshold for which generator matrix parameters are assumed to be fixed at zero (if "EM" object)
- cimethod: "Direct" and "SdR" use analytical expressions of the Fisher information matrix, "BS" employs the numerical approach of Bladt and Soerensen, 2009 (if "EM" object)
- expmethod: method to compute matrix exponentials (see ?expm from expm package for more information)

Details

If gm is based on the "EM" method (expectation-maximization algorithm), the function computes a Wald confidence interval based on the method of Oakes, 1999. IF gm is based on the "GS" method (Gibbs sampler), the function computes an equal-tailed credibility interval.

Value

generator matrix confidence bounds

Author(s)

Marius Pfeuffer

References

M. Bladt and M. Soerensen. Efficient Estimation of Transition Rates Between Credit Ratings from Observations at Discrete Time Points. Quantitative Finance, 9(2):147-160, 2009

D. Oakes. Direct calculation of the information matrix via the EM algorithm. Journal of the Royal Statistical Society: Series B (Statistical Methodology), 61(2):479-482, 1999

G. Smith and G. dos Reis. Robust and Consistent Estimation of Generators in Credit Risk. Quantitative Finance 18(6):983-1001, 2018

G. dos Reis, M. Pfeuffer, G. Smith: Capturing Rating Momentum in the Estimation of Probabilities of Default, With Application to Credit Rating Migrations (In Preparation), 2018

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)

## Oakes Confidence Interval
ciem=gmci(gmem,alpha=0.05)
ciem
```

---

gmci.default *Confidence / Credibility Intervals for Generator Matrix Objects*

Description

Default function to derive confidence / credibility intervals for "EM" or "GS" based generator matrix objects

Usage

```
## Default S3 method:
gmci(gm, alpha, eps = 1e-04, cimethod="Direct", expmethod = "PadeRBS", ...)
```

Arguments

gm	a "EM" or "GS" generator matrix object
alpha	significance level
eps	threshold for which generator matrix parameters are assumed to be fixed at zero (if "EM" object)
cimethod	"Direct" or "SdR" use analytical expressions of the Fisher information matrix, "BS" emloy the numerical expressions of Bladt and Soerensen, 2009 (if "EM" object)
expmethod	method to compute matrix exponentials (see ?expm from expm package for more information)
...	additional arguments

Details

If gm is based on the "EM" method (expectation-maximization algorithm), the function computes a Wald confidence interval based on the method of Oakes, 1999. IF gm is based on the "GS" method (Gibbs sampler), the function computes an equal-tailed credibility interval.

Value

generator matrix confidence bounds

Author(s)

Marius Pfeuffer

References

G. dos Reis, M. Pfeuffer, G. Smith: Capturing Rating Momentum in the Estimation of Probabilities of Default, With Application to Credit Rating Migrations (In Preparation), 2018

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)

## Oakes Confidence Interval
ciem=gmci(gmem,alpha=0.05)
ciem
```

gmDA *Diagonal Adjustment*

Description

Function for deriving a Markov generator matrix estimate based on the diagonal adjustment method of Israel et al., 2001

Usage

```
gmDA(tmrel, te, logmethod = "Eigen")
```

Arguments

tmrel	matrix of relative transition frequencies
te	time elapsed in transition process
logmethod	method for computation of matrix logarithm, by default eigendecomposition is chosen (see ?logm from expm package for more information)

Details

A candidate solution is derived by the matrix logarithm and then adjusted in order to fulfil the properties of a Markov generator matrix.

Value

generator matrix estimate

Author(s)

Marius Pfeuffer

References

R. B. Israel et al.: Finding Generators for Markov Chains via Empirical Transition Matrices, with Applications to Credit Ratings. Mathematical Finance 11(2):245-265, 2001

Examples

```
## Derive matrix of relative transition frequencies
data(tm_abs)
tm_rel=rbind((tm_abs/rowSums(tm_abs))[1:7,],c(rep(0,7),1))

## Derive diagonal adjustment generator matrix estimate
gmda=gmDA(tm_rel,1)
gmda
```

gmEM *Expectation-Maximization Algorithm*

Description

Function for deriving a Markov generator matrix estimate by an instance of the expectation-maximization algorithm (described by Bladt and Soerensen, 2005)

Usage

```
gmEM(tmabs, te, gmguess, eps = 1e-06, niter = 10000, expmethod = "PadeRBS",
verbose = FALSE)
```

Arguments

tmabs	matrix of absolute transition frequencies
te	time elapsed in transition process
gmguess	initial guess (for generator matrix)
eps	stop criterion: stop, if relative change in log-likelihood is smaller than eps
niter	stop criterion: maximum number of iterations
expmethod	method for computation of matrix exponential, by default "PadeRBS" is chosen (see ?expm from expm package for more information)
verbose	verbose mode

Details

A maximum likelihood generator matrix estimate is derived by an instance of the expectation-maximization algorithm.

Value

generator matrix estimate

Author(s)

Marius Pfeuffer

References

M. Bladt and M. Soerensen: Statistical Inference for Discretely Observed Markov Jump Processes. Journal of the Royal Statistical Society B 67(3):395-410, 2005

Examples

```
data(tm_abs)

## Initial guess for generator matrix (absorbing default state)
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

## Derive expectation-maximization algorithm generator matrix estimate
gmem=gmEM(tmabs=tm_abs,1,gmguess=gm0,verbose=TRUE)
gmem
```

---

gmGS *Gibbs Sampler*

Description

Function for deriving a Markov generator matrix estimate by Gibbs sampling (described by Bladt and Soerensen, 2005)

Usage

```
gmGS(tmabs, te, prior, burnin, conv_pvalue = 0, conv_freq = 10,
niter = 10000, sampl_method = "Unif", expmethod = "PadeRBS", verbose = FALSE,
combmat=NULL, sampl_func = NULL)
```

Arguments

tmabs	matrix of absolute transition frequencies
te	time elapsed in transition process
prior	list of prior parameters (Gamma prior)
burnin	number of burn-in iterations
conv_pvalue	convergence criterion: stop, if Heidelberger and Welch's diagnostic assumes convergence (see coda package), convergence check is only employed if conv_pvalue>0
conv_freq	convergence criterion: absolute frequency of convergence evaluations
niter	stop criterion: stop, if maximum number of iterations is exceeded
sampl_method	method for sampling paths from endpoint-conditioned Markov processes. options: "Unif" - Uniformization sampling, "ModRej" - Modified Rejection Sampling
expmethod	method for computation of matrix exponential, by default "PadeRBS" is chosen (see ?expm from expm package for more information)
verbose	verbose mode
combmat	matrix specifying the combined use of sampling methods: "U" - uniformization sampling, "M" - modified rejection sampling
sampl_func	interface for own endpoint-conditioned Markov process sampling function

Details

A posterior mean generator matrix estimate is derived by Gibbs Sampling. The gamma distribution is used as prior.

Value

generator matrix estimate

Author(s)

Marius Pfeuffer

References

M. Bladt and M. Soerensen: Statistical Inference for Discretely Observed Markov Jump Processes. Journal of the Royal Statistical Society B 67(3):395-410, 2005

See Also

rNijTRiT_ModRej, rNijTRiT_Unif

Examples

```
data(tm_abs)

## Example prior parametrization (absorbing default state)
pr=list()
pr[[1]]=matrix(1,8,8)
pr[[1]][8,]=0

pr[[2]]=c(rep(5,7),Inf)

## Derive Gibbs sampling generator matrix estimate

gmgs=gmGS(tmabs=tm_abs,te=1,sampl_method="Unif",prior=pr,burnin=10,niter=100,verbose=TRUE)
gmgs
```

---

gmQO *Quasi-Optimization*

Description

Function for deriving a Markov generator matrix estimate based on the quasi-optimization procedure of Kreinin and Sidelnikova, 2001

Usage

```
gmQO(tmrel, te, logmethod = "Eigen")
```

Arguments

tmrel	matrix of relative transition frequencies
te	time elapsed in transition process
logmethod	method for computation of matrix logarithm, by default eigendecomposition is chosen (see ?logm from expm package for more information)

Details

From the set of possible Markov generator matrices, the one is chosen which is closest to a matrix logarithm based candidate solution in terms of sum of squared deviations.

Value

generator matrix estimate

Author(s)

Marius Pfeuffer

References

E. Kreinin and M. Sidelnikova: Regularization Algorithms for Transition Matrices. Algo Research Quarterly 4(1):23-40, 2001

Examples

```
data(tm_abs)
## Derive matrix of relative transition frequencies
data(tm_abs)
tm_rel=rbind((tm_abs/rowSums(tm_abs))[1:7,],c(rep(0,7),1))

## Derive quasi optimization generator matrix estimate
gmqo=gmQO(tm_rel,1)
gmqo
```

---

gmWA *Weighted Adjustment*

Description

Function for deriving a Markov generator matrix estimate based on the weighted adjustment method of Israel et al., 2001

Usage

```
gmWA(tmrel, te, logmethod = "Eigen")
```

Arguments

tmrel	matrix of relative transition frequencies
te	time elapsed in transition process
logmethod	method for computation of matrix logarithm, by default eigendecomposition is chosen (see ?logm from expm package for more information)

Details

A candidate solution is derived by the matrix logarithm and then adjusted in order to fulfil the properties of a Markov generator matrix.

Value

generator matrix estimate

Author(s)

Marius Pfeuffer

References

R. B. Israel et al.: Finding Generators for Markov Chains via Empirical Transition Matrices, with Applications to Credit Ratings. Mathematical Finance 11(2):245-265, 2001

Examples

```
## Derive matrix of relative transition frequencies
data(tm_abs)
tm_rel=rbind((tm_abs/rowSums(tm_abs))[1:7,],c(rep(0,7),1))

## Derive weighted adjustment generator matrix estimate
gmwa=gmWA(tm_rel,1)
gmwa
```

---

plot.gm *Plot Function for Generator Matrix Estimation Objects*

Description

Function for visualizing the output of a generator matrix estimation procedure.

Usage

```
## S3 method for class 'gm'
plot(x, mattext, col = c("grey", "red"), main = x$method, las = 1,
xlab = "To", ylab = "From", xnames, ynames, cex = 1, fig = 3, opacity_factor, ...)
```

Arguments

x	a generator matrix estimation object
mattext	optional: matrix of strings replacing the parameter estimates
col	two element vector of basis colors for positive and negative parameter estimate entries
main	optional: plot title
las	orientation of x and y axis elements
xlab	x axis name
ylab	y axis name
xnames	description of x axis elements
ynames	description of y axis elements
cex	font size
fig	number of significant figure to be plotted
opacity_factor	two element vector for specification of opacity for positive and negative parameter entry highlighting (must be greater than zero)
...	additional arguments

Value

no value, plot function

Author(s)

Marius Pfeuffer

See Also

print.gm, summary.gm, plotM

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)
plot(gmem)
```

plot.gmci *Plot Function for Generator Matrix Confidence / Credibility Interval Objects*

Description

Function for visualizing the boundaries of generator matrix confidence / credibility intervals

Usage

```
## S3 method for class 'gmci'
plot(x, mattext, col = c("grey", "red"), main, las = 1, xlab = "To",
ylab = "From", xnames, ynames, cex = 1, fig = 2, opacity_factor, ...)
```

Arguments

x	a generator matrix confidence / credibility interval object
mattext	optional: matrix of strings replacing the parameter estimates
col	two element vector of basis colors for positive and negative parameter estimate entries
main	optional: plot title
las	orientation of x and y axis elements
xlab	x axis name
ylab	y axis name
xnames	description of x axis elements
ynames	description of y axis elements
cex	font size
fig	number of significant figures to be plotted
opacity_factor	two element vector for specification of opacity for positive and negative parameter entry highlighting (must be greater than zero)
...	additional arguments

Value

no value, plot function

Author(s)

Marius Pfeuffer

See Also

print.gmci, plotM

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)
plot(gmem)

## Confidence Interval
ciem=gmci(gmem,alpha=0.05)
plot(ciem)
```

---

plotM *Matrix Plot Function*

Description

Function to visualize matrices

Usage

```
plotM(mat, mattext, col = c("grey", "red"), main, las = 1, xlab = "To",
ylab = "From", xnames, ynames, cex = min(1, nrow(mat)/8), fig = 3, opacity_factor)
```

Arguments

mat	a matrix
mattext	optional: matrix of strings replacing the original matrix entries
col	two element vector of basis colors for positive and negative matrix entries
main	optional: plot title
las	orientation of x and y axis elements
xlab	x axis name
ylab	y axis name
xnames	description of x axis elements
ynames	description of y axis elements
cex	font size
fig	number of significant figures to be plotted
opacity_factor	two element vector for specification of opacity for positive and negative parameter entry highlighting (must be greater than zero)

Value

no value, plot function

Author(s)

Marius Pfeuffer

See Also

plot.gm, plot.gmci

Examples

```
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

plotM(gm0)
```

---

print.gm *Print Method for Generator Matrix Estimation Objects*

Description

Function for printing the results of a generator matrix estimation

Usage

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

Arguments

x	a generator matrix estimation object
...	additional arguments

Value

generator matrix

See Also

summary.gm, plot.gm

print.gmci *Print Method for Generator Matrix Confidence / Credibility Interval Objects*

Description

Function for printing the boundaries of a generator matrix confidence / credibility interval

Usage

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

Arguments

x	a generator matrix confidence / credibility interval
...	additional arguments

Value

generator matrix confidence bounds

See Also

plot.gmci

rNijTRiT_ModRej *C++ Based Modified Rejection Sampling*

Description

Function for generating initial and endpoint-conditioned Markov process sampling paths for a given discrete-time transition matrix

Usage

```
rNijTRiT_ModRej(tmabs, te, gm)
```

Arguments

tmabs	matrix of absolute transition frequencies
te	time elapsed in transition process
gm	generator matrix

Details

Function for the simulation of paths from an endpoint-conditioned Markov process. Returns number of transitions NijT and cumulative holding times RiT.

Value

endpoint-conditioned sampling path

Author(s)

Jon Fintzi, Marius Pfeuffer

References

J. Fintzi: R Package ECctmc, 2016.

A. Hobolth and E. A. Stone: Simulation from Endpoint-Conditioned, Continuous-Time Markov Chains on a Finite State Space, with Applications to Molecular Evolution. Annals of Applied Statistics 3(3):1204-1231, 2009

Examples

```
data(tm_abs)

## Initial guess for generator matrix (absorbing default state)

gm=matrix(1,8,8)
diag(gm)=0
diag(gm)=-rowSums(gm)
gm[8,]=0

rNijTRiT_ModRej(tm_abs,1,gm)
```

---

rNijTRiT_Unif *C++ Based Uniformization Sampling*

Description

Function for generating initial and endpoint-conditioned Markov process sampling paths for a given discrete-time transition matrix

Usage

```
rNijTRiT_Unif(tmabs, te, gm, tpm)
```

Arguments

tmabs	matrix of absolute transition frequencies
te	time elapsed in transition process
gm	generator matrix
tpm	discrete-time transition probability matrix, matrix exponential of gm

Details

Function for the simulation of paths from an endpoint-conditioned Markov process. Returns number of transitions NijT and cumulative holding times RiT.

Value

endpoint-conditioned sampling path

Author(s)

Jon Fintzi, Marius Pfeuffer

References

J. Fintzi: R Package ECctmc, 2016.

A. Hobolth and E. A. Stone: Simulation from Endpoint-Conditioned, Continuous-Time Markov Chains on a Finite State Space, with Applications to Molecular Evolution. Annals of Applied Statistics 3(3):1204-1231, 2009

Examples

```
data(tm_abs)

## Generator Matrix
gm=matrix(1,8,8)
diag(gm)=0
diag(gm)=-rowSums(gm)
gm[8,]=0

## Transition Probability Matrix
library(expm)
te=1
tpm=expm(gm*te)

rNijTRiT_Unif(tm_abs,te,gm,tpm)
```

summary.gm — *Extended Output for Generator Matrix Estimate Objects*

Description

Function for providing results and extended output of a generator matrix estimation procedure.

Usage

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

Arguments

object	a generator matrix estimation object
...	additional arguments

Value

estimation summary

See Also

print.gm, plot.gm

tmci — *Delta Method Confidence Intervals for Matrix Exponential Transformations of Generator Matrix Objects*

Description

Generic function to derive delta method based confidence intervals for matrix exponential transformations of "EM" based generator matrix objects

Usage

```
tmci(gmem, alpha, te, eps = 1e-04, expmethod = "PadeRBS")
```

Arguments

gmem	an "EM" generator matrix object
alpha	significance level
te	discrete time horizon for which the interval is supposed to be computed
eps	threshold for which generator matrix parameters are assumed to be fixed at zero
expmethod	method to compute matrix exponentials (see ?expm from expm package for more information)

Details

Confidence intervals for discrete-time transition matrix predictions given generator matrix estimates are computed by using the delta method for matrix exponential transformations.

Value

transition matrix confidence bounds

References

G. dos Reis, M. Pfeuffer, G. Smith: Capturing Rating Momentum in the Estimation of Probabilities of Default, With Application to Credit Rating Migrations (In Preparation), 2018

Examples

```
data(tm_abs)

## Maximum Likelihood Generator Matrix Estimate
gm0=matrix(1,8,8)
diag(gm0)=0
diag(gm0)=-rowSums(gm0)
gm0[8,]=0

gmem=gm(tm_abs,te=1,method="EM",gmguess=gm0)

## 2.5 Year Transition Matrix Confidence Interval
citm=tmci(gmem,alpha=0.05,te=2.5)
citm
```

---

tm_abs *Single Year Corporate Credit Rating Transitions*

Description

Matrix of Standard and Poor's Global Corporate Rating Transition Frequencies 2000 (NR Removed)

Usage

```
data("tm_abs")
```

Format

The format is: num [1:8, 1:8] 17 2 0 0 0 0 0 0 1 455 ... - attr(*, "dimnames")=List of 2 ..$: chr [1:8] "AAA" "AA" "A" "BBB" ... ..$: chr [1:8] "AAA" "AA" "A" "BBB" ...

References

European Securities and Markets Authority, 2016

https://cerep.esma.europa.eu/cerep-web/statistics/transitionMatrice.xhtml

Examples

```
data(tm_abs)

## Matrix of relative transition frequencies
tm_rel=rbind((tm_abs/rowSums(tm_abs))[1:7,],c(rep(0,7),1))
tm_rel
```

Index