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

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Description Functions for estimating Markov generator matrices from discrete-time observations. The implemented approaches comprise diagonal adjustment, weighted adjustment and quasi-optimization of matrix logarithm based candidate solutions, an expectation-maximization algorithm as well as a Gibbs sampler.

License GPL-3

Imports Rcpp (>= 0.12.13), coda, expm, numDeriv

Suggests knitr, rmarkdown, R.rsp, markovchain

LinkingTo Rcpp, RcppArmadillo

VignetteBuilder knitr, R.rsp

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`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]

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 (To Appear), 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

```
## Not run:
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)

## End(Not run)
```

`ciEMBS` *Wald Confidence Interval*

Description

Function to derive a Wald confidence interval for expectation-maximization based maximum likelihood generator matrix estimate. The Fisher information estimation method of Oakes, 1999 is employed and the numerical expressions of Bladt and Soerensen, 2009 are used.

Usage

```
ciEMBS(x, alpha, eps = 1e-04, expmethod = "PadeRBS")
```

Arguments

`x`	expectation-maximization output object
`alpha`	significance level
`eps`	threshold for which generator matrix parameters are assumed to be fixed at zero
`expmethod`	method for computation of matrix exponential, by default "PadeRBS" is chosen (see `?expm` from `expm` package for more information)

Details

Computation of confidence interval on the basis of the last iteration of the expectation-maximization algorithm.

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 B 61(2):479-482, 1999

Examples

```
## Not run:
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=gm(tm=tm_abs,te=1,method="EM",gmguess=gm0,verbose=TRUE)

## derive confidence interval
ciem=ciEMBS(gmem, alpha=0.05)
ciem

## End(Not run)
```

`ciEMSdR` *Wald Confidence Interval*

Description

Function to derive a Wald confidence interval for expectation-maximization based maximum likelihood generator matrix estimate. The Fisher information estimation method of Oakes, 1999 is employed and the analytical expressions of Smith and dos Reis, 2017 are used.

Usage

```
ciEMSdR(x, alpha, eps = 1e-04, expmethod = "PadeRBS")
```

Arguments

`x`	expectation-maximization output object
`alpha`	significance level
`eps`	threshold for which generator matrix parameters are assumed to be fixed at zero
`expmethod`	method for computation of matrix exponential, by default "PadeRBS" is chosen (see `?expm` from `expm` package for more information)

Details

Computation of confidence interval on the basis of the last iteration of the expectation-maximization algorithm.

Author(s)

Greig Smith, Goncalo dos Reis, 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 B 61(2):479-482, 1999

G. Smith and G. dos Reis. Robust and Consistent Estimation of Generators in Credit Risk. Quantitative Finance (To Appear), 2017

Examples

```
## Not run:
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=gm(tm=tm_abs,te=1,method="EM",gmguess=gm0,verbose=TRUE)

## derive confidence interval
ciem=ciEMSdR(gmem, alpha=0.05)
ciem

## End(Not run)
```

---

ciGS *Equal Tailed Credibility Interval*

Description

Function to derive an equal-tailed credibility interval from Gibbs sampling draws as described by Bladt and Soerensen, 2009.

Usage

```
ciGS(x, alpha)
```

Arguments

x	Gibbs sampling output object
alpha	significance level

Details

Computation of credibility interval es empirical quantiles of Gibbs sampling draws.

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

Examples

```
## Not run:
data(tm_abs)

## Prior
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=gm(tm=tm_abs,te=1,method="GS",sampl_method="Unif",prior=pr,burnin=10,niter=100)

cigs=ciGS(gmgs,alpha=.05)
cigs

## End(Not run)
```

---

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

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)
```

---

expmMC *Matrix Exponential Function*

Description

Computation of the matrix exponential and interface to the markovchain package

Usage

```
expmMC(gm, t, method = "PadeRBS", order = 8)
```

Arguments

gm	generator matrix (either gm or matrix object)
t	time horizon
method	method to compute the matrix exponential, see expm for details
order	order for Pade or Taylor method, see expm for details

Details

An interface to the markovchain package is provided so that the resulting transition matrices are returned as markovchain objects and can be further processed in the markovchain package, e.g., visualized (see example below).

Author(s)

G. A. Spedicato, M. Pfeuffer

References

G. A. Spedicato: Discrete Time Markov Chains with R. The R Journal (To Appear), 2017

See Also

expm

Examples

```
### Exemplary Transition Matrix
tm0=matrix(1:16,4,4)
tm0=tm0/rowSums(tm0)
tm0[4,]=c(0,0,0,1)

### Generator Matrix Estimate
gm_est=gm(tm0,te=1,method="DA")
gm_est

### Matrix Exponential and Conversion to markovchain object
### (markovchain package needs to be installed)
mc=expmMC(gm_est,.5)
if(require("markovchain")==TRUE){
  plot(mc)
}
```

---

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.

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
```

---

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.

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: "SdR" for using the analytical expressions of Smith and dos Reis, 2017 or "BS" for 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)

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.

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 (To Appear), 2017

See Also

ciEMSdR, ciEMBS, ciGS

Examples

```
## Not run:
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

## End(Not run)
```

---

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="SdR", 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	"SdR" for using the analytical expressions of Smith and dos Reis, 2017 or "BS" for 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.

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 (To Appear), 2017

See Also

ciEMSdR, ciEMBS, ciGS

Examples

```
## Not run:
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

## End(Not run)
```

---

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.

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.

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.

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
## Not run:
gmgs=gmGS(tmabs=tm_abs,te=1,sampl_method="Unif",prior=pr,burnin=10,niter=100,verbose=TRUE)
gmgs

## End(Not run)
```

---

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.

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.

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

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

Author(s)

Marius Pfeuffer

See Also

print.gmci, plotM

Examples

```
## Not run:
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)

## End(Not run)
```

---

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)

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

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

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.

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.

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

See Also

print.gm, plot.gm

---

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
```

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