

# Package ‘Itsa’

February 14, 2012

**Version** 1.4

**Date** 2010-11-30

**Title** Linear time series analysis

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**Depends** R (>= 2.1.0)

**Recommends** FGN

**Description** Methods of developing linear time series modelling.  
Methods are given for loglikelihood computation, forecasting and simulation.

**Classification/ACM** G.3, G.4, I.5.1

**Classification/MS** 62M10, 91B84

**License** GPL (>= 2)

**URL** <http://www.stats.uwo.ca/faculty/aim>

**Repository** CRAN

**Date/Publication** 2010-11-30 19:46:10

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ltsa-package	<i>Linear time series analysis</i>
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## Description

Linear time series modelling. Methods are given for loglikelihood computation, forecasting and simulation.

## Details

Package: Itsa  
 Type: Package  
 Version: 1.4  
 Date: 2010-11-30  
 License: GPL (>= 2)

FUNCTION	SUMMARY
DHSimulate	Davies and Harte algorithm for time series simulation
DLAcfToAR	from Acf to AR using Durbin-Levinson recursion
DLLoglikelihood	exact loglikelihood using Durbin-Levinson algorithm
DLResiduals	exact one-step residuals, Durbin-Levinson algorithm
DLSimulate	exact simulation of Gaussian time series using DL
is.toeplitz	test for Toeplitz matrix
PredictionVariance	two methods provided
tacvfARMA	theoretical autocovariances
ToeplitzInverseUpdate	update inverse
TrenchForecast	general algorithm for forecasting
TrenchInverse	efficient algorithm for inverse of Toeplitz matrix
TrenchLogLikelihood	exact loglikelihood
TrenchMean	exact MLE for mean

**Author(s)**

A. I. McLeod, Hao Yu and Zinovi Krougly.

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**References**

Hipel, K.W. and McLeod, A.I., (2005). Time Series Modelling of Water Resources and Environmental Systems. Electronic reprint of our book originally published in 1994. <http://www.stats.uwo.ca/faculty/aim/1994Book/>.

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[DHSimulate](#), [DLAcfToAR](#), [DLLoglikelihood](#), [DLResiduals](#), [DLSimulate](#), [is.toeplitz](#), [PredictionVariance](#), [tacvfARMA](#), [ToeplitzInverseUpdate](#), [TrenchForecast](#), [TrenchInverse](#), [TrenchLoglikelihood](#), [TrenchMean](#),

**Examples**

```
#Example 1: DHSimulate
#First define acf for fractionally-differenced white noise and then simulate using DHSimulate
'tacvfFdw' <-
function(d, maxlag)
{
  x <- numeric(maxlag + 1)
  x[1] <- gamma(1 - 2 * d)/gamma(1 - d)^2
  for(i in 1:maxlag)
    x[i + 1] <- ((i - 1 + d)/(i - d)) * x[i]
  x
}
n<-1000
rZ<-tacvfFdw(0.25, n-1) #length 1000
Z<-DHSimulate(n, rZ)
acf(Z)

#Example 2: DLAcfToAR
#
n<-10
d<-0.4
r<-tacvfFdw(d, n)
r<-(r/r[1])[-1]
HoskingPacf<-d/(-d+(1:n))
cbind(DLAcfToAR(r),HoskingPacf)

#Example 3: DLLoglikelihood
#Using Z and rZ in Example 1.
DLLoglikelihood(rZ, Z)
```

```

#Example 4: DLResiduals
#Using Z and rZ in Example 1.
DLResiduals(rZ, Z)

#Example 5: DLSimulate
#Using Z in Example 1.
z<-DLSimulate(n, rZ)
plot.ts(z)

#Example 6: is.toeplitz
is.toeplitz(toeplitz(1:5))

#Example 7: PredictionVariance
#Compare with predict.Arima
#general script, just change z, p, q, ML
z<-sqrt(sunspot.year)
n<-length(z)
p<-9
q<-0
ML<-10
#for different data/model just reset above
out<-arima(z, order=c(p,0,q))
sda<-as.vector(predict(out, n.ahead=ML)$se)
#
phi<-theta<-numeric(0)
if (p>0) phi<-coef(out)[1:p]
if (q>0) theta<-coef(out)[(p+1):(p+q)]
zm<-coef(out)[p+q+1]
sigma2<-out$sigma2
r<-sigma2*tacvfARMA(phi, theta, maxLag=n+ML-1)
sdb<-sqrt(PredictionVariance(r, maxLead=ML))
cbind(sda,sdb)

#Example 8: tacfARMA
#There are two methods: tacvfARMA and ARMAacf.
#tacvfARMA is more general since it computes the autocovariances function
# given the ARMA parameters and the innovation variance whereas ARMAacf
# only computes the autocorrelations. Sometimes tacvfARMA is more suitable
# for what is needed and provides a better result than ARMAacf as in the
# the following example.
#
#general script, just change z, p, q, ML
z<-sqrt(sunspot.year)
n<-length(z)
p<-9
q<-0
ML<-5
#for different data/model just reset above
out<-arima(z, order=c(p,0,q))
phi<-theta<-numeric(0)
if (p>0) phi<-coef(out)[1:p]
if (q>0) theta<-coef(out)[(p+1):(p+q)]
zm<-coef(out)[p+q+1]

```

```

sigma2<-out$sigma2
rA<-tacvfARMA(phi, theta, maxLag=n+ML-1, sigma2=sigma2)
rB<-var(z)*ARMAacf(ar=phi, ma=theta, lag.max=n+ML-1)
#rA and rB are slightly different
cbind(rA[1:5],rB[1:5])

#Example 9: ToeplitzInverseUpdate
#In this example we compute the update inverse directly and using ToeplitzInverseUpdate and
#compare the result.
phi<-0.8
sde<-30
n<-30
r<-arima.sim(n=30,list(ar=phi),sd=sde)
r<-phi^(0:(n-1))/(1-phi^2)*sde^2
n1<-25
G<-toeplitz(r[1:n1])
GI<-solve(G) #could also use TrenchInverse
GIupdate<-ToeplitzInverseUpdate(GI,r[1:n1],r[n1+1])
GIdirect<-solve(toeplitz(r[1:(n1+1)]))
ERR<-sum(abs(GIupdate-GIdirect))
ERR

#Example 10: TrenchForecast
#Compare TrenchForecast and predict.Arima
#general script, just change z, p, q, ML
z<-sqrt(sunspot.year)
n<-length(z)
p<-9
q<-0
ML<-10
#for different data/model just reset above
out<-arima(z, order=c(p,0,q))
Fp<-predict(out, n.ahead=ML)
phi<-theta<-numeric(0)
if (p>0) phi<-coef(out)[1:p]
if (q>0) theta<-coef(out)[(p+1):(p+q)]
zm<-coef(out)[p+q+1]
sigma2<-out$sigma2
#r<-var(z)*ARMAacf(ar=phi, ma=theta, lag.max=n+ML-1)
#When r is computed as above, it is not identical to below
r<-sigma2*tacvfARMA(phi, theta, maxLag=n+ML-1)
F<-TrenchForecast(z, r, zm, n, maxLead=ML)
#the forecasts are identical using tacvfARMA
#

#Example 11: TrenchInverse
#invert a matrix of order n and compute the maximum absolute error
# in the product of this inverse with the original matrix
n<-5
r<-0.8^(0:(n-1))

```

```

G<-toeplitz(r)
Gi<-TrenchInverse(G)
GGi<-crossprod(t(G),Gi)
id<-matrix(0, nrow=n, ncol=n)
diag(id)<-1
err<-max(abs(id-GGi))
err

#Example 12: TrenchLoglikelihood
#simulate a time series and compute the concentrated loglikelihood using DLLoglikelihood and
#compare this with the value given by TrenchLoglikelihood.
phi<-0.8
n<-200
r<-phi^(0:(n-1))
z<-arima.sim(model=list(ar=phi), n=n)
LD<-DLLoglikelihood(r,z)
LT<-TrenchLoglikelihood(r,z)
ans<-c(LD,LT)
names(ans)<-c("DLLoglikelihood", "TrenchLoglikelihood")

#Example 13: TrenchMean
phi<- -0.9
a<-rnorm(100)
z<-numeric(length(a))
phi<- -0.9
n<-100
a<-rnorm(n)
z<-numeric(n)
mu<-100
sig<-10
z[1]<-a[1]*sig/sqrt(1-phi^2)
for (i in 2:n)
z[i]<-phi*z[i-1]+a[i]*sig
z<-z+mu
r<-phi^(0:(n-1))
meanMLE<-TrenchMean(r,z)
meanBLUE<-mean(z)
ans<-c(meanMLE, meanBLUE)
names(ans)<-c("BLUE", "MLE")
ans

```

**Description**

Uses the Davies-Harte algorithm to simulate a Gaussian time series with specified autocovariance function.

**Usage**

```
DHSimulate(n, r, ReportTestOnly = FALSE, rand.gen = rnorm, ...)
```

**Arguments**

n	length of time series to be generated
r	autocovariances at lags 0,1,...
ReportTestOnly	FALSE – Run normally so terminates with an error if Davies-Harte condition does not hold. Otherwise if TRUE, then output is TRUE if the Davies-Harte condition holds and FALSE if it does not.
rand.gen	random number generator to use. It is assumed to have mean zero and variance one.
...	optional arguments passed to rand.gen

**Details**

The method uses the FFT and so is most efficient if the series length,  $n$ , is a power of 2. The method requires that a complicated non-negativity condition be satisfied. Craigmile (2003) discusses this condition in more detail and shows for anti-persistent time series this condition will always be satisfied. Sometimes, as in the case of fractinally differenced white noise with parameter  $d=0.45$  and  $n=5000$ , this condition fails and the algorithm doesn't work. In this case, an error message is generated and the function halts.

**Value**

Either a vector of length containing the simulated time series if Davies-Harte condition holds and `ReportTestOnly = FALSE`. If argument `ReportTestOnly` is set to `TRUE`, then output is logical variable indicating if Davies-Harte condition holds, `TRUE`, or if it does not, `FALSE`.

**Author(s)**

A.I. McLeod

**References**

Craigmile, P.F. (2003). Simulating a class of stationary Gaussian processes using the Davies-Harte algorithm, with application to long memory processes. *Journal of Time Series Analysis*, 24, 505-511.

Davies, R. B. and Harte, D. S. (1987). Tests for Hurst Effect. *Biometrika* 74, 95–101.

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, *Journal of Statistical Software*.

**See Also**

[\DLSimulate](#), [SimGLP](#), [arima.sim](#)

**Examples**

```

#simulate a process with autocovariance function 1/(k+1), k=0,1,...
# and plot it
n<-2000
r<-1/sqrt(1:n)
z<-DHSimulate(n, r)
plot.ts(z)

#simulate AR(1) and produce a table comparing the theoretical and sample
# autocovariances and autocorrelations
phi<- -0.8
n<-4096
g0<-1/(1-phi^2)
#theoretical autocovariances
tacvf<-g0*(phi^(0:(n-1)))
z<-DHSimulate(n, tacvf)
#autocorrelations
sacf<-acf(z, plot=FALSE)$acf
#autocovariances
sacvf<-acf(z, plot=FALSE,type="covariance")$acf
tacf<-tacvf/tacvf[1]
tb<-matrix(c(tacvf[1:10],sacvf[1:10],tacf[1:10],sacf[1:10]),ncol=4)
dimnames(tb)<-list(0:9, c("Tacvf","Sacvf","Tacf","Sacf"))
tb

#Show the Davies-Harte condition sometimes hold and sometimes does not
# in the case of fractionally differenced white noise
#
#Define autocovariance function for fractionally differenced white noise
'tacvfFdown' <-
function(d, maxlag)
{
  x <- numeric(maxlag + 1)
  x[1] <- gamma(1 - 2 * d)/gamma(1 - d)^2
  for(i in 1:maxlag)
    x[i + 1] <- ((i - 1 + d)/(i - d)) * x[i]
  x
}
#Build table to show values of d for which condition is TRUE when n=5000
n<-5000
ds<-c(-0.45, -0.25, -0.05, 0.05, 0.25, 0.45)
tb<-logical(length(ds))
names(tb)<-ds
for (kd in 1:length(ds)){
  d<-ds[kd]
  r<-tacvfFdown(d, n-1)
  tb[kd]<-DHSimulate(n, r, ReportTestOnly = TRUE)
}
tb

```

DLAcfToAR

*Autocorrelations to AR parameters***Description**

Given autocorrelations at lags 1,...,n the AR parameters corresponding to the AR coefficients, partial autocorrelations (pacf) and standardized minimum-mean-square predictor variance (sigsqk) are computed. Can also be used as a test for valid acf sequence.

**Usage**

```
DLAcfToAR(r, useC = TRUE, PDSequenceTestQ = FALSE)
```

**Arguments**

r	autocorrelations starting at lag 1
useC	TRUE, C-interface function used. Otherwise if FALSE calculations are done in R
PDSequenceTestQ	FALSE, an error message is given if the autocorrelation sequence is not pd otherwise test for pd

**Details**

This function is more general than the built-in `acf2AR` since it provides the pacf and standardized minimum-mean-square error predictors. The standardized minimum-mean-square error predictor variances are defined as the minimum-mean-square error predictor variance for an AR process with unit variance. So for a sufficiently high-order, an approximation to the innovation variance is obtained.

The pacf may be used as an alternative parameterization for the linear time series model (McLeod and Zhang, 2006).

**Value**

a matrix with 3 columns and `length(r)` rows is returned corresponding to the ar coefficients, pacf and sigsqk when `PDSequenceTestQ = FALSE`. Otherwise when `PDSequenceTestQ = TRUE`, the result is TRUE or FALSE according as the autocorrelation is a valid positive-definite sequence.

**Author(s)**

A.I. McLeod

**References**

McLeod, A.I. and Zhang, Y. (2006). Partial autocorrelation parameterization for subset autoregression. *Journal of Time Series Analysis*, 27, 599-612.

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, *Journal of Statistical Software*.

**See Also**

[acf2AR](#), [ar](#)

**Examples**

```

#Example 1: Yule-Walker estimates
z<-log(lynx)
p<-11
r<-(acf(z, lag.max=p, plot=FALSE)$acf)[-1]
ans<-DLAcfToAR(r)
#compare with built-in ar
phiAR<-ar(z,aic=FALSE, order.max=p, method="yw")$ar
#yet another way is to use acf2AR
phi2<-(acf2AR(c(1,r)))[p,]
cbind(ans,phiAR,phi2)
#
#Example 2: AR(1) illustration
#For AR(1) case compare useC = T and F
r<-0.9^(1:3)
DLAcfToAR(r, useC=TRUE)
DLAcfToAR(r, useC=FALSE)
DLAcfToAR(r, useC=TRUE, PDSequenceTestQ=TRUE)
DLAcfToAR(r, useC=FALSE, PDSequenceTestQ=TRUE)
#
#Example 3: test for valid tacf
r<-c(0.8, rep(0,99))
DLAcfToAR(r, PDSequenceTestQ=TRUE)
#
#Example 4: Fractional-difference example
#Hosking (1981), pacf, zeta[k]=d/(k-d)
#we compare this numerically with our procedure
'tacvfFdown' <-
function(d, maxlag)
{
  x <- numeric(maxlag + 1)
  x[1] <- gamma(1 - 2 * d)/gamma(1 - d)^2
  for(i in 1:maxlag)
    x[i + 1] <- ((i - 1 + d)/(i - d)) * x[i]
  x
}
n<-10
d<-0.4
r<-tacvfFdown(d, n)
r<-(r/r[1])[-1]
HoskingPacf<-d/(-d+(1:n))
cbind(DLAcfToAR(r),HoskingPacf)
#
# Example 5: Determining a suitable MA approximation
#Find MA approximation to hyperbolic decay series
N<-10^4 #pick N so large that mmse forecast error converged
r<-1/sqrt(1:N)
out<-DLAcfToAR(r[-1])

```

```
InnovationVariance<-out[nrow(out),3]
phi<-out[,1]
psi<-ARMAtoMA(ar=phi, lag.max=N)
Error<-r[1]-InnovationVariance*(1+sum(psi^2))
```

---

DLLoglikelihood	<i>Durbin-Levinsion Loglikelihood</i>
-----------------	---------------------------------------

---

### Description

The Durbin-Levinsion algorithm is used for the computation of the exact loglikelihood function.

### Usage

```
DLLoglikelihood(r, z, useC = TRUE)
```

### Arguments

r	autocovariance or autocorrelation at lags 0,...,n-1, where n is length(z)
z	time series data
useC	TRUE, use compiled C, otherwise R

### Details

The concentrated loglikelihood function may be written  $L_m(\beta) = -(n/2) \cdot \log(S/n) - 0.5 \cdot g$ , where  $\beta$  is the parameter vector,  $n$  is the length of the time series,  $S = z' M z$ ,  $z$  is the mean-corrected time series,  $M$  is the inverse of the covariance matrix setting the innovation variance to one and  $g = -\log(\det(M))$ . This method was given in Li (1981) for evaluating the loglikelihood function in the case of the fractionally differenced white noise.

### Value

The loglikelihood concentrated over the parameter for the innovation variance is returned.

### Note

The purpose of this function is to provide a check on the TrenchLoglikelihood function. Completely different algorithms are used in each case but the numerical values should agree.

### Author(s)

A.I. McLeod

### References

W.K. Li (1981). Topics in Time Series Analysis. Ph.D. Thesis, University of Western Ontario.  
 McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[FGNLL TrenchLoglikelihood](#)

**Examples**

```
#Compare direct evaluation of AR(1) loglikelihood with DL method
#First define the exact concentrated loglikelihood function for AR(1)
AR1Loglikelihood <-function(phi,z){
  n<-length(z)
  S<-(z[1]^2)*(1-phi^2) + sum((z[-1]-phi*z[-n])^2)
  0.5*log(1-phi^2)-(n/2)*log(S/n)
}
#Next run script to compare numerically the loglikelihoods.
#They should be identical.
phi<-0.8
n<-200
z<-arima.sim(list(ar=phi), n=n)
phis<-seq(0.1,0.95,0.05)
ansAR1<-ansDL<-numeric(length(phis))
for (i in 1:length(phis)) {
  ansAR1[i] <- AR1Loglikelihood(phis[i],z)
  r<-(1/(1-phis[i]^2))*phis[i]^(0:(n-1))
  ansDL[i] <- DLLoglikelihood(r,z,useC=FALSE)
}
ans<-matrix(c(ansDL,ansAR1),ncol=2)
dimnames(ans)<-list(phis, c("DL-method","AR1-method"))

#compute loglikelihood for white noise
z<-rnorm(100)
DLLoglikelihood(c(1,rep(0,length(z)-1)), z)

#simulate a time series and compute the concentrated loglikelihood using DLLoglikelihood and
#compare this with the value given by TrenchLoglikelihood.
phi<-0.8
n<-200
r<-phi^(0:(n-1))
z<-arima.sim(model=list(ar=phi), n=n)
LD<-DLLoglikelihood(r,z)
LT<-TrenchLoglikelihood(r,z)
ans<-c(LD,LT)
names(ans)<-c("DLLoglikelihood","TrenchLoglikelihood")

#compare timings. See (McLeod, Yu, Krougly, Table 8).
n<-5000
ds<-c(-0.45, -0.25, -0.05, 0.05, 0.25, 0.45)
tim<-matrix(numeric(3*length(ds)),ncol=3)
for (i in 1:length(ds)){
  d<-ds[i]
  alpha <- 1-2*d #equivalent hyperbolic autocorrelation
  r <- (1/(1:n))^alpha
  z<-DLSimulate(n,r)
}
```

```

tim1a<-system.time(LL1<-DLLoglikelihood(r,z))[1]
tim1b<-system.time(LL1<-DLLoglikelihood(r,z,useC=FALSE))[1]
tim2<-system.time(LL2<-TrenchLoglikelihood(r,z))[1]
tim[i,]<-c(tim1a,tim1b, tim2)
}
dimnames(tim)<-list(ds, c("DL-C", "DL-R", "Trench"))
tim

```

DLResiduals

*Prediction residuals***Description**

The Durbin-Levison algorithm is used to compute the one-step prediction residuals.

**Usage**

```
DLResiduals(r, z, useC = TRUE, StandardizedQ=TRUE)
```

**Arguments**

r	vector of length n containing the autocovariances or autocorrelations at lags 0,...,n-1
z	vector of length n, mean-corrected time series data
useC	if TRUE, the compiled C code is used, otherwise the computations are done entirely in R and much slower
StandardizedQ	TRUE, the residuals are divided by their standard deviation or FALSE, the raw prediction residuals are computed

**Details**

If the model is correct the standardized prediction residuals are approximately NID(0,1) and are asymptotically equivalent to the usual innovation residuals divided by the residual sd. This means that the usual diagnostic checks, such as the Ljung-Box test may be used.

**Value**

Vector of length n containing the residuals

**Author(s)**

A.I. McLeod

**References**

W.K. Li (1981). Topics in Time Series Analysis. Ph.D. Thesis, University of Western Ontario.  
 McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[DLLoglikelihood](#)

**Examples**

```
# For the AR(1) the prediction residuals and innovation residuals are the same (except for
# t=1). In this example we demonstrate the equality of these two types of residuals.
#
phi<-0.8
sde<-30
n<-30
z<-arima.sim(n=30,list(ar=phi),sd=sde)
r<-phi^(0:(n-1))/(1-phi^2)*sde^2
e<-DLResiduals(r,z)
a<-numeric(n)
for (i in 2:n)
  a[i]=z[i]-phi*z[i-1]
a<-a/sde
ERR<-sum(abs(e[-1]-a[-1]))
ERR
#
#Simulate AR(1) and compute the MLE for the innovation variance
phi <- 0.5
n <- 2000
sigsq <- 9
z<-arima.sim(model=list(ar=phi), n=n, sd=sqrt(sigsq))
g0 <- sigsq/(1-phi^2)
r <- g0*phi^(0:(n-1))
#comparison of estimate with actual
e<-DLResiduals(r,z,useC=FALSE, StandardizedQ=FALSE)
sigsqHat <- var(e)
ans<-c(sigsqHat,sigsq)
names(ans)<-c("estimate","theoretical")
ans
```

---

DLSimulate

---

*Simulate linear time series*


---

**Description**

The Durbin-Levinson recursions are used to simulate a stationary time series given an unit innovation sequence and given autocovariance function. Requires

$$O(n^2)$$

flops.

**Usage**

```
DLSimulate(n, r, useC = TRUE, rand.gen = rnorm, ...)
```

**Arguments**

n	length of time series to be generated
r	autocovariances, lags 0, ...,
useC	=TRUE, use C interface. Otherwise direct computation.
rand.gen	random number generator to use
...	optional arguments passed to rand.gen

**Details**

See Hipel and McLeod (1994) or McLeod, Yu and Krougly (2007).

**Value**

simulated time series of length n

**Author(s)**

A.I. McLeod

**References**

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[DHSimulate](#), [SimGLP](#), [SimulateFGN](#) [codearima.sim](#)

**Examples**

```
#Simulate hyperbolic decay time series
#with Hurst coefficient, H=0.9
n<-2000
H<-0.9
alpha<-2*(1-H) #hyperbolic decay parameter
r<-(1/(1:n))^alpha
z<-DLSimulate(n, r)
plot.ts(z)
#can use HurstK function in FGN library to estimate H
```

---

is.toeplitz	<i>test if argument is a symmetric Toeplitz matrix</i>
-------------	--

---

**Description**

Auxiliary function, used to validate the input of TrenchInverse

**Usage**

```
is.toeplitz(x)
```

**Arguments**

x	value to be tested
---	--------------------

**Details**

A symmetric Toeplitz matrix of order  $n$  has  $(i,j)$ -entry of the form  $g[abs(1+i-j)]$ , where  $g$  is a vector of length  $n$ .

**Value**

returns True or False according to whether  $x$  is or is not a symmetric Toeplitz matrix

**Author(s)**

A.I. McLeod

**See Also**

[TrenchInverse](#), [toeplitz](#)

**Examples**

```
is.toeplitz(toeplitz(1:5))  
is.toeplitz(5)
```

---

PredictionVariance	<i>Prediction variance</i>
--------------------	----------------------------

---

**Description**

The prediction variance of the forecast for lead times  $l=1,\dots,\text{maxLead}$  is computed.

**Usage**

```
PredictionVariance(r, maxLead = 1, DLQ = TRUE)
```

**Arguments**

r	the autocovariances at lags 0, 1, 2, ...
maxLead	maximum lead time of forecast
DLQ	Using Durbin-Levinson if TRUE. Otherwise Trench algorithm used.

**Details**

Two algorithms are available which are described in detail in McLeod, Yu and Krougly (2007). The default method, DLQ=TRUE, uses the autocovariances provided in r to determine the optimal linear mean-square error predictor of order  $\text{length}(r)-1$ . The mean-square error of this predictor is the lead-one error variance. The moving-average expansion of this model is used to compute any remaining variances (McLeod, Yu and Krougly, 2007). With the other algorithm, when DLQ=FALSE, a direct matrix representation of the forecast variances is used (McLeod, Yu and Krougly, 2007). The Trench method is exact. Provided the length of r is large enough, the two methods will agree.

**Value**

vector of length maxLead containing the variances

**Author(s)**

A.I. McLeod

**References**

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[predict.Arima](#), [TrenchForecast](#)

**Examples**

```

#Example 1. Compare using DL method or Trench method
va<-PredictionVariance(0.9^(0:10), maxLead=10)
vb<-PredictionVariance(0.9^(0:10), maxLead=10, DLQ=FALSE)
cbind(va,vb)
#
#Example 2. Compare with predict.Arima
#general script, just change z, p, q, ML
z<-sqrt(sunspot.year)
n<-length(z)
p<-9
q<-0
ML<-10
#for different data/model just reset above
out<-arima(z, order=c(p,0,q))
sda<-as.vector(predict(out, n.ahead=ML)$se)
#
phi<-theta<-numeric(0)
if (p>0) phi<-coef(out)[1:p]
if (q>0) theta<-coef(out)[(p+1):(p+q)]
zm<-coef(out)[p+q+1]
sigma2<-out$sigma2
r<-sigma2*tacvfARMA(phi, theta, maxLag=n+ML-1)
sdb<-sqrt(PredictionVariance(r, maxLead=ML))
cbind(sda,sdb)
#
#
#Example 3. DL and Trench method can give different results
# when the acvf is slowly decaying. Trench is always
# exact based on a finite-sample.
L<-5
r<-1/sqrt(1:(L+1))
va<-PredictionVariance(r, maxLead=L)
vb<-PredictionVariance(r, maxLead=L, DLQ=FALSE)
cbind(va,vb) #results are slightly different
r<-1/sqrt(1:(1000)) #larger number of autocovariances
va<-PredictionVariance(r, maxLead=L)
vb<-PredictionVariance(r, maxLead=L, DLQ=FALSE)
cbind(va,vb) #results now agree

```

---

SimGLP

*Simulate GLP given innovations*


---

**Description**

Simulates a General Linear Time Series that can have nonGaussian innovations. It uses the FFT so it is  $O(N \log(N))$  flops where  $N=\text{length}(a)$  and  $N$  is assumed to be a power of 2. The R function `convolve` is used which implements the FFT.

**Usage**

```
SimGLP(psi, a)
```

**Arguments**

**psi** vector, length Q, of MA coefficients starting with 1.

**a** vector, length Q+n, of innovations, where n is the length of time series to be generated.

**Details**

$$z_t = \sum_{k=0}^Q \text{psi}_k a_{t-k}$$

where  $t = 1, \dots, n$  and the innovations  $a_t, t=1-Q, \dots, 0, 1, \dots, n$  are given in the input vector **a**.

Since `convolve` uses the FFT this is faster than direct computation.

**Value**

vector of length n, where  $n = \text{length}(a) - \text{length}(\text{psi})$

**Author(s)**

A.I. McLeod

**See Also**

[convolve](#), [arima.sim](#)

**Examples**

```
#Simulate an AR(1) process with parameter phi=0.8 of length n=100 with
# innovations from a t-distribution with 5 df and plot it.
#
phi<-0.8
psi<-phi^(0:127)
n<-100
Q<-length(psi)-1
a<-rt(n+Q,5)
z<-SimGLP(psi,a)
z<-ts(z)
plot(z)
```

---

 tacvfARMA

*theoretical autocovariance function (acvf) of ARMA*


---

**Description**

The theoretical autocovariance function of ARMA(p,q) process is computed. This is more useful in some situations than the built-in R function [ARMAacf](#). See Details.

**Usage**

```
tacvfARMA(phi = numeric(0), theta = numeric(0), maxLag = 1, sigma2 = 1)
```

**Arguments**

phi	ar parameters
theta	ma parameters
maxLag	acvf is computed at lags 0, ..., maxLag
sigma2	innovation variance

**Details**

The details of the autocovariance computation are given in McLeod (1975).

In addition to this computation, we also test if the model is stationary-causal or not. The test, which is included directly in the function, uses the Durbin-Levison recursion to transform from the phi parameters to the pacf. See McLeod and Zhang (2006, eqn. (1)) for more details. Formally, the stationary-causal condition requires that all roots of the polynomial equation,

$$1 - \text{phi}[1] * B - \dots - \text{phi}[p] * B^p = 0$$

must lie outside the unit circle (Brockwell and Davis, 1991, Section 3.3).

This function is included because it is necessary to demonstrate that in the case of ARMA models, [TrenchInverse](#) and the built-in R function [predict.Arima](#) produce equivalent results. See Example 1 in the documentation for [TrenchForecast](#) and the example discussed in McLeod, Yu and Krougly (2007, 3.2).

**Value**

Vector of length maxLag containing the autocovariances at lags 0, ..., maxLag. But see Warning below.

**Note**

An error is returned if the model is not stationary-causal.

**Author(s)**

A.I. McLeod

## References

- P.J. Brockwell and R.A. Davis (1991) Time Series: Theory and Methods. Springer.
- A.I. McLeod (1975) Derivation of the theoretical autocovariance function of autoregressive-moving average models, Applied Statistics 24, 255-256.
- A.I. McLeod and Zhang, Y. (2006) Partial autocorrelation parameterizations for subset autoregression, Journal of Time Series Analysis,
- McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

## See Also

[ARMAacf](#)

## Examples

```
#Example 1. Estimate the acvf of a fitted ARMA model
#There are two methods but they give slightly different results,
#general script, just change z, p, q, ML
z<-sqrt(sunspot.year)
n<-length(z)
p<-9
q<-0
ML<-5
#for different data/model just reset above
out<-arima(z, order=c(p,0,q))
phi<-theta<-numeric(0)
if (p>0) phi<-coef(out)[1:p]
if (q>0) theta<-coef(out)[(p+1):(p+q)]
zm<-coef(out)[p+q+1]
sigma2<-out$sigma2
rA<-tacvfARMA(phi, theta, maxLag=n+ML-1, sigma2=sigma2)
rB<-var(z)*ARMAacf(ar=phi, ma=theta, lag.max=n+ML-1)
#rA and rB are slightly different
cbind(rA[1:5],rB[1:5])
#
#Example 2. Compute Rsq for fitted ARMA model
#Rsq = 1 - (series variance / innovation variance)
#Again there are two methods but only the first method is guaranteed to
#produce an Rsq which is non-negative!
#Run last example and then evaluate the script below:
RsqA <- 1 - rA/sigma2
RsqB <- 1 - rB/sigma2
#
#Example 3. Test if model is stationary-causal or not.
StationaryQ <- function(phi) tryCatch(is.vector(tacvfARMA(phi=phi)),error=function(e) FALSE )
StationaryQ(1.1) #AR(1) with phi=1.1 is not stationary-causal.
#try with parameters from Example 1 above
StationaryQ(phi)
```

---

ToeplitzInverseUpdate *Inverse of Toeplitz matrix of order n+1 given inverse of order n*

---

**Description**

Let  $G$  be a Toeplitz matrix of order  $n$  and with  $(i,j)$ -element,  $r[|i-j|]$ . So the first row of  $G$  may be written  $(r[0], \dots, r[n-1])$ . Suppose the next element in the sequence is  $r[n]$ . Then the inverse of the Toeplitz matrix whose first row is  $(r[0], \dots, r[n])$  may be obtained either using `ToeplitzInverseUpdate` or directly using `TrenchInverse`. `ToeplitzInverseUpdate` is somewhat faster.

**Usage**

```
ToeplitzInverseUpdate(GI, r, rnew)
```

**Arguments**

GI	inverse of Toeplitz matrix $G$ of order $n$
r	first row of $G$ , ie $r[0], \dots, r[n-1]$
rnew	next element, $r[n]$

**Details**

Although this update requires  $O(n^2)$  flops, the same as `TrenchInverse`, it is somewhat faster in practice.

**Value**

inverse matrix of order  $n+1$

**Author(s)**

A.I. McLeod

**References**

Graybill, F.A. (1983). *Matrices with Applications in Statistics*.  
McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, *Journal of Statistical Software*.

**See Also**

[TrenchInverse](#)

**Examples**

```

#In this example we compute the update inverse directly and using ToeplitzInverseUpdate and
#compare the result.
phi<-0.8
sde<-30
n<-30
r<-arima.sim(n=30,list(ar=phi),sd=sde)
r<-phi^(0:(n-1))/(1-phi^2)*sde^2
n1<-25
G<-toeplitz(r[1:n1])
GI<-solve(G) #could also use TrenchInverse
GIupdate<-ToeplitzInverseUpdate(GI,r[1:n1],r[n1+1])
GIdirect<-solve(toeplitz(r[1:(n1+1)]))
ERR<-sum(abs(GIupdate-GIdirect))
ERR

```

---

TrenchForecast	<i>Minimum Mean Square Forecast</i>
----------------	-------------------------------------

---

**Description**

Given time series of length  $n+m$ , the forecasts for lead times  $k=1,\dots,L$  are computed starting with forecast origin at time  $t=n$  and continuing up to  $t=n+m$ . The input time series is of length  $n+m$ . For purely out-of-sample forecasts we may take  $n=\text{length}(z)$ . Note that the parameter  $m$  is inferred using the fact that  $m=\text{length}(z)-n$ .

**Usage**

```
TrenchForecast(z, r, zm, n, maxLead, UpdateAlgorithmQ = TRUE)
```

**Arguments**

$z$	time series data, length $n+m$
$r$	autocovariances of $\text{length}(z)+L-1$ or until damped out
$zm$	mean parameter in model
$n$	forecast origin, $n$
$\text{maxLead}$	$=L$ , the maximum lead time
$\text{UpdateAlgorithmQ}$	$= \text{TRUE}$ , use efficient update method, otherwise if $\text{UpdateAlgorithmQ}=\text{FALSE}$ , the direct inverse matrix is computed each time

**Details**

The minimum mean-square error forecast of  $z[N+k]$  given time series data  $z[1], \dots, z[N]$  is denoted by  $z_N(k)$ , where  $N$  is called the forecast origin and  $k$  is the lead time. This algorithm computes a table for  $z_N(k)$ ,  $N = n, \dots, n + m$ ;  $k = 1, \dots, m$ . The minimum mean-square error forecast is simply the conditional expectation of  $z_{N+k}$  given the time series up to including time  $t = N$ . This conditional expectation works out to the same thing as the conditional expectation in an appropriate multivariate normal distribution – even if no normality assumption is made. See McLeod, Yu, Krougly (2007, eqn. 8). Similar remarks hold for the variance of the forecast. An error message is given if  $\text{length}(r) < n + L - 1$ .

**Value**

A list with components

Forecasts            matrix with  $m+1$  rows and  $\text{maxLead}$  columns with the forecasts

SDForecasts        matrix with  $m+1$  rows and  $\text{maxLead}$  columns with the sd of the forecasts

**Note**

An error message is given if  $r$  is not a pd sequence, that is, the Toeplitz matrix of  $r$  must be pd. This could occur if you were to approximate a GLP which is near the stationary boundary by a MA(Q) with  $Q$  not large enough. In the bootstrap simulation experiment reported in our paper McLeod, Yu and Krougly (2007) we initially approximated the FGN autocorrelations by setting them to zero after lag 553 but in this case the ARMA(2,1) forecasts were always better. When we used all required lags of the acvf then the FGN forecasts were better as we expected. From this experience, we don't recommend setting high-order acf lags to zero unless the values are in fact very small.

**Author(s)**

A.I. McLeod

**References**

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[TrenchInverse](#)

**Examples**

```
#Example 1. Compare TrenchForecast and predict.Arima
#general script, just change z, p, q, ML
z<-sqrt(sunspot.year)
n<-length(z)
p<-9
q<-0
ML<-10
#for different data/model just reset above
```

```

out<-arima(z, order=c(p,0,q))
Fp<-predict(out, n.ahead=ML)

phi<-theta<-numeric(0)
if (p>0) phi<-coef(out)[1:p]
if (q>0) theta<-coef(out)[(p+1):(p+q)]
zm<-coef(out)[p+q+1]
sigma2<-out$sigma2
#r<-var(z)*ARMAacf(ar=phi, ma=theta, lag.max=n+ML-1)
#When r is computed as above, it is not identical to below
r<-sigma2*tacvfARMA(phi, theta, maxLag=n+ML-1)
F<-TrenchForecast(z, r, zm, n, maxLead=ML)
#the forecasts are identical using tacvfARMA
#
#Example 2. Compare AR(1) Forecasts. Show how
#Forecasts from AR(1) are easily calculated directly.
#We compare AR(1) forecasts and their sd's.
#Define a function for the AR(1) case
AR1Forecast <- function(z,phi,n,maxLead){
  nz<-length(z)
  m<-nz-n
  zf<-vf<-matrix(numeric(maxLead*m),ncol=maxLead)
  zorigin<-z[n:nz]
  zf<-outer(zorigin,phi^(1:maxLead))
  vf<-matrix(rep(1-phi^(2*(1:maxLead))),m+1,byrow=TRUE,ncol=maxLead)/(1-phi^2)
  list(zf=zf,sdf=sqrt(vf))
}
#generate AR(1) series and compare the forecasts
phi<-0.9
n<-200
m<-5
N<-n+m
z<-arima.sim(list(ar=phi), n=N)
maxLead<-3
nr<-N+maxLead-1
r<-(1/(1-phi^2))*phi^(0:nr)
ansT1<-TrenchForecast(z,r,0,n,maxLead)
ansT2<-TrenchForecast(z,r,0,n,maxLead,UpdateAlgorithmQ=FALSE)
ansAR1<-AR1Forecast(z,phi,n,maxLead)

```

---

TrenchInverse

*compute the matrix inverse of a positive-definite Toeplitz matrix*


---

### Description

The Trench algorithm (Golub and Vanload, 1983) is implemented in C and interfaced to R. This provides an expedient method for obtaining the matrix inverse of the covariance matrix of  $n$  successive observations from a stationary time series. Some applications of this are discussed by McLeod and Krougly (2005).

**Usage**

TrenchInverse(G)

**Arguments**

G a positive definite Toeplitz matrix

**Value**

the matrix inverse of G is computed

**Warning**

You should test the input x using `is.toeplitz(x)` if you are not sure if x is a symmetric Toeplitz matrix.

**Note**

TrenchInverse(x) assumes that x is a symmetric Toeplitz matrix but it does not specifically test for this. Instead it merely takes the first row of x and passes this directly to the C code program which uses this more compact storage format. The C code program then computes the inverse. An error message is given if the C code algorithm encounters a non-positive definite input.

**Author(s)**

A.I. McLeod

**References**

Golub, G. and Van Loan (1983). Matrix Computations, 2nd Ed. John Hoptkins University Press, Baltimore. Algorithm 5.7-3.

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[TrenchLoglikelihood](#), [is.toeplitz](#), [DLLoglikelihood](#), [TrenchMean](#), [solve](#)

**Examples**

```
#compute inverse of matrix and compare with result from solve
data(LakeHuron)
r<-acf(LakeHuron, plot=FALSE, lag.max=4)$acf
R<-toeplitz(c(r))
Ri<-TrenchInverse(R)
Ri2<-solve(R)
Ri
Ri2

#invert a matrix of order n and compute the maximum absolute error
# in the product of this inverse with the original matrix
```

```

n<-5
r<-0.8^(0:(n-1))
G<-toeplitz(r)
Gi<-TrenchInverse(G)
GGi<-crossprod(t(G),Gi)
id<-matrix(0, nrow=n, ncol=n)
diag(id)<-1
err<-max(abs(id-GGi))
err

```

---

TrenchLoglikelihood     *Loglikelihood function of stationary time series using Trench algorithm*

---

### Description

The Trench matrix inversion algorithm is used to compute the exact concentrated loglikelihood function.

### Usage

```
TrenchLoglikelihood(r, z)
```

### Arguments

r	autocovariance or autocorrelation at lags 0,...,n-1, where n is length(z)
z	time series data

### Details

The concentrated loglikelihood function may be written  $Lm(\beta) = -(n/2) \cdot \log(S/n) - 0.5 \cdot g$ , where  $\beta$  is the parameter vector,  $n$  is the length of the time series,  $S = z' M z$ ,  $z$  is the mean-corrected time series,  $M$  is the inverse of the covariance matrix setting the innovation variance to one and  $g = -\log(\det(M))$ .

### Value

The loglikelihood concentrated over the parameter for the innovation variance is returned.

### Author(s)

A.I. McLeod

### References

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[DLLoglikelihood](#)

**Examples**

```
#compute loglikelihood for white noise
z<-rnorm(100)
TrenchLoglikelihood(c(1,rep(0,length(z)-1)), z)

#simulate a time series and compute the concentrated loglikelihood using DLLoglikelihood and
#compare this with the value given by TrenchLoglikelihood.
phi<-0.8
n<-200
r<-phi^(0:(n-1))
z<-arima.sim(model=list(ar=phi), n=n)
LD<-DLLoglikelihood(r,z)
LT<-TrenchLoglikelihood(r,z)
ans<-c(LD,LT)
names(ans)<-c("DLLoglikelihood","TrenchLoglikelihood")
```

---

TrenchMean

*Exact MLE for mean given the autocorrelation function*

---

**Description**

Sometimes this is also referred to as the BLUE.

**Usage**

```
TrenchMean(r, z)
```

**Arguments**

**r** vector of autocorrelations or autocovariances of length  $n$   
**z** time series data vector of length  $n$

**Value**

the estimate of the mean

**Note**

An error is given if  $r$  is not a positive-definite sequence or if the lengths of  $r$  and  $z$  are not equal.

**Author(s)**

A.I. McLeod

**References**

McLeod, A.I., Yu, Hao, Krougly, Zinovi L. (2007). Algorithms for Linear Time Series Analysis, Journal of Statistical Software.

**See Also**

[TrenchInverse](#)

**Examples**

```
#compare BLUE and sample mean
phi<- -0.9
a<-rnorm(100)
z<-numeric(length(a))
phi<- -0.9
n<-100
a<-rnorm(n)
z<-numeric(n)
mu<-100
sig<-10
z[1]<-a[1]*sig/sqrt(1-phi^2)
for (i in 2:n)
z[i]<-phi*z[i-1]+a[i]*sig
z<-z+mu
r<-phi^(0:(n-1))
meanMLE<-TrenchMean(r,z)
meanBLUE<-mean(z)
ans<-c(meanMLE, meanBLUE)
names(ans)<-c("BLUE", "MLE")
ans
```

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