Package 'cTMed'

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Version 1.0.4		
Description Calculates standard errors and confidence intervals for effects in continuous-time mediation models. This package extends the work of Deboeck and Preacher (2015) <doi:10.1080 10705511.2014.973960=""> and Ryan and Hamaker (2021) <doi:10.1007 s11336-021-09767-0=""> by providing methods to generate standard errors and confidence intervals for the total, direct, and indirect effects in these models.</doi:10.1007></doi:10.1080>		
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Contents		
BootMed		

2 Contents

DeltaBetaStd	11
DeltaIndirectCentral	15
DeltaMed	18
DeltaMedStd	22
DeltaTotalCentral	26
Direct	29
DirectStd	32
ExpCov	
ExpMean	36
ndirect	38
ndirectCentral	40
ndirectStd	42
MCBeta	44
MCBetaStd	47
MCIndirectCentral	51
MCMed	55
MCMedStd	58
MCPhi	
MCTotalCentral	65
Med	
MedStd	71
olot.ctmeddelta	73
olot.ctmedmc	75
olot.ctmedmed	76
olot.ctmedtraj	78
PosteriorBeta	79
PosteriorIndirectCentral	81
PosteriorMed	84
PosteriorTotalCentral	87
orint.ctmeddelta	
print.ctmedeffect	92
print.ctmedmc	93
orint.ctmedmcphi	95
print.ctmedmed	96
orint.ctmedtraj	97
ummary.ctmeddelta	98
ummary.ctmedmc	100
ummary.ctmedmed	102
ummary.ctmedposteriorphi	103
ummary.ctmedtraj	104
Total	105
TotalCentral	107
TotalStd	109
Trajectory	
	113

Index

BootMed 3

BootMed	Bootstrap Sampling Distribution of Total, Direct, and Indirect Effects of X on Y Through M Over a Specific Time Interval or a Range of Time
	Intervals

Description

This function generates a bootstrap method sampling distribution of the total, direct and indirect effects of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model drift matrix $\mathbf{\Phi}$.

Usage

```
BootMed(phi, phi_hat, delta_t, from, to, med, ncores = NULL, tol = 0.01)
```

Arguments

phi	List of numeric matrices. Each element of the list is a bootstrap estimate of the drift matrix (Φ). Each matrix should have row and column names pertaining to the variables in the system.
phi_hat	Numeric matrix. The estimated drift matrix $(\hat{\Phi})$ from the original data set. phi_hat should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval (Δt).
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
tol	Numeric. Smallest possible time interval to allow.

Details

```
See Total(), Direct(), and Indirect() for more details.
```

Value

Returns an object of class ctmedmc which is a list with the following elements:

```
call Function call.
args Function arguments.
fun Function used ("BootMed").
output A list with length of length(delta_t).
```

4 confint.ctmeddelta

Each element in the output list has the following elements:

est A vector of total, direct, and indirect effects.

thetahatstar A matrix of bootstrap total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

Other Continuous Time Mediation Functions: DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

confint.ctmeddelta

Delta Method Confidence Intervals

Description

Delta Method Confidence Intervals

Usage

```
## S3 method for class 'ctmeddelta'
confint(object, parm = NULL, level = 0.95, ...)
```

Arguments

object Object of class ctmeddelta.

parm a specification of which parameters are to be given confidence intervals, either

a vector of numbers or a vector of names. If missing, all parameters are consid-

ered.

level the confidence level required.

... additional arguments.

confint.ctmeddelta 5

Value

Returns a data frame of confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) \leftarrow rownames(phi) \leftarrow c("x", "m", "y")
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
    0.00495, 0.00024, -0.00093,
    0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
    0.00024, 0.00214, 0.00012,
    -0.00061, 0.00012, 0.00156,
    0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
  ),
  nrow = 9
)
```

Specific time interval ------

6 confint.ctmedmc

```
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
confint(delta, level = 0.95)
# Range of time intervals ------
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
)
confint(delta, level = 0.95)
```

confint.ctmedmc

Monte Carlo Method Confidence Intervals

Description

Monte Carlo Method Confidence Intervals

Usage

```
## S3 method for class 'ctmedmc'
confint(object, parm = NULL, level = 0.95, ...)
```

Arguments

object Object of class ctmedmc.

parm a specification of which parameters are to be given confidence intervals, either

a vector of numbers or a vector of names. If missing, all parameters are consid-

ered.

level the confidence level required.

... additional arguments.

Value

Returns a data frame of confidence intervals.

confint.ctmedmc 7

Author(s)

Ivan Jacob Agaloos Pesigan

```
set.seed(42)
phi <- matrix(</pre>
  data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
   0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
   0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
    0.00024, 0.00214, 0.00012,
    -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
  ),
  nrow = 9
# Specific time interval ------
mc <- MCMed(</pre>
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
```

8 DeltaBeta

```
delta_t = 1,
 from = "x",
 to = "y",
 med = "m",
 R = 100L # use a large value for R in actual research
)
confint(mc, level = 0.95)
# Range of time intervals ------
mc <- MCMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m",
 R = 100L \text{ \# use a large value for } R \text{ in actual research}
)
confint(mc, level = 0.95)
```

DeltaBeta

Delta Method Sampling Variance-Covariance Matrix for the Elements of the Matrix of Lagged Coefficients Over a Specific Time Interval or a Range of Time Intervals

Description

This function computes the delta method sampling variance-covariance matrix for the elements of the matrix of lagged coefficients β over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix Φ .

Usage

```
DeltaBeta(phi, vcov_phi_vec, delta_t, ncores = NULL, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) . phi should have row and column names pertaining to the variables in the system.
vcov_phi_vec	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\Phi\right)$.
delta_t	Vector of positive numbers. Time interval (Δt).
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when the length of delta_t is long.
tol	Numeric. Smallest possible time interval to allow.

DeltaBeta 9

Details

See Total().

Delta Method:

Let θ be $\text{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\text{vec}(\hat{\Phi})$. By the multivariate central limit theory, the function \mathbf{g} using $\hat{\theta}$ as input can be expressed as:

$$\sqrt{n}\left(\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) - \mathbf{g}\left(\boldsymbol{\theta}\right)\right) \xrightarrow{\mathrm{D}} \mathcal{N}\left(0, \mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

where **J** is the matrix of first-order derivatives of the function **g** with respect to the elements of θ and Γ is the asymptotic variance-covariance matrix of $\hat{\theta}$.

From the former, we can derive the distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ as follows:

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), n^{-1}\mathbf{J}\mathbf{\Gamma}\mathbf{J}'\right)$$

The uncertainty associated with the estimator $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is, therefore, given by $n^{-1}\mathbf{J}\Gamma\mathbf{J}'$. When Γ is unknown, by substitution, we can use the estimated sampling variance-covariance matrix of $\hat{\boldsymbol{\theta}}$, that is, $\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)$ for $n^{-1}\Gamma$. Therefore, the sampling variance-covariance matrix of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is given by

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), \mathbf{J}\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right) \mathbf{J}'\right).$$

Value

Returns an object of class ctmeddelta which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("DeltaBeta").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

delta_t Time interval.

jacobian Jacobian matrix.

est Estimated elements of the matrix of lagged coefficients.

vcov Sampling variance-covariance matrix of estimated elements of the matrix of lagged coefficients.

Author(s)

Ivan Jacob Agaloos Pesigan

10 DeltaBeta

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
```

```
0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Specific time interval ------
DeltaBeta(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1
)
# Range of time intervals ------
delta <- DeltaBeta(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5
)
plot(delta)
# Methods ------
# DeltaBeta has a number of methods including
# print, summary, confint, and plot
print(delta)
summary(delta)
confint(delta, level = 0.95)
plot(delta)
```

DeltaBetaStd

Delta Method Sampling Variance-Covariance Matrix for the Elements of the Standardized Matrix of Lagged Coefficients Over a Specific Time Interval or a Range of Time Intervals

Description

This function computes the delta method sampling variance-covariance matrix for the elements of the standardized matrix of lagged coefficients β over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix Φ and process noise covariance matrix Σ .

Usage

```
DeltaBetaStd(phi, sigma, vcov_theta, delta_t, ncores = NULL, tol = 0.01)
```

Arguments

Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.

sigma
Numeric matrix. The process noise covariance matrix (Σ) .

vcov_theta
Numeric matrix. The sampling variance-covariance matrix of vec (Φ) and vech (Σ) delta_t
Numeric. Time interval (Δt) .

ncores
Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.

tol
Numeric. Smallest possible time interval to allow.

Details

See TotalStd().

Delta Method:

Let θ be a vector that combines $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise and $\operatorname{vech}(\Sigma)$, that is, the unique elements of the Σ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be a vector that combines $\operatorname{vec}(\hat{\Phi})$ and $\operatorname{vech}(\hat{\Sigma})$. By the multivariate central limit theory, the function \mathbf{g} using $\hat{\theta}$ as input can be expressed as:

$$\sqrt{n}\left(\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) - \mathbf{g}\left(\boldsymbol{\theta}\right)\right) \xrightarrow{\mathrm{D}} \mathcal{N}\left(0, \mathbf{J}\mathbf{\Gamma}\mathbf{J}'\right)$$

where **J** is the matrix of first-order derivatives of the function **g** with respect to the elements of θ and Γ is the asymptotic variance-covariance matrix of $\hat{\theta}$.

From the former, we can derive the distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ as follows:

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), n^{-1}\mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

The uncertainty associated with the estimator $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is, therefore, given by $n^{-1}\mathbf{J}\Gamma\mathbf{J}'$. When Γ is unknown, by substitution, we can use the estimated sampling variance-covariance matrix of $\hat{\boldsymbol{\theta}}$, that is, $\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)$ for $n^{-1}\Gamma$. Therefore, the sampling variance-covariance matrix of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is given by

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), \mathbf{J}\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right) \mathbf{J}'\right).$$

Value

Returns an object of class ctmeddelta which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("DeltaBetaStd").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

delta_t Time interval.

jacobian Jacobian matrix.

est Estimated elements of the matrix of lagged coefficients.

vcov Sampling variance-covariance matrix of estimated elements of the matrix of lagged coefficients.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
  data = c(
    0.24455556, 0.02201587, -0.05004762,
    0.02201587, 0.07067800, 0.01539456,
    -0.05004762, 0.01539456, 0.07553061
  ),
  nrow = 3
)
vcov_theta <- matrix(</pre>
```

```
data = c(
    0.00843, 0.00040, -0.00151, -0.00600, -0.00033,
    0.00110, 0.00324, 0.00020, -0.00061, -0.00115,
   0.00011, 0.00015, 0.00001, -0.00002, -0.00001,
   0.00040, 0.00374, 0.00016, -0.00022, -0.00273,
   -0.00016, 0.00009, 0.00150, 0.00012, -0.00010,
   -0.00026, 0.00002, 0.00012, 0.00004, -0.00001,
   -0.00151, 0.00016, 0.00389, 0.00103, -0.00007,
    -0.00283, -0.00050, 0.00000, 0.00156, 0.00021,
    -0.00005, -0.00031, 0.00001, 0.00007, 0.00006,
    -0.00600, -0.00022, 0.00103, 0.00644, 0.00031,
    -0.00119, -0.00374, -0.00021, 0.00070, 0.00064,
    -0.00015, -0.00005, 0.00000, 0.00003, -0.00001,
    -0.00033, -0.00273, -0.00007, 0.00031, 0.00287,
   0.00013, -0.00014, -0.00170, -0.00012, 0.00006,
   0.00014, -0.00001, -0.00015, 0.00000, 0.00001,
   0.00110, -0.00016, -0.00283, -0.00119, 0.00013,
   0.00297, 0.00063, -0.00004, -0.00177, -0.00013,
    0.00005, 0.00017, -0.00002, -0.00008, 0.00001,
    0.00324, 0.00009, -0.00050, -0.00374, -0.00014,
    0.00063, 0.00495, 0.00024, -0.00093, -0.00020,
    0.00006, -0.00010, 0.00000, -0.00001, 0.00004,
    0.00020, 0.00150, 0.00000, -0.00021, -0.00170,
    -0.00004, 0.00024, 0.00214, 0.00012, -0.00002,
    -0.00004, 0.00000, 0.00006, -0.00005, -0.00001,
    -0.00061, 0.00012, 0.00156, 0.00070, -0.00012,
    -0.00177, -0.00093, 0.00012, 0.00223, 0.00004,
    -0.00002, -0.00003, 0.00001, 0.00003, -0.00013,
    -0.00115, -0.00010, 0.00021, 0.00064, 0.00006,
    -0.00013, -0.00020, -0.00002, 0.00004, 0.00057,
   0.00001, -0.00009, 0.00000, 0.00000, 0.00001,
   0.00011, -0.00026, -0.00005, -0.00015, 0.00014,
   0.00005, 0.00006, -0.00004, -0.00002, 0.00001,
    0.00012, 0.00001, 0.00000, -0.00002, 0.00000,
    0.00015, 0.00002, -0.00031, -0.00005, -0.00001,
    0.00017, -0.00010, 0.00000, -0.00003, -0.00009,
     0.00001, \ 0.00014, \ 0.00000, \ 0.00000, \ -0.00005, \\
    0.00001, 0.00012, 0.00001, 0.00000, -0.00015,
    -0.00002, 0.00000, 0.00006, 0.00001, 0.00000,
    0.00000, 0.00000, 0.00010, 0.00001, 0.00000,
    -0.00002, 0.00004, 0.00007, 0.00003, 0.00000,
    -0.00008, -0.00001, -0.00005, 0.00003, 0.00000,
   -0.00002, 0.00000, 0.00001, 0.00005, 0.00001,
    -0.00001, -0.00001, 0.00006, -0.00001, 0.00001,
   0.00001, 0.00004, -0.00001, -0.00013, 0.00001,
    0.00000, -0.00005, 0.00000, 0.00001, 0.00012
 ),
 nrow = 15
)
# Specific time interval -------
DeltaBetaStd(
 phi = phi,
```

DeltaIndirectCentral 15

```
sigma = sigma,
 vcov_theta = vcov_theta,
 delta_t = 1
)
# Range of time intervals ------
delta <- DeltaBetaStd(</pre>
 phi = phi,
 sigma = sigma,
 vcov_theta = vcov_theta,
 delta_t = 1:5
plot(delta)
# Methods ------
# DeltaBetaStd has a number of methods including
# print, summary, confint, and plot
print(delta)
summary(delta)
confint(delta, level = 0.95)
plot(delta)
```

DeltaIndirectCentral

Delta Method Sampling Variance-Covariance Matrix for the Indirect Effect Centrality Over a Specific Time Interval or a Range of Time Intervals

Description

This function computes the delta method sampling variance-covariance matrix for the indirect effect centrality over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix Φ .

Usage

```
DeltaIndirectCentral(phi, vcov_phi_vec, delta_t, ncores = NULL, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
	,
vcov_phi_vec	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\mathbf{\Phi}\right)$.
delta_t	Vector of positive numbers. Time interval (Δt) .
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when the length of delta_t is long.
tol	Numeric. Smallest possible time interval to allow.

16 DeltaIndirectCentral

Details

See IndirectCentral() more details.

Delta Method:

Let θ be $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\operatorname{vec}(\hat{\Phi})$. By the multivariate central limit theory, the function \mathbf{g} using $\hat{\theta}$ as input can be expressed as:

$$\sqrt{n}\left(\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) - \mathbf{g}\left(\boldsymbol{\theta}\right)\right) \xrightarrow{\mathrm{D}} \mathcal{N}\left(0, \mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

where **J** is the matrix of first-order derivatives of the function **g** with respect to the elements of θ and Γ is the asymptotic variance-covariance matrix of $\hat{\theta}$.

From the former, we can derive the distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ as follows:

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), n^{-1}\mathbf{J}\mathbf{\Gamma}\mathbf{J}'\right)$$

The uncertainty associated with the estimator $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is, therefore, given by $n^{-1}\mathbf{J}\Gamma\mathbf{J}'$. When Γ is unknown, by substitution, we can use the estimated sampling variance-covariance matrix of $\hat{\boldsymbol{\theta}}$, that is, $\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)$ for $n^{-1}\Gamma$. Therefore, the sampling variance-covariance matrix of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is given by

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), \mathbf{J}\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)\mathbf{J}'\right).$$

Value

Returns an object of class ctmeddelta which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("DeltaIndirectCentral").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

delta_t Time interval.

jacobian Jacobian matrix.

est Estimated indirect effect centrality.

vcov Sampling variance-covariance matrix of estimated indirect effect centrality.

Author(s)

Ivan Jacob Agaloos Pesigan

DeltaIndirectCentral 17

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaMed(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.002704274, -0.001475275, 0.000949122,
    -0.001619422, 0.000885122, -0.000569404,
    0.00085493, -0.000465824, 0.000297815,
    -0.001475275, 0.004428442, -0.002642303,
    0.000980573, -0.00271817, 0.001618805,
    -0.000586921, 0.001478421, -0.000871547,
    0.000949122, -0.002642303, 0.006402668,
    -0.000697798, 0.001813471, -0.004043138,
    0.000463086, -0.001120949, 0.002271711,
    -0.001619422, 0.000980573, -0.000697798,
    0.002079286, -0.001152501, 0.000753,
    -0.001528701, 0.000820587, -0.000517524,
    0.000885122, -0.00271817, 0.001813471,
    -0.001152501, 0.00342605, -0.002075005,
    0.000899165, -0.002532849, 0.001475579,
    -0.000569404, 0.001618805, -0.004043138,
    0.000753, -0.002075005, 0.004984032,
    -0.000622255, 0.001634917, -0.003705661,
    0.00085493, -0.000586921, 0.000463086,
    -0.001528701, 0.000899165, -0.000622255,
```

```
0.002060076, -0.001096684, 0.000686386,
   -0.000465824, 0.001478421, -0.001120949,
   0.000820587, -0.002532849, 0.001634917,
   -0.001096684, 0.003328692, -0.001926088,
   0.000297815, -0.000871547, 0.002271711,
   -0.000517524, 0.001475579, -0.003705661,
   0.000686386, -0.001926088, 0.004726235
 ),
 nrow = 9
)
# Specific time interval ------
DeltaIndirectCentral(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1
)
# Range of time intervals ------
delta <- DeltaIndirectCentral(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5
)
plot(delta)
# Methods ------
# DeltaIndirectCentral has a number of methods including
# print, summary, confint, and plot
print(delta)
summary(delta)
confint(delta, level = 0.95)
plot(delta)
```

DeltaMed

Delta Method Sampling Variance-Covariance Matrix for the Total, Direct, and Indirect Effects of X on Y Through M Over a Specific Time Interval or a Range of Time Intervals

Description

This function computes the delta method sampling variance-covariance matrix for the total, direct, and indirect effects of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix $\mathbf{\Phi}$.

Usage

```
DeltaMed(phi, vcov_phi_vec, delta_t, from, to, med, ncores = NULL, tol = 0.01)
```

Arguments

Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.

vcov_phi_vec Numeric matrix. The sampling variance-covariance matrix of $\text{vec}(\Phi)$.

delta_t Vector of positive numbers. Time interval (Δt) .

from Character string. Name of the independent variable X in phi. to Character string. Name of the dependent variable Y in phi. med Character vector. Name/s of the mediator variable/s in phi.

ncores Positive integer. Number of cores to use. If ncores = NULL, use a single core.

Consider using multiple cores when the length of delta_t is long.

tol Numeric. Smallest possible time interval to allow.

Details

See Total(), Direct(), and Indirect() for more details.

Delta Method:

Let θ be $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\operatorname{vec}(\hat{\Phi})$. By the multivariate central limit theory, the function g using $\hat{\theta}$ as input can be expressed as:

$$\sqrt{n}\left(\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) - \mathbf{g}\left(\boldsymbol{\theta}\right)\right) \xrightarrow{\mathrm{D}} \mathcal{N}\left(0, \mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

where **J** is the matrix of first-order derivatives of the function **g** with respect to the elements of θ and Γ is the asymptotic variance-covariance matrix of $\hat{\theta}$.

From the former, we can derive the distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ as follows:

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), n^{-1}\mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

The uncertainty associated with the estimator $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is, therefore, given by $n^{-1}\mathbf{J}\Gamma\mathbf{J}'$. When Γ is unknown, by substitution, we can use the estimated sampling variance-covariance matrix of $\hat{\boldsymbol{\theta}}$, that is, $\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)$ for $n^{-1}\Gamma$. Therefore, the sampling variance-covariance matrix of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is given by

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), \mathbf{J}\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)\mathbf{J}'\right).$$

Value

Returns an object of class ctmeddelta which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("DeltaMed").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

delta_t Time interval.

jacobian Jacobian matrix.

est Estimated total, direct, and indirect effects.

vcov Sampling variance-covariance matrix of the estimated total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
```

```
-0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
   -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
   -0.00033, -0.00273, -0.00007,
   0.00031, 0.00287, 0.00013,
   -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
   -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050,
   -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Specific time interval ------
DeltaMed(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
)
# Range of time intervals ------
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
)
plot(delta)
# Methods ------
# DeltaMed has a number of methods including
# print, summary, confint, and plot
print(delta)
summary(delta)
confint(delta, level = 0.95)
plot(delta)
```

DeltaMedStd	Delta Method Sampling Variance-Covariance Matrix for the Stan-
	dardized Total, Direct, and Indirect Effects of X on Y Through M Over
	a Specific Time Interval or a Range of Time Intervals

Description

This function computes the delta method sampling variance-covariance matrix for the standardized total, direct, and indirect effects of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix $\mathbf{\Phi}$ and process noise covariance matrix $\mathbf{\Sigma}$.

Usage

```
DeltaMedStd(
   phi,
   sigma,
   vcov_theta,
   delta_t,
   from,
   to,
   med,
   ncores = NULL,
   tol = 0.01
)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
vcov_theta	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\mathbf{\Phi}\right)$ and $\operatorname{vech}\left(\mathbf{\Sigma}\right)$
delta_t	Numeric. Time interval (Δt).
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
tol	Numeric. Smallest possible time interval to allow.

Details

See TotalStd(), DirectStd(), and IndirectStd() for more details.

Delta Method:

Let θ be a vector that combines $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise and $\operatorname{vech}(\Sigma)$, that is, the unique elements of the Σ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be a vector that combines $\operatorname{vec}(\hat{\Phi})$ and $\operatorname{vech}(\hat{\Sigma})$. By the multivariate central limit theory, the function \mathbf{g} using $\hat{\theta}$ as input can be expressed as:

$$\sqrt{n}\left(\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) - \mathbf{g}\left(\boldsymbol{\theta}\right)\right) \xrightarrow{\mathrm{D}} \mathcal{N}\left(0, \mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

where **J** is the matrix of first-order derivatives of the function **g** with respect to the elements of θ and Γ is the asymptotic variance-covariance matrix of $\hat{\theta}$.

From the former, we can derive the distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ as follows:

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), n^{-1}\mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

The uncertainty associated with the estimator $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is, therefore, given by $n^{-1}\mathbf{J}\Gamma\mathbf{J}'$. When Γ is unknown, by substitution, we can use the estimated sampling variance-covariance matrix of $\hat{\boldsymbol{\theta}}$, that is, $\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)$ for $n^{-1}\Gamma$. Therefore, the sampling variance-covariance matrix of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is given by

$$\mathbf{g}\left(\hat{\boldsymbol{ heta}}\right) pprox \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{ heta}
ight), \mathbf{J}\hat{\mathbb{V}}\left(\hat{\boldsymbol{ heta}}\right) \mathbf{J}'\right).$$

Value

Returns an object of class ctmeddelta which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("DeltaMedStd").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

delta t Time interval.

jacobian Jacobian matrix.

est Estimated total, direct, and indirect effects.

vcov Sampling variance-covariance matrix of the estimated total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
  data = c(
    0.24455556, 0.02201587, -0.05004762,
    0.02201587, 0.07067800, 0.01539456,
    -0.05004762, 0.01539456, 0.07553061
  ),
  nrow = 3
)
vcov_theta <- matrix(
  data = c(
    0.00843, 0.00040, -0.00151, -0.00600, -0.00033,
    0.00110, 0.00324, 0.00020, -0.00061, -0.00115,
    0.00011, 0.00015, 0.00001, -0.00002, -0.00001,
    0.00040, 0.00374, 0.00016, -0.00022, -0.00273,
    -0.00016, 0.00009, 0.00150, 0.00012, -0.00010,
    -0.00026, 0.00002, 0.00012, 0.00004, -0.00001,
    -0.00151, 0.00016, 0.00389, 0.00103, -0.00007,
    -0.00283, -0.00050, 0.00000, 0.00156, 0.00021,
    -0.00005, -0.00031, 0.00001, 0.00007, 0.00006,
    -0.00600, -0.00022, 0.00103, 0.00644, 0.00031,
    -0.00119, -0.00374, -0.00021, 0.00070, 0.00064,
    -0.00015, -0.00005, 0.00000, 0.00003, -0.00001,
```

```
-0.00033, -0.00273, -0.00007, 0.00031, 0.00287,
   0.00013, -0.00014, -0.00170, -0.00012, 0.00006,
   0.00014, -0.00001, -0.00015, 0.00000, 0.00001,
   0.00110, -0.00016, -0.00283, -0.00119, 0.00013,
   0.00297, 0.00063, -0.00004, -0.00177, -0.00013,
   0.00005, 0.00017, -0.00002, -0.00008, 0.00001,
   0.00324, 0.00009, -0.00050, -0.00374, -0.00014,
   0.00063, 0.00495, 0.00024, -0.00093, -0.00020,
   0.00006, -0.00010, 0.00000, -0.00001, 0.00004,
   0.00020, 0.00150, 0.00000, -0.00021, -0.00170,
   -0.00004, 0.00024, 0.00214, 0.00012, -0.00002,
   -0.00004, 0.00000, 0.00006, -0.00005, -0.00001,
   -0.00061, 0.00012, 0.00156, 0.00070, -0.00012,
   -0.00177, -0.00093, 0.00012, 0.00223, 0.00004,
   -0.00002, -0.00003, 0.00001, 0.00003, -0.00013,
   -0.00115, -0.00010, 0.00021, 0.00064, 0.00006,
   -0.00013, -0.00020, -0.00002, 0.00004, 0.00057,
   0.00001, -0.00009, 0.00000, 0.00000, 0.00001,
   0.00011, -0.00026, -0.00005, -0.00015, 0.00014,
   0.00005, 0.00006, -0.00004, -0.00002, 0.00001,
   0.00012, 0.00001, 0.00000, -0.00002, 0.00000,
   0.00015, 0.00002, -0.00031, -0.00005, -0.00001,
   0.00017, -0.00010, 0.00000, -0.00003, -0.00009,
   0.00001, 0.00014, 0.00000, 0.00000, -0.00005,
   0.00001, 0.00012, 0.00001, 0.00000, -0.00015,
   -0.00002, 0.00000, 0.00006, 0.00001, 0.00000,
   0.00000, 0.00000, 0.00010, 0.00001, 0.00000,
   -0.00002, 0.00004, 0.00007, 0.00003, 0.00000,
   -0.00008, -0.00001, -0.00005, 0.00003, 0.00000,
   -0.00002, 0.00000, 0.00001, 0.00005, 0.00001,
   -0.00001, -0.00001, 0.00006, -0.00001, 0.00001,
   0.00001, 0.00004, -0.00001, -0.00013, 0.00001,
   0.00000, -0.00005, 0.00000, 0.00001, 0.00012
 ),
 nrow = 15
)
# Specific time interval -------
DeltaMedStd(
 phi = phi,
 sigma = sigma,
 vcov_theta = vcov_theta,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
)
# Range of time intervals -------
delta <- DeltaMedStd(</pre>
 phi = phi,
 sigma = sigma,
 vcov_theta = vcov_theta,
```

26 DeltaTotalCentral

 ${\tt DeltaTotalCentral}$

Delta Method Sampling Variance-Covariance Matrix for the Total Effect Centrality Over a Specific Time Interval or a Range of Time Intervals

Description

This function computes the delta method sampling variance-covariance matrix for the total effect centrality over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix Φ .

Usage

```
DeltaTotalCentral(phi, vcov_phi_vec, delta_t, ncores = NULL, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
vcov_phi_vec	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\Phi\right)$.
delta_t	Vector of positive numbers. Time interval (Δt) .
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when the length of delta_t is long.
tol	Numeric. Smallest possible time interval to allow.

Details

See TotalCentral() more details.

DeltaTotalCentral 27

Delta Method:

Let θ be $\text{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\text{vec}(\hat{\Phi})$. By the multivariate central limit theory, the function \mathbf{g} using $\hat{\theta}$ as input can be expressed as:

$$\sqrt{n}\left(\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) - \mathbf{g}\left(\boldsymbol{\theta}\right)\right) \xrightarrow{\mathrm{D}} \mathcal{N}\left(0, \mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

where **J** is the matrix of first-order derivatives of the function **g** with respect to the elements of θ and Γ is the asymptotic variance-covariance matrix of $\hat{\theta}$.

From the former, we can derive the distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ as follows:

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), n^{-1}\mathbf{J}\boldsymbol{\Gamma}\mathbf{J}'\right)$$

The uncertainty associated with the estimator $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is, therefore, given by $n^{-1}\mathbf{J}\Gamma\mathbf{J}'$. When Γ is unknown, by substitution, we can use the estimated sampling variance-covariance matrix of $\hat{\boldsymbol{\theta}}$, that is, $\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right)$ for $n^{-1}\Gamma$. Therefore, the sampling variance-covariance matrix of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ is given by

$$\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right) \approx \mathcal{N}\left(\mathbf{g}\left(\boldsymbol{\theta}\right), \mathbf{J}\hat{\mathbb{V}}\left(\hat{\boldsymbol{\theta}}\right) \mathbf{J}'\right).$$

Value

Returns an object of class ctmeddelta which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("DeltaTotalCentral").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

delta_t Time interval.

jacobian Jacobian matrix.

est Estimated total effect centrality.

vcov Sampling variance-covariance matrix of estimated total effect centrality.

Author(s)

Ivan Jacob Agaloos Pesigan

28 DeltaTotalCentral

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
```

Direct 29

```
0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Specific time interval ------
DeltaTotalCentral(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1
)
# Range of time intervals ------
delta <- DeltaTotalCentral(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5
plot(delta)
# DeltaTotalCentral has a number of methods including
# print, summary, confint, and plot
print(delta)
summary(delta)
confint(delta, level = 0.95)
plot(delta)
```

Direct

Direct Effect of X on Y Over a Specific Time Interval

Description

This function computes the direct effect of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt using the first-order stochastic differential equation model's drift matrix $\mathbf{\Phi}$.

Usage

```
Direct(phi, delta_t, from, to, med)
```

30 Direct

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval (Δt).
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.

Details

The direct effect of the independent variable X on the dependent variable Y relative to some mediator variables \mathbf{m} is given by

$$Direct_{\Delta t_{i,j}} = \exp(\Delta t \mathbf{D} \mathbf{\Phi} \mathbf{D})_{i,j}$$

where Φ denotes the drift matrix, \mathbf{D} a diagonal matrix where the diagonal elements corresponding to mediator variables \mathbf{m} are set to zero and the rest to one, i the row index of Y in Φ , j the column index of X in Φ , and Δt the time interval.

Linear Stochastic Differential Equation Model:

The measurement model is given by

$$\mathbf{y}_{i,t} = \mathbf{\nu} + \mathbf{\Lambda} \boldsymbol{\eta}_{i,t} + \boldsymbol{\varepsilon}_{i,t}, \quad ext{with} \quad \boldsymbol{\varepsilon}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{\Theta}\right)$$

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\boldsymbol{\Lambda}$, and $\boldsymbol{\Theta}$ are model parameters. $\mathbf{y}_{i,t}$ represents a vector of observed random variables, $\boldsymbol{\eta}_{i,t}$ a vector of latent random variables, and $\boldsymbol{\varepsilon}_{i,t}$ a vector of random measurement errors, at time t and individual i. $\boldsymbol{\nu}$ denotes a vector of intercepts, $\boldsymbol{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of $\boldsymbol{\varepsilon}$.

An alternative representation of the measurement error is given by

$$oldsymbol{arepsilon}_{i,t} = oldsymbol{\Theta}^{rac{1}{2}} \mathbf{z}_{i,t}, \quad ext{with} \quad \mathbf{z}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{I}\right)$$

where $\mathbf{z}_{i,t}$ is a vector of independent standard normal random variables and $\left(\Theta^{\frac{1}{2}}\right)\left(\Theta^{\frac{1}{2}}\right)' = \Theta$. The dynamic structure is given by

$$\mathrm{d}\boldsymbol{\eta}_{i,t} = \left(\boldsymbol{\iota} + \boldsymbol{\Phi} \boldsymbol{\eta}_{i,t}\right) \mathrm{d}t + \boldsymbol{\Sigma}^{\frac{1}{2}} \mathrm{d}\mathbf{W}_{i,t}$$

where ι is a term which is unobserved and constant over time, Φ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, Σ is the matrix of volatility or randomness in the process, and $\mathrm{d}W$ is a Wiener process or Brownian motion, which represents random fluctuations.

Value

Returns an object of class ctmedeffect which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("Direct").

output The direct effect.

Direct 31

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
delta_t <- 1
Direct(
  phi = phi,
  delta_t = delta_t,
  from = x^{*},
  to = "y",
  med = "m"
)
phi <- matrix(</pre>
  data = c(
    -6, 5.5, 0, 0,
    1.25, -2.5, 5.9, -7.3,
    0, 0, -6, 2.5,
    5, 0, 0, -6
  ),
  nrow = 4
)
colnames(phi) <- rownames(phi) <- paste0("y", 1:4)</pre>
```

32 DirectStd

```
Direct(
   phi = phi,
   delta_t = delta_t,
   from = "y2",
   to = "y4",
   med = c("y1", "y3")
)
```

DirectStd

Standardized Direct Effect of X on Y Over a Specific Time Interval

Description

This function computes the standardized direct effect of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt using the first-order stochastic differential equation model's drift matrix $\mathbf{\Phi}$ and process noise covariance matrix $\mathbf{\Sigma}$.

Usage

```
DirectStd(phi, sigma, delta_t, from, to, med)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
delta_t	Numeric. Time interval (Δt) .
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.

Details

The standardized direct effect of the independent variable X on the dependent variable Y relative to some mediator variables \mathbf{m} is given by

$$\operatorname{Direct}_{\Delta t_{i,j}}^{*} = \mathbf{S}\left(\exp\left(\Delta t \mathbf{D} \mathbf{\Phi} \mathbf{D}\right)_{i,j}\right) \mathbf{S}^{-1}$$

where Φ denotes the drift matrix, \mathbf{D} a diagonal matrix where the diagonal elements corresponding to mediator variables \mathbf{m} are set to zero and the rest to one, i the row index of Y in Φ , j the column index of X in Φ , \mathbf{S} a diagonal matrix with model-implied standard deviations on the diagonals, and Δt the time interval.

DirectStd 33

Value

Returns an object of class ctmedeffect which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("DirectStd").output The direct effect.
```

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) \leftarrow rownames(phi) \leftarrow c("x", "m", "y")
sigma <- matrix(</pre>
  data = c(
    0.24455556, 0.02201587, -0.05004762,
    0.02201587, 0.07067800, 0.01539456,
    -0.05004762, 0.01539456, 0.07553061
  ),
  nrow = 3
)
```

34 ExpCov

```
delta_t <- 1
DirectStd(
   phi = phi,
   sigma = sigma,
   delta_t = delta_t,
   from = "x",
   to = "y",
   med = "m"
)</pre>
```

ExpCov

Model-Implied State Covariance Matrix

Description

The function returns the model-implied state covariance matrix for a particular time interval Δt given by

$$\operatorname{vec}\left(\operatorname{Cov}\left(\boldsymbol{\eta}\right)\right) = \left(\mathbf{J} - \boldsymbol{\beta}_{\Delta t} \otimes \boldsymbol{\beta}_{\Delta t}\right)^{-1} \operatorname{vec}\left(\boldsymbol{\Psi}_{\Delta t}\right)$$

where

$$eta_{\Delta t} = \exp\left(\Delta t \mathbf{\Phi}\right),$$
 $oldsymbol{\Psi}_{\Delta t} = \mathbf{\Phi}^{\#} \left(\exp\left(\Delta t \mathbf{\Phi}\right) - \mathbf{J}\right) \operatorname{vec}\left(\mathbf{\Sigma}\right), \quad ext{and}$
 $oldsymbol{\Phi}^{\#} = \left(\mathbf{\Phi} \otimes \mathbf{I}\right) + \left(\mathbf{I} \otimes \mathbf{\Phi}\right).$

Note that I and J are identity matrices.

Usage

```
ExpCov(phi, sigma, delta_t)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ), phi should have row and column names pertaining to the variables in the system.
	pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
delta_t	Numeric. Time interval (Δt).

Details

Linear Stochastic Differential Equation Model:

The measurement model is given by

$$\mathbf{y}_{i,t} = oldsymbol{
u} + oldsymbol{\Lambda} oldsymbol{\eta}_{i,t} + oldsymbol{arepsilon}_{i,t}, \quad ext{with} \quad oldsymbol{arepsilon}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, oldsymbol{\Theta}
ight)$$

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\boldsymbol{\Lambda}$, and $\boldsymbol{\Theta}$ are model parameters. $\mathbf{y}_{i,t}$ represents a vector of observed random variables, $\boldsymbol{\eta}_{i,t}$ a vector of latent random variables, and

ExpCov 35

 $\varepsilon_{i,t}$ a vector of random measurement errors, at time t and individual i. ν denotes a vector of intercepts, Λ a matrix of factor loadings, and Θ the covariance matrix of ε .

An alternative representation of the measurement error is given by

$$\boldsymbol{\varepsilon}_{i,t} = \boldsymbol{\Theta}^{\frac{1}{2}} \mathbf{z}_{i,t}, \quad \text{with} \quad \mathbf{z}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{I}\right)$$

where $\mathbf{z}_{i,t}$ is a vector of independent standard normal random variables and $\left(\Theta^{\frac{1}{2}}\right)\left(\Theta^{\frac{1}{2}}\right)' = \Theta$. The dynamic structure is given by

$$\mathrm{d} oldsymbol{\eta}_{i,t} = \left(oldsymbol{\iota} + oldsymbol{\Phi} oldsymbol{\eta}_{i,t}
ight) \mathrm{d} t + oldsymbol{\Sigma}^{rac{1}{2}} \mathrm{d} \mathbf{W}_{i,t}$$

where ι is a term which is unobserved and constant over time, Φ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, Σ is the matrix of volatility or randomness in the process, and $\mathrm{d}W$ is a Wiener process or Brownian motion, which represents random fluctuations.

Value

Returns a numeric matrix.

Author(s)

Ivan Jacob Agaloos Pesigan

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
  data = c(
    0.24, 0.02, -0.05,
    0.02, 0.07, 0.02,
    -0.05, 0.02, 0.08
  ),
  nrow = 3
)
```

36 ExpMean

```
delta_t <- 1
ExpCov(
   phi = phi,
   sigma = sigma,
   delta_t = delta_t
)</pre>
```

ExpMean

Model-Implied State Mean Vector

Description

The function returns the model-implied state mean vector for a particular time interval Δt given by

Mean
$$(\boldsymbol{\eta}) = (\mathbf{I} - \boldsymbol{\beta}_{\Delta t})^{-1} \boldsymbol{\alpha}_{\Delta t}$$

where

$$eta_{\Delta t} = \exp\left(\Delta t \mathbf{\Phi}\right),$$
 $oldsymbol{lpha}_{\Delta t} = \mathbf{\Phi}^{-1} \left(oldsymbol{eta}_{\Delta t} - \mathbf{I}\right) oldsymbol{\iota}.$

Note that I is an identity matrix.

Usage

```
ExpMean(phi, iota, delta_t)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
iota	Numeric vector. An unobserved term that is constant over time (ι) .
delta_t	Numeric. Time interval (Δt).

Details

Linear Stochastic Differential Equation Model:

The measurement model is given by

$$\mathbf{y}_{i,t} = \mathbf{\nu} + \mathbf{\Lambda} \boldsymbol{\eta}_{i,t} + \boldsymbol{\varepsilon}_{i,t}, \quad ext{with} \quad \boldsymbol{\varepsilon}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{\Theta}\right)$$

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\boldsymbol{\Lambda}$, and $\boldsymbol{\Theta}$ are model parameters. $\mathbf{y}_{i,t}$ represents a vector of observed random variables, $\boldsymbol{\eta}_{i,t}$ a vector of latent random variables, and $\boldsymbol{\varepsilon}_{i,t}$ a vector of random measurement errors, at time t and individual i. $\boldsymbol{\nu}$ denotes a vector of intercepts, $\boldsymbol{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of $\boldsymbol{\varepsilon}$.

An alternative representation of the measurement error is given by

$$\boldsymbol{\varepsilon}_{i,t} = \boldsymbol{\Theta}^{\frac{1}{2}} \mathbf{z}_{i,t}, \quad \text{with} \quad \mathbf{z}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{I}\right)$$

ExpMean 37

where $\mathbf{z}_{i,t}$ is a vector of independent standard normal random variables and $\left(\Theta^{\frac{1}{2}}\right)\left(\Theta^{\frac{1}{2}}\right)' = \Theta$. The dynamic structure is given by

$$\mathrm{d} \boldsymbol{\eta}_{i,t} = \left(\boldsymbol{\iota} + \boldsymbol{\Phi} \boldsymbol{\eta}_{i,t} \right) \mathrm{d} t + \boldsymbol{\Sigma}^{\frac{1}{2}} \mathrm{d} \mathbf{W}_{i,t}$$

where ι is a term which is unobserved and constant over time, Φ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, Σ is the matrix of volatility or randomness in the process, and $\mathrm{d}W$ is a Wiener process or Brownian motion, which represents random fluctuations.

Value

Returns a numeric matrix.

Author(s)

Ivan Jacob Agaloos Pesigan

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")
iota <- c(.5, .3, .4)
delta_t <- 1
ExpMean(
  phi = phi,
  iota = iota,
    delta_t = delta_t
)</pre>
```

38 Indirect

Indirect

Indirect Effect of X on Y Through M Over a Specific Time Interval

Description

This function computes the indirect effect of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt using the first-order stochastic differential equation model's drift matrix $\mathbf{\Phi}$.

Usage

Indirect(phi, delta_t, from, to, med)

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval (Δt).
from	Character string. Name of the independent variable X in \mathtt{phi} .
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.

Details

The indirect effect of the independent variable X on the dependent variable Y relative to some mediator variables \mathbf{m} over a specific time interval Δt is given by

Indirect_{$$\Delta t_{i,j}$$} = exp $(\Delta t \mathbf{\Phi})_{i,j}$ - exp $(\Delta t \mathbf{D_m} \mathbf{\Phi} \mathbf{D_m})_{i,j}$

where Φ denotes the drift matrix, $\mathbf{D_m}$ a matrix where the off diagonal elements are zeros and the diagonal elements are zero for the index/indices of mediator variables \mathbf{m} and one otherwise, i the row index of Y in Φ , j the column index of X in Φ , and Δt the time interval.

Linear Stochastic Differential Equation Model:

The measurement model is given by

$$\mathbf{y}_{i,t} = oldsymbol{
u} + oldsymbol{\Lambda} oldsymbol{\eta}_{i,t} + oldsymbol{arepsilon}_{i,t}, \quad ext{with} \quad oldsymbol{arepsilon}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, oldsymbol{\Theta}
ight)$$

where $\mathbf{y}_{i,t}$, $\eta_{i,t}$, and $\varepsilon_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\boldsymbol{\Lambda}$, and $\boldsymbol{\Theta}$ are model parameters. $\mathbf{y}_{i,t}$ represents a vector of observed random variables, $\eta_{i,t}$ a vector of latent random variables, and $\varepsilon_{i,t}$ a vector of random measurement errors, at time t and individual i. $\boldsymbol{\nu}$ denotes a vector of intercepts, $\boldsymbol{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of ε .

An alternative representation of the measurement error is given by

$$\boldsymbol{\varepsilon}_{i,t} = \boldsymbol{\Theta}^{\frac{1}{2}} \mathbf{z}_{i,t}, \quad \text{with} \quad \mathbf{z}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{I}\right)$$

where $\mathbf{z}_{i,t}$ is a vector of independent standard normal random variables and $\left(\mathbf{\Theta}^{\frac{1}{2}}\right)\left(\mathbf{\Theta}^{\frac{1}{2}}\right)' = \mathbf{\Theta}$.

Indirect 39

The dynamic structure is given by

$$\mathrm{d}\boldsymbol{\eta}_{i,t} = (\boldsymbol{\iota} + \boldsymbol{\Phi}\boldsymbol{\eta}_{i,t})\,\mathrm{d}t + \boldsymbol{\Sigma}^{\frac{1}{2}}\mathrm{d}\mathbf{W}_{i,t}$$

where ι is a term which is unobserved and constant over time, Φ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, Σ is the matrix of volatility or randomness in the process, and $\mathrm{d}W$ is a Wiener process or Brownian motion, which represents random fluctuations.

Value

Returns an object of class ctmedeffect which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("Indirect").
```

4 4 751 : 1: 4 66 4

output The indirect effect.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
),
  nrow = 3</pre>
```

40 IndirectCentral

```
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
delta_t <- 1
Indirect(
  phi = phi,
  delta_t = delta_t,
  from = "x",
  to = "y",
  med = "m"
)
phi <- matrix(</pre>
  data = c(
    -6, 5.5, 0, 0,
    1.25, -2.5, 5.9, -7.3,
    0, 0, -6, 2.5,
   5, 0, 0, -6
  ),
  nrow = 4
)
colnames(phi) \leftarrow rownames(phi) \leftarrow paste0("y", 1:4)
Indirect(
  phi = phi,
  delta_t = delta_t,
 from = "y2",
 to = "y4",
  med = c("y1", "y3")
```

IndirectCentral

Indirect Effect Centrality

Description

Indirect Effect Centrality

Usage

```
IndirectCentral(phi, delta_t, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
delta_t	Vector of positive numbers. Time interval (Δt) .
tol	Numeric. Smallest possible time interval to allow.

IndirectCentral 41

Details

Indirect effect centrality is the sum of all possible indirect effects between different pairs of variables in which a specific variable serves as the only mediator.

Value

Returns an object of class ctmedmed which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("IndirectCentral").output A matrix of indirect effect centrality.
```

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

42 IndirectStd

```
phi = phi,
 delta_t = 1
)
# Range of time intervals ------
indirect_central <- IndirectCentral(</pre>
 phi = phi,
 delta_t = 1:30
plot(indirect_central)
# Methods -----
# IndirectCentral has a number of methods including
# print, summary, and plot
indirect_central <- IndirectCentral(</pre>
 phi = phi,
 delta_t = 1:5
)
print(indirect_central)
summary(indirect_central)
plot(indirect_central)
```

IndirectStd

Standardized Indirect Effect of X on Y Through M Over a Specific Time Interval

Description

This function computes the standardized indirect effect of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt using the first-order stochastic differential equation model's drift matrix $\mathbf{\Phi}$ and process noise covariance matrix $\mathbf{\Sigma}$.

Usage

```
IndirectStd(phi, sigma, delta_t, from, to, med)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
delta_t	Numeric. Time interval (Δt) .
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.

IndirectStd 43

Details

The standardized indirect effect of the independent variable X on the dependent variable Y relative to some mediator variables \mathbf{m} over a specific time interval Δt is given by

$$Indirect^*_{\Delta t_{i,j}} = Total^*_{\Delta t} - Direct^*_{\Delta t}$$

where $\operatorname{Total}_{\Delta t}^*$ and $\operatorname{Direct}_{\Delta t}^*$ are standardized total and direct effects for time interval Δt .

Value

Returns an object of class ctmedeffect which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("IndirectStd").
```

Author(s)

Ivan Jacob Agaloos Pesigan

output The indirect effect.

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)</pre>
```

44 MCBeta

```
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
  data = c(
    0.24455556, 0.02201587, -0.05004762,
    0.02201587, 0.07067800, 0.01539456,
    -0.05004762, 0.01539456, 0.07553061
  ),
  nrow = 3
)
delta_t <- 1
IndirectStd(
  phi = phi,
  sigma = sigma,
  delta_t = delta_t,
  from = "x",
  to = "y",
  med = "m"
)
```

MCBeta

Monte Carlo Sampling Distribution for the Elements of the Matrix of Lagged Coefficients Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a Monte Carlo method sampling distribution for the elements of the matrix of lagged coefficients β over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model drift matrix Φ .

Usage

```
MCBeta(
   phi,
   vcov_phi_vec,
   delta_t,
   R,
   test_phi = TRUE,
   ncores = NULL,
   seed = NULL,
   tol = 0.01
)
```

Arguments

Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.

vcov_phi_vec Numeric matrix. The sampling variance-covariance matrix of $\text{vec}\left(\Phi\right)$.

MCBeta 45

delta_t Numeric. Time interval (Δt).

R Positive integer. Number of replications.

test_phi Logical. If test_phi = TRUE, the function tests the stability of the generated

drift matrix Φ . If the test returns FALSE, the function generates a new drift

matrix Φ and runs the test recursively until the test returns TRUE.

ncores Positive integer. Number of cores to use. If ncores = NULL, use a single core.

Consider using multiple cores when number of replications R is a large value.

seed Random seed.

tol Numeric. Smallest possible time interval to allow.

Details

See Total().

Monte Carlo Method:

Let θ be $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\operatorname{vec}(\hat{\Phi})$. Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

$$\hat{oldsymbol{ heta}} \sim \mathcal{N}\left(oldsymbol{ heta}, \mathbb{V}\left(\hat{oldsymbol{ heta}}
ight)
ight)$$

Using this distributional assumption, a sampling distribution of $\hat{\theta}$ which we refer to as $\hat{\theta}^*$ can be generated by replacing the population parameters with sample estimates, that is,

$$\hat{oldsymbol{ heta}}^* \sim \mathcal{N}\left(\hat{oldsymbol{ heta}}, \hat{\mathbb{V}}\left(\hat{oldsymbol{ heta}}
ight)
ight).$$

Let $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ be a parameter that is a function of the estimated parameters. A sampling distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$, which we refer to as $\mathbf{g}\left(\hat{\boldsymbol{\theta}}^*\right)$, can be generated by using the simulated estimates to calculate \mathbf{g} . The standard deviations of the simulated estimates are the standard errors. Percentiles corresponding to $100\left(1-\alpha\right)\%$ are the confidence intervals.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("MCBeta").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est A vector of total, direct, and indirect effects.

thetahatstar A matrix of Monte Carlo total, direct, and indirect effects.

46 MCBeta

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
set.seed(42)
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
 data = c(
   0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
```

```
0.00110, -0.00016, -0.00283,
   -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050,
   -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Specific time interval ------
MCBeta(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 R = 100L # use a large value for R in actual research
)
# Range of time intervals ------
mc <- MCBeta(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 R = 100L # use a large value for R in actual research
)
plot(mc)
# Methods -----
# MCBeta has a number of methods including
# print, summary, confint, and plot
print(mc)
summary(mc)
confint(mc, level = 0.95)
plot(mc)
```

MCBetaStd

Monte Carlo Sampling Distribution for the Elements of the Standardized Matrix of Lagged Coefficients Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a Monte Carlo method sampling distribution for the elements of the standardized matrix of lagged coefficients β over a specific time interval Δt or a range of time intervals

using the first-order stochastic differential equation model drift matrix Φ and process noise covariance matrix Σ .

Usage

```
MCBetaStd(
   phi,
   sigma,
   vcov_theta,
   delta_t,
   R,
   test_phi = TRUE,
   ncores = NULL,
   seed = NULL,
   tol = 0.01
)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) . phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
vcov_theta	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\mathbf{\Phi}\right)$ and $\operatorname{vech}\left(\mathbf{\Sigma}\right)$
delta_t	Numeric. Time interval (Δt).
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix Φ . If the test returns FALSE, the function generates a new drift matrix Φ and runs the test recursively until the test returns TRUE.
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
seed	Random seed.
tol	Numeric. Smallest possible time interval to allow.

Details

See TotalStd().

Monte Carlo Method:

Let θ be a vector that combines $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise and $\operatorname{vech}(\Sigma)$, that is, the unique elements of the Σ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be a vector that combines $\operatorname{vec}(\hat{\Phi})$ and $\operatorname{vech}(\hat{\Sigma})$. Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

$$\hat{oldsymbol{ heta}} \sim \mathcal{N}\left(oldsymbol{ heta}, \mathbb{V}\left(\hat{oldsymbol{ heta}}
ight)
ight)$$

Using this distributional assumption, a sampling distribution of $\hat{\theta}$ which we refer to as $\hat{\theta}^*$ can be generated by replacing the population parameters with sample estimates, that is,

$$\hat{oldsymbol{ heta}}^* \sim \mathcal{N}\left(\hat{oldsymbol{ heta}}, \hat{\mathbb{V}}\left(\hat{oldsymbol{ heta}}
ight)
ight).$$

Let $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ be a parameter that is a function of the estimated parameters. A sampling distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$, which we refer to as $\mathbf{g}\left(\hat{\boldsymbol{\theta}}^*\right)$, can be generated by using the simulated estimates to calculate \mathbf{g} . The standard deviations of the simulated estimates are the standard errors. Percentiles corresponding to $100\left(1-\alpha\right)\%$ are the confidence intervals.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("MCBetaStd").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est A vector of total, direct, and indirect effects.

thetahatstar A matrix of Monte Carlo total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
 data = c(
   0.24455556, 0.02201587, -0.05004762,
   0.02201587, 0.07067800, 0.01539456,
    -0.05004762, 0.01539456, 0.07553061
 ),
 nrow = 3
)
vcov_theta <- matrix(
 data = c(
    0.00843, 0.00040, -0.00151, -0.00600, -0.00033,
   0.00110, 0.00324, 0.00020, -0.00061, -0.00115,
    0.00011, 0.00015, 0.00001, -0.00002, -0.00001,
   0.00040, 0.00374, 0.00016, -0.00022, -0.00273,
   -0.00016, 0.00009, 0.00150, 0.00012, -0.00010,
   -0.00026, 0.00002, 0.00012, 0.00004, -0.00001,
   -0.00151, 0.00016, 0.00389, 0.00103, -0.00007,
   -0.00283, -0.00050, 0.00000, 0.00156, 0.00021,
   -0.00005, -0.00031, 0.00001, 0.00007, 0.00006,
    -0.00600, -0.00022, 0.00103, 0.00644, 0.00031,
    -0.00119, -0.00374, -0.00021, 0.00070, 0.00064,
    -0.00015, -0.00005, 0.00000, 0.00003, -0.00001,
    -0.00033, -0.00273, -0.00007, 0.00031, 0.00287,
    0.00013, -0.00014, -0.00170, -0.00012, 0.00006,
    0.00014, \ -0.00001, \ -0.00015, \ 0.00000, \ 0.00001, \\
   0.00110, -0.00016, -0.00283, -0.00119, 0.00013,
   0.00297, 0.00063, -0.00004, -0.00177, -0.00013,
   0.00005, 0.00017, -0.00002, -0.00008, 0.00001,
   0.00324, 0.00009, -0.00050, -0.00374, -0.00014,
    0.00063, 0.00495, 0.00024, -0.00093, -0.00020,
    0.00006, -0.00010, 0.00000, -0.00001, 0.00004,
    0.00020, 0.00150, 0.00000, -0.00021, -0.00170,
    -0.00004, 0.00024, 0.00214, 0.00012, -0.00002,
    -0.00004, 0.00000, 0.00006, -0.00005, -0.00001,
    -0.00061, 0.00012, 0.00156, 0.00070, -0.00012,
    -0.00177, -0.00093, 0.00012, 0.00223, 0.00004,
    -0.00002, -0.00003, 0.00001, 0.00003, -0.00013,
   -0.00115, -0.00010, 0.00021, 0.00064, 0.00006,
    -0.00013, -0.00020, -0.00002, 0.00004, 0.00057,
   0.00001, -0.00009, 0.00000, 0.00000, 0.00001,
   0.00011, -0.00026, -0.00005, -0.00015, 0.00014,
   0.00005, 0.00006, -0.00004, -0.00002, 0.00001,
```

MCIndirectCentral 51

```
0.00012, 0.00001, 0.00000, -0.00002, 0.00000,
   0.00015, 0.00002, -0.00031, -0.00005, -0.00001,
   0.00017, -0.00010, 0.00000, -0.00003, -0.00009,
   0.00001, 0.00014, 0.00000, 0.00000, -0.00005,
   0.00001, 0.00012, 0.00001, 0.00000, -0.00015,
   -0.00002, 0.00000, 0.00006, 0.00001, 0.00000,
   0.00000, 0.00000, 0.00010, 0.00001, 0.00000,
   -0.00002, 0.00004, 0.00007, 0.00003, 0.00000,
   -0.00008, -0.00001, -0.00005, 0.00003, 0.00000,
   -0.00002, 0.00000, 0.00001, 0.00005, 0.00001,
   -0.00001, -0.00001, 0.00006, -0.00001, 0.00001,
   0.00001, 0.00004, -0.00001, -0.00013, 0.00001,
   0.00000, -0.00005, 0.00000, 0.00001, 0.00012
 ),
 nrow = 15
)
# Specific time interval ------
MCBetaStd(
 phi = phi,
 sigma = sigma,
 vcov_theta = vcov_theta,
 delta_t = 1,
 R = 100L # use a large value for R in actual research
)
# Range of time intervals -------
mc <- MCBetaStd(</pre>
 phi = phi,
 sigma = sigma,
 vcov_theta = vcov_theta,
 delta_t = 1:5,
 R = 100L # use a large value for R in actual research
)
plot(mc)
# Methods ------
# MCBetaStd has a number of methods including
# print, summary, confint, and plot
print(mc)
summary(mc)
confint(mc, level = 0.95)
plot(mc)
```

MCIndirectCentral

Monte Carlo Sampling Distribution of Indirect Effect Centrality Over a Specific Time Interval or a Range of Time Intervals

Description

52

This function generates a Monte Carlo method sampling distribution of the indirect effect centrality at a particular time interval Δt using the first-order stochastic differential equation model drift matrix Φ .

Usage

```
MCIndirectCentral(
  phi,
  vcov_phi_vec,
  delta_t,
  R,
  test_phi = TRUE,
  ncores = NULL,
  seed = NULL,
  tol = 0.01
)
```

Arguments

phi	Numaria matrix	The drift matrix	Ж)	phi should have row and column names
DUIT	Numeric maurix.	The arm maurix (Ψ).	phi should have row and column hames

pertaining to the variables in the system.

vcov_phi_vec Numeric matrix. The sampling variance-covariance matrix of $vec(\Phi)$.

delta_t Numeric. Time interval (Δt).

R Positive integer. Number of replications.

test_phi Logical. If test_phi = TRUE, the function tests the stability of the generated

drift matrix Φ . If the test returns FALSE, the function generates a new drift

matrix Φ and runs the test recursively until the test returns TRUE.

ncores Positive integer. Number of cores to use. If ncores = NULL, use a single core.

Consider using multiple cores when number of replications R is a large value.

seed Random seed.

tol Numeric. Smallest possible time interval to allow.

Details

See IndirectCentral() for more details.

Monte Carlo Method:

Let θ be $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\operatorname{vec}(\hat{\Phi})$. Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

$$\hat{oldsymbol{ heta}} \sim \mathcal{N}\left(oldsymbol{ heta}, \mathbb{V}\left(\hat{oldsymbol{ heta}}
ight)
ight)$$

Using this distributional assumption, a sampling distribution of $\hat{\theta}$ which we refer to as $\hat{\theta}^*$ can be generated by replacing the population parameters with sample estimates, that is,

$$\hat{oldsymbol{ heta}}^* \sim \mathcal{N}\left(\hat{oldsymbol{ heta}}, \hat{\mathbb{V}}\left(\hat{oldsymbol{ heta}}
ight)
ight).$$

MCIndirectCentral 53

Let $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ be a parameter that is a function of the estimated parameters. A sampling distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$, which we refer to as $\mathbf{g}\left(\hat{\boldsymbol{\theta}}^*\right)$, can be generated by using the simulated estimates to calculate \mathbf{g} . The standard deviations of the simulated estimates are the standard errors. Percentiles corresponding to $100 \left(1-\alpha\right)\%$ are the confidence intervals.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("MCIndirectCentral").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est A vector of indirect effect centrality.

thetahatstar A matrix of Monte Carlo indirect effect centrality.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
set.seed(42)
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,</pre>
```

54 MCIndirectCentral

```
0, 0, -0.693
 ),
 nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
 data = c(
   0.00843, 0.00040, -0.00151,
   -0.00600, -0.00033, 0.00110,
   0.00324, 0.00020, -0.00061,
   0.00040, 0.00374, 0.00016,
   -0.00022, -0.00273, -0.00016,
   0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
   -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
   -0.00033, -0.00273, -0.00007,
   0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Specific time interval ------
MCIndirectCentral(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 R = 100L # use a large value for R in actual research
)
# Range of time intervals ------
mc <- MCIndirectCentral(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 R = 100L # use a large value for R in actual research
)
```

MCMed 55

```
# Methods ------
# McIndirectCentral has a number of methods including
# print, summary, confint, and plot
print(mc)
summary(mc)
confint(mc, level = 0.95)
plot(mc)
```

MCMed

Monte Carlo Sampling Distribution of Total, Direct, and Indirect Effects of X on Y Through M Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a Monte Carlo method sampling distribution of the total, direct and indirect effects of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model drift matrix $\mathbf{\Phi}$.

Usage

```
MCMed(
   phi,
   vcov_phi_vec,
   delta_t,
   from,
   to,
   med,
   R,
   test_phi = TRUE,
   ncores = NULL,
   seed = NULL,
   tol = 0.01
)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
vcov_phi_vec	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\mathbf{\Phi}\right)$.
delta_t	Numeric. Time interval (Δt).
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.

56 MCMed

med Character vector. Name/s of the mediator variable/s in phi.
 R Positive integer. Number of replications.
 test_phi Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix Φ. If the test returns FALSE, the function generates a new drift matrix Φ and runs the test recursively until the test returns TRUE.
 ncores Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
 seed Random seed.
 tol Numeric. Smallest possible time interval to allow.

Details

See Total(), Direct(), and Indirect() for more details.

Monte Carlo Method:

Let θ be $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\operatorname{vec}(\hat{\Phi})$. Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

$$\hat{oldsymbol{ heta}} \sim \mathcal{N}\left(oldsymbol{ heta}, \mathbb{V}\left(\hat{oldsymbol{ heta}}
ight)
ight)$$

Using this distributional assumption, a sampling distribution of $\hat{\theta}$ which we refer to as $\hat{\theta}^*$ can be generated by replacing the population parameters with sample estimates, that is,

$$\hat{oldsymbol{ heta}}^* \sim \mathcal{N}\left(\hat{oldsymbol{ heta}}, \hat{\mathbb{V}}\left(\hat{oldsymbol{ heta}}
ight)
ight).$$

Let $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ be a parameter that is a function of the estimated parameters. A sampling distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$, which we refer to as $\mathbf{g}\left(\hat{\boldsymbol{\theta}}^*\right)$, can be generated by using the simulated estimates to calculate \mathbf{g} . The standard deviations of the simulated estimates are the standard errors. Percentiles corresponding to $100\left(1-\alpha\right)\%$ are the confidence intervals.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("MCMed").

output A list with length of length(delta_t).

Each element in the output list has the following elements:

est A vector of total, direct, and indirect effects.

thetahatstar A matrix of Monte Carlo total, direct, and indirect effects.

MCMed 57

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
set.seed(42)
phi <- matrix(</pre>
 data = c(
    -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
 data = c(
   0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
```

58 MCMedStd

```
0.00110, -0.00016, -0.00283,
   -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050,
   -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Specific time interval ------
MCMed(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m",
 R = 100L \; \# \; use \; a \; large \; value \; for \; R \; in \; actual \; research
)
# Range of time intervals ------
mc <- MCMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m",
 R = 100L # use a large value for R in actual research
)
plot(mc)
# Methods -----
# MCMed has a number of methods including
# print, summary, confint, and plot
print(mc)
summary(mc)
confint(mc, level = 0.95)
```

MCMedStd

Monte Carlo Sampling Distribution of Standardized Total, Direct, and Indirect Effects of X on Y Through M Over a Specific Time Interval or a Range of Time Intervals

MCMedStd 59

Description

This function generates a Monte Carlo method sampling distribution of the standardized total, direct and indirect effects of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model drift matrix $\mathbf{\Phi}$ and process noise covariance matrix $\mathbf{\Sigma}$.

Usage

```
MCMedStd(
    phi,
    sigma,
    vcov_theta,
    delta_t,
    from,
    to,
    med,
    R,
    test_phi = TRUE,
    ncores = NULL,
    seed = NULL,
    tol = 0.01
)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) . phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
vcov_theta	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\Phi\right)$ and $\operatorname{vech}\left(\Sigma\right)$
delta_t	Numeric. Time interval (Δt).
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix Φ . If the test returns FALSE, the function generates a new drift matrix Φ and runs the test recursively until the test returns TRUE.
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
seed	Random seed.
tol	Numeric. Smallest possible time interval to allow.

Details

See TotalStd(), DirectStd(), and IndirectStd() for more details.

Monte Carlo Method:

Let θ be a vector that combines $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise and $\operatorname{vech}(\Sigma)$, that is, the unique elements of the Σ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be a vector that combines $\operatorname{vec}(\hat{\Phi})$ and $\operatorname{vech}(\hat{\Sigma})$. Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

$$\hat{oldsymbol{ heta}} \sim \mathcal{N}\left(oldsymbol{ heta}, \mathbb{V}\left(\hat{oldsymbol{ heta}}
ight)
ight)$$

Using this distributional assumption, a sampling distribution of $\hat{\theta}$ which we refer to as $\hat{\theta}^*$ can be generated by replacing the population parameters with sample estimates, that is,

$$\hat{oldsymbol{ heta}}^* \sim \mathcal{N}\left(\hat{oldsymbol{ heta}}, \hat{\mathbb{V}}\left(\hat{oldsymbol{ heta}}
ight)
ight).$$

Let $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ be a parameter that is a function of the estimated parameters. A sampling distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$, which we refer to as $\mathbf{g}\left(\hat{\boldsymbol{\theta}}^*\right)$, can be generated by using the simulated estimates to calculate \mathbf{g} . The standard deviations of the simulated estimates are the standard errors. Percentiles corresponding to $100\left(1-\alpha\right)\%$ are the confidence intervals.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("MCMedStd").

output A list with length of length(delta_t).

Each element in the output list has the following elements:

est A vector of total, direct, and indirect effects.

thetahatstar A matrix of Monte Carlo total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

MCMedStd 61

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ).
 nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
 data = c(
   0.24455556, 0.02201587, -0.05004762,
   0.02201587, 0.07067800, 0.01539456,
   -0.05004762, 0.01539456, 0.07553061
 ),
 nrow = 3
)
vcov_theta <- matrix(
 data = c(
    0.00843, 0.00040, -0.00151, -0.00600, -0.00033,
   0.00110, 0.00324, 0.00020, -0.00061, -0.00115,
   0.00011, 0.00015, 0.00001, -0.00002, -0.00001,
   0.00040, 0.00374, 0.00016, -0.00022, -0.00273,
   -0.00016, 0.00009, 0.00150, 0.00012, -0.00010,
    -0.00026, 0.00002, 0.00012, 0.00004, -0.00001,
   -0.00151, 0.00016, 0.00389, 0.00103, -0.00007,
   -0.00283, -0.00050, 0.00000, 0.00156, 0.00021,
   -0.00005, -0.00031, 0.00001, 0.00007, 0.00006,
   -0.00600, -0.00022, 0.00103, 0.00644, 0.00031,
   -0.00119, -0.00374, -0.00021, 0.00070, 0.00064,
   -0.00015, -0.00005, 0.00000, 0.00003, -0.00001,
    -0.00033, -0.00273, -0.00007, 0.00031, 0.00287,
   0.00013, -0.00014, -0.00170, -0.00012, 0.00006,
   0.00014, -0.00001, -0.00015, 0.00000, 0.00001,
   0.00110, -0.00016, -0.00283, -0.00119, 0.00013,
   0.00297, 0.00063, -0.00004, -0.00177, -0.00013,
   0.00005, 0.00017, -0.00002, -0.00008, 0.00001,
   0.00324, 0.00009, -0.00050, -0.00374, -0.00014,
   0.00063, 0.00495, 0.00024, -0.00093, -0.00020,
   0.00006, -0.00010, 0.00000, -0.00001, 0.00004,
   0.00020, 0.00150, 0.00000, -0.00021, -0.00170,
   -0.00004, 0.00024, 0.00214, 0.00012, -0.00002,
   -0.00004, 0.00000, 0.00006, -0.00005, -0.00001,
```

62 MCMedStd

```
-0.00061, 0.00012, 0.00156, 0.00070, -0.00012,
   -0.00177, -0.00093, 0.00012, 0.00223, 0.00004,
   -0.00002, -0.00003, 0.00001, 0.00003, -0.00013,
   -0.00115, -0.00010, 0.00021, 0.00064, 0.00006,
   -0.00013, -0.00020, -0.00002, 0.00004, 0.00057,
   0.00001, -0.00009, 0.00000, 0.00000, 0.00001,
   0.00011, -0.00026, -0.00005, -0.00015, 0.00014,
   0.00005, 0.00006, -0.00004, -0.00002, 0.00001,
   0.00012, 0.00001, 0.00000, -0.00002, 0.00000,
   0.00015, 0.00002, -0.00031, -0.00005, -0.00001,
   0.00017, -0.00010, 0.00000, -0.00003, -0.00009,
   0.00001, 0.00014, 0.00000, 0.00000, -0.00005,
   0.00001, 0.00012, 0.00001, 0.00000, -0.00015,
   -0.00002, 0.00000, 0.00006, 0.00001, 0.00000,
   0.00000, 0.00000, 0.00010, 0.00001, 0.00000,
   -0.00002, 0.00004, 0.00007, 0.00003, 0.00000,
   -0.00008, -0.00001, -0.00005, 0.00003, 0.00000,
   -0.00002, 0.00000, 0.00001, 0.00005, 0.00001,
   -0.00001, -0.00001, 0.00006, -0.00001, 0.00001,
   0.00001, 0.00004, -0.00001, -0.00013, 0.00001,
   0.00000, -0.00005, 0.00000, 0.00001, 0.00012
 ),
 nrow = 15
)
# Specific time interval -------
MCMedStd(
 phi = phi,
 sigma = sigma,
 vcov_theta = vcov_theta,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m",
 R = 100L # use a large value for R in actual research
)
# Range of time intervals ------
mc <- MCMedStd(</pre>
 phi = phi,
 sigma = sigma,
 vcov_theta = vcov_theta,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m",
 R = 100L # use a large value for R in actual research
)
plot(mc)
# Methods ------
# MCMedStd has a number of methods including
# print, summary, confint, and plot
```

MCPhi 63

```
print(mc)
summary(mc)
confint(mc, level = 0.95)
```

MCPhi

Generate Random Drift Matrices Using the Monte Carlo Method

Description

This function generates random drift matrices Φ using the Monte Carlo method.

Usage

```
MCPhi(phi, vcov_phi_vec, R, test_phi = TRUE, ncores = NULL, seed = NULL)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
vcov_phi_vec	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\Phi\right)$.
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix Φ . If the test returns FALSE, the function generates a new drift matrix Φ and runs the test recursively until the test returns TRUE.
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.

Details

seed

Monte Carlo Method:

Random seed.

Let θ be $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\operatorname{vec}(\hat{\Phi})$. Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

$$\hat{oldsymbol{ heta}} \sim \mathcal{N}\left(oldsymbol{ heta}, \mathbb{V}\left(\hat{oldsymbol{ heta}}
ight)
ight)$$

Using this distributional assumption, a sampling distribution of $\hat{\theta}$ which we refer to as $\hat{\theta}^*$ can be generated by replacing the population parameters with sample estimates, that is,

$$\hat{oldsymbol{ heta}}^* \sim \mathcal{N}\left(\hat{oldsymbol{ heta}}, \hat{\mathbb{V}}\left(\hat{oldsymbol{ heta}}
ight)
ight).$$

64 MCPhi

Value

Returns an object of class ctmedmc which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("MCPhi").output A list simulated drift matrices.
```

Author(s)

Ivan Jacob Agaloos Pesigan

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
set.seed(42)
phi <- matrix(</pre>
 data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
MCPhi(
  phi = phi,
  vcov_phi_vec = 0.1 * diag(9),
  R = 100L # use a large value for R in actual research
)
phi <- matrix(</pre>
  data = c(
    -6, 5.5, 0, 0,
    1.25, -2.5, 5.9, -7.3,
    0, 0, -6, 2.5,
    5, 0, 0, -6
  ),
  nrow = 4
colnames(phi) <- rownames(phi) <- paste0("y", 1:4)</pre>
MCPhi(
  phi = phi,
  vcov_phi_vec = 0.1 * diag(16),
```

MCTotalCentral 65

```
R = 100L, # use a large value for R in actual research
test_phi = FALSE
)
```

MCTotalCentral

Monte Carlo Sampling Distribution of Total Effect Centrality Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a Monte Carlo method sampling distribution of the total effect centrality at a particular time interval Δt using the first-order stochastic differential equation model drift matrix Φ .

Usage

```
MCTotalCentral(
  phi,
  vcov_phi_vec,
  delta_t,
  R,
  test_phi = TRUE,
  ncores = NULL,
  seed = NULL,
  tol = 0.01
)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ). phi should have row and column names pertaining to the variables in the system.
vcov_phi_vec	Numeric matrix. The sampling variance-covariance matrix of $\operatorname{vec}\left(\mathbf{\Phi}\right)$.
delta_t	Numeric. Time interval (Δt).
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix Φ . If the test returns FALSE, the function generates a new drift matrix Φ and runs the test recursively until the test returns TRUE.
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
seed	Random seed.
tol	Numeric. Smallest possible time interval to allow.

Details

66

See TotalCentral() for more details.

Monte Carlo Method:

Let θ be $\operatorname{vec}(\Phi)$, that is, the elements of the Φ matrix in vector form sorted column-wise. Let $\hat{\theta}$ be $\operatorname{vec}(\hat{\Phi})$. Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

$$\hat{oldsymbol{ heta}} \sim \mathcal{N}\left(oldsymbol{ heta}, \mathbb{V}\left(\hat{oldsymbol{ heta}}
ight)
ight)$$

Using this distributional assumption, a sampling distribution of $\hat{\theta}$ which we refer to as $\hat{\theta}^*$ can be generated by replacing the population parameters with sample estimates, that is,

$$\hat{oldsymbol{ heta}}^* \sim \mathcal{N}\left(\hat{oldsymbol{ heta}}, \hat{\mathbb{V}}\left(\hat{oldsymbol{ heta}}
ight)
ight).$$

Let $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$ be a parameter that is a function of the estimated parameters. A sampling distribution of $\mathbf{g}\left(\hat{\boldsymbol{\theta}}\right)$, which we refer to as $\mathbf{g}\left(\hat{\boldsymbol{\theta}}^*\right)$, can be generated by using the simulated estimates to calculate \mathbf{g} . The standard deviations of the simulated estimates are the standard errors. Percentiles corresponding to $100\left(1-\alpha\right)\%$ are the confidence intervals.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("MCTotalCentral").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est A vector of total effect centrality.

thetahatstar A matrix of Monte Carlo total effect centrality.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

MCTotalCentral 67

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
set.seed(42)
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
 data = c(
   0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
   0.00324, 0.00020, -0.00061,
   0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283.
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
    0.00495, 0.00024, -0.00093,
    0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
    0.00024, 0.00214, 0.00012,
    -0.00061, 0.00012, 0.00156,
    0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
```

Med Med

```
# Specific time interval ------
MCTotalCentral(
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 R = 100L # use a large value for R in actual research
)
# Range of time intervals -----
mc <- MCTotalCentral(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 R = 100L # use a large value for R in actual research
)
plot(mc)
# Methods ------
# MCTotalCentral has a number of methods including
# print, summary, confint, and plot
print(mc)
summary(mc)
confint(mc, level = 0.95)
plot(mc)
```

Med

Total, Direct, and Indirect Effects of X on Y Through M Over a Specific Time Interval or a Range of Time Intervals

Description

This function computes the total, direct, and indirect effects of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix $\mathbf{\Phi}$.

Usage

```
Med(phi, delta_t, from, to, med, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ). phi should have row and column names pertaining to the variables in the system.
delta_t	Vector of positive numbers. Time interval (Δt).
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.
tol	Numeric. Smallest possible time interval to allow.

Med 69

Details

See Total(), Direct(), and Indirect() for more details.

Linear Stochastic Differential Equation Model:

The measurement model is given by

$$\mathbf{y}_{i,t} = oldsymbol{
u} + oldsymbol{\Lambda} oldsymbol{\eta}_{i,t} + oldsymbol{arepsilon}_{i,t}, \quad ext{with} \quad oldsymbol{arepsilon}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, oldsymbol{\Theta}
ight)$$

where $\mathbf{y}_{i,t}$, $\eta_{i,t}$, and $\varepsilon_{i,t}$ are random variables and ν , Λ , and Θ are model parameters. $\mathbf{y}_{i,t}$ represents a vector of observed random variables, $\eta_{i,t}$ a vector of latent random variables, and $\varepsilon_{i,t}$ a vector of random measurement errors, at time t and individual i. ν denotes a vector of intercepts, Λ a matrix of factor loadings, and Θ the covariance matrix of ε .

An alternative representation of the measurement error is given by

$$oldsymbol{arepsilon}_{i,t} = oldsymbol{\Theta}^{rac{1}{2}} \mathbf{z}_{i,t}, \quad ext{with} \quad \mathbf{z}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{I}
ight)$$

where $\mathbf{z}_{i,t}$ is a vector of independent standard normal random variables and $\left(\Theta^{\frac{1}{2}}\right)\left(\Theta^{\frac{1}{2}}\right)' = \Theta$. The dynamic structure is given by

$$\mathrm{d}\boldsymbol{\eta}_{i,t} = \left(\boldsymbol{\iota} + \boldsymbol{\Phi}\boldsymbol{\eta}_{i,t}\right) \mathrm{d}t + \boldsymbol{\Sigma}^{\frac{1}{2}} \mathrm{d}\mathbf{W}_{i,t}$$

where ι is a term which is unobserved and constant over time, Φ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, Σ is the matrix of volatility or randomness in the process, and $\mathrm{d}W$ is a Wiener process or Brownian motion, which represents random fluctuations.

Value

Returns an object of class ctmedmed which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("Med").

output A matrix of total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

70 Med

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
)
colnames(phi) \leftarrow rownames(phi) \leftarrow c("x", "m", "y")
# Specific time interval ------
Med(
 phi = phi,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
)
# Range of time intervals ------
med <- Med(
 phi = phi,
 delta_t = 1:30,
 from = "x",
 to = "y",
 med = "m"
)
plot(med)
# Methods -----
# Med has a number of methods including
# print, summary, and plot
med <- Med(</pre>
 phi = phi,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
print(med)
summary(med)
plot(med)
```

MedStd 71

MedStd	Standardized Total, Direct, and Indirect Effects of X on Y Through M Over a Specific Time Interval or a Range of Time Intervals

Description

This function computes the standardized total, direct, and indirect effects of the independent variable X on the dependent variable Y through mediator variables $\mathbf m$ over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model's drift matrix Φ and process noise covariance matrix Σ .

Usage

```
MedStd(phi, sigma, delta_t, from, to, med, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
delta_t	Numeric. Time interval (Δt) .
from	Character string. Name of the independent variable X in phi.
to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.
tol	Numeric. Smallest possible time interval to allow.

Details

```
See TotalStd(), DirectStd(), and IndirectStd() for more details.
```

Value

Returns an object of class ctmedmed which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("MedStd").output A matrix of total, direct, and indirect effects.
```

Author(s)

Ivan Jacob Agaloos Pesigan

72 MedStd

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
 data = c(
   0.24455556, 0.02201587, -0.05004762,
   0.02201587, 0.07067800, 0.01539456,
   -0.05004762, 0.01539456, 0.07553061
 ),
 nrow = 3
# Specific time interval ------
MedStd(
 phi = phi,
 sigma = sigma,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
)
# Range of time intervals ------
med <- MedStd(</pre>
 phi = phi,
```

plot.ctmeddelta 73

```
sigma = sigma,
 delta_t = 1:30,
 from = "x",
 to = "y",
 med = "m"
)
plot(med)
# Methods ------
# MedStd has a number of methods including
# print, summary, and plot
med <- MedStd(</pre>
 phi = phi,
 sigma = sigma,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
)
print(med)
summary(med)
plot(med)
```

plot.ctmeddelta

Plot Method for an Object of Class ctmeddelta

Description

Plot Method for an Object of Class ctmeddelta

Usage

```
## S3 method for class 'ctmeddelta'
plot(x, alpha = 0.05, col = NULL, ...)
```

Arguments

Х	Object of class ctmeddelta.
alpha	Numeric. Significance level
col	Character vector. Optional argument. Character vector of colors.
	Additional arguments.

Value

Displays plots of point estimates and confidence intervals.

74 plot.ctmeddelta

Author(s)

Ivan Jacob Agaloos Pesigan

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
 data = c(
   0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
   0.00324, 0.00020, -0.00061,
   0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
   0.00009, 0.00150, 0.00012,
   -0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
   -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
   -0.00033, -0.00273, -0.00007,
   0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050,
   -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Range of time intervals -------
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
```

plot.ctmedmc 75

```
from = "x",
  to = "y",
  med = "m"
)
plot(delta)
```

plot.ctmedmc

Plot Method for an Object of Class ctmedmc

Description

Plot Method for an Object of Class ctmedmc

Usage

```
## S3 method for class 'ctmedmc'
plot(x, alpha = 0.05, col = NULL, ...)
```

Arguments

x	Object of class ctmedmc.
alpha	Numeric. Significance level
col	Character vector. Optional argument. Character vector of colors.
	Additional arguments.

Value

Displays plots of point estimates and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

```
set.seed(42)
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")
vcov_phi_vec <- matrix(
  data = c(</pre>
```

76 plot.ctmedmed

```
0.00843, 0.00040, -0.00151,
   -0.00600, -0.00033, 0.00110,
   0.00324, 0.00020, -0.00061,
   0.00040, 0.00374, 0.00016,
   -0.00022, -0.00273, -0.00016,
   0.00009, 0.00150, 0.00012,
   -0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
   -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
   -0.00033, -0.00273, -0.00007,
   0.00031, 0.00287, 0.00013,
   -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
   -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050,
   -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
# Range of time intervals ------
mc <- MCMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
 R = 100L # use a large value for R in actual research
plot(mc)
```

plot.ctmedmed

Plot Method for an Object of Class ctmedmed

Description

Plot Method for an Object of Class ctmedmed

plot.ctmedmed 77

Usage

```
## S3 method for class 'ctmedmed'
plot(x, col = NULL, legend_pos = "topright", ...)
```

Arguments

x Object of class ctmedmed.

col Character vector. Optional argument. Character vector of colors.

legend_pos Character vector. Optional argument. Legend position.

... Additional arguments.

Value

Displays plots of point estimates and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
# Range of time intervals ------
med <- Med(
 phi = phi,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
)
plot(med)
```

78 plot.ctmedtraj

plot.ctmedtraj

Plot Method for an Object of Class ctmedtraj

Description

Plot Method for an Object of Class ctmedtraj

Usage

```
## S3 method for class 'ctmedtraj'
plot(x, legend_pos = "topright", total = TRUE, ...)
```

Arguments

```
    x Object of class ctmedtraj.
    legend_pos Character vector. Optional argument. Legend position.
    total Logical. If total = TRUE, include the total effect trajectory. If total = FALSE, exclude the total effect trajectory.
    ... Additional arguments.
```

Value

Displays trajectory plots of the effects.

Author(s)

Ivan Jacob Agaloos Pesigan

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")

traj <- Trajectory(
  mu0 = c(3, 3, -3),
    time = 150,
    phi = phi,
    med = "m"
)

plot(traj)</pre>
```

PosteriorBeta 79

PosteriorBeta	Posterior Sampling Distribution for the Elements of the Matrix of Lagged Coefficients Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a posterior sampling distribution for the elements of the matrix of lagged coefficients β over a specific time interval Δt or a range of time intervals using the first-order stochastic differential equation model drift matrix Φ .

Usage

```
PosteriorBeta(phi, delta_t, ncores = NULL, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval (Δt).
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
tol	Numeric. Smallest possible time interval to allow.

Details

```
See Total().
```

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("PosteriorBeta").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est A vector of total, direct, and indirect effects.

thetahatstar A matrix of Monte Carlo total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

80 PosteriorBeta

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
```

PosteriorIndirectCentral 81

```
0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
phi <- MCPhi(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 R = 1000L
)$output
# Specific time interval ------
PosteriorBeta(
 phi = phi,
 delta_t = 1
)
# Range of time intervals ------
posterior <- PosteriorBeta(</pre>
 phi = phi,
 delta_t = 1:5
plot(posterior)
# Methods -----
# PosteriorBeta has a number of methods including
# print, summary, confint, and plot
print(posterior)
summary(posterior)
confint(posterior, level = 0.95)
plot(posterior)
```

PosteriorIndirectCentral

Posterior Distribution of the Indirect Effect Centrality Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a posterior distribution of the indirect effect centrality over a specific time interval Δt or a range of time intervals using the posterior distribution of the first-order stochastic differential equation model drift matrix Φ .

82 PosteriorIndirectCentral

Usage

PosteriorIndirectCentral(phi, delta_t, ncores = NULL, tol = 0.01)

Arguments

phi List of numeric matrices. Each element of the list is a sample from the posterior

distribution of the drift matrix (Φ). Each matrix should have row and column

names pertaining to the variables in the system.

delta_t Numeric. Time interval (Δt).

ncores Positive integer. Number of cores to use. If ncores = NULL, use a single core.

Consider using multiple cores when number of replications R is a large value.

tol Numeric. Smallest possible time interval to allow.

Details

See TotalCentral() for more details.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("PosteriorIndirectCentral").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est Mean of the posterior distribution of the total, direct, and indirect effects.

thetahatstar Posterior distribution of the total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

PosteriorIndirectCentral 83

See Also

Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorMed(), PosteriorTotalCentral(), TotalCentral(), TotalStd(), Trajectory()

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
 data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
   0.00324, 0.00020, -0.00061,
   0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
   0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
    0.00495, 0.00024, -0.00093,
    0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
    0.00024, 0.00214, 0.00012,
    -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
phi <- MCPhi(</pre>
```

84 PosteriorMed

```
phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 R = 1000L
)$output
# Specific time interval -------
PosteriorIndirectCentral(
 phi = phi,
 delta_t = 1
)
# Range of time intervals ------
posterior <- PosteriorIndirectCentral(</pre>
 phi = phi,
 delta_t = 1:5
# Methods ------
# PosteriorIndirectCentral has a number of methods including
# print, summary, confint, and plot
print(posterior)
summary(posterior)
confint(posterior, level = 0.95)
plot(posterior)
```

PosteriorMed

Posterior Distribution of Total, Direct, and Indirect Effects of X on Y Through M Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a posterior distribution of the total, direct and indirect effects of the independent variable X on the dependent variable Y through mediator variables \mathbf{m} over a specific time interval Δt or a range of time intervals using the posterior distribution of the first-order stochastic differential equation model drift matrix $\mathbf{\Phi}$.

Usage

```
PosteriorMed(phi, delta_t, from, to, med, ncores = NULL, tol = 0.01)
```

Arguments

phi	List of numeric matrices. Each element of the list is a sample from the posterior distribution of the drift matrix (Φ). Each matrix should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval (Δt).
from	Character string. Name of the independent variable X in phi.

PosteriorMed 85

to	Character string. Name of the dependent variable Y in phi.
med	Character vector. Name/s of the mediator variable/s in phi.
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
tol	Numeric. Smallest possible time interval to allow.

Details

See Total(), Direct(), and Indirect() for more details.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("PosteriorMed").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est Mean of the posterior distribution of the total, direct, and indirect effects.

thetahatstar Posterior distribution of the total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

86 PosteriorMed

```
phi <- matrix(</pre>
  data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) \leftarrow rownames(phi) \leftarrow c("x", "m", "y")
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
   0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
    0.00495, 0.00024, -0.00093,
    0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
    -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
  ),
  nrow = 9
)
phi <- MCPhi(</pre>
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  R = 1000L
)$output
# Specific time interval ------
PosteriorMed(
  phi = phi,
```

PosteriorTotalCentral 87

```
delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
)
# Range of time intervals ------
posterior <- PosteriorMed(</pre>
 phi = phi,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
# PosteriorMed has a number of methods including
# print, summary, confint, and plot
print(posterior)
summary(posterior)
confint(posterior, level = 0.95)
plot(posterior)
```

PosteriorTotalCentral Posterior Distribution of the Total Effect Centrality Over a Specific Time Interval or a Range of Time Intervals

Description

This function generates a posterior distribution of the total effect centrality over a specific time interval Δt or a range of time intervals using the posterior distribution of the first-order stochastic differential equation model drift matrix Φ .

Usage

```
PosteriorTotalCentral(phi, delta_t, ncores = NULL, tol = 0.01)
```

Arguments

phi	List of numeric matrices. Each element of the list is a sample from the posterior distribution of the drift matrix (Φ). Each matrix should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval (Δt).
ncores	Positive integer. Number of cores to use. If ncores = NULL, use a single core. Consider using multiple cores when number of replications R is a large value.
tol	Numeric. Smallest possible time interval to allow.

88 PosteriorTotalCentral

Details

See TotalCentral() for more details.

Value

Returns an object of class ctmedmc which is a list with the following elements:

call Function call.

args Function arguments.

fun Function used ("PosteriorTotalCentral").

output A list the length of which is equal to the length of delta_t.

Each element in the output list has the following elements:

est Mean of the posterior distribution of the total, direct, and indirect effects.

thetahatstar Posterior distribution of the total, direct, and indirect effects.

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), Total(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)</pre>
```

PosteriorTotalCentral 89

```
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
 data = c(
   0.00843, 0.00040, -0.00151,
   -0.00600, -0.00033, 0.00110,
   0.00324, 0.00020, -0.00061,
   0.00040, 0.00374, 0.00016,
   -0.00022, -0.00273, -0.00016,
   0.00009, 0.00150, 0.00012,
   -0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
   -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
   -0.00033, -0.00273, -0.00007,
   0.00031, 0.00287, 0.00013,
   -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
   -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050.
   -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
phi <- MCPhi(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 R = 1000L
)$output
# Specific time interval ------
PosteriorTotalCentral(
 phi = phi,
 delta_t = 1
)
# Range of time intervals ------
posterior <- PosteriorTotalCentral(</pre>
 phi = phi,
 delta_t = 1:5
)
# Methods ------
```

90 print.ctmeddelta

```
# PosteriorTotalCentral has a number of methods including
# print, summary, confint, and plot
print(posterior)
summary(posterior)
confint(posterior, level = 0.95)
plot(posterior)
```

print.ctmeddelta

Print Method for Object of Class ctmeddelta

Description

Print Method for Object of Class ctmeddelta

Usage

```
## S3 method for class 'ctmeddelta'
print(x, alpha = 0.05, digits = 4, ...)
```

Arguments

x an object of class ctmeddelta. alpha Numeric vector. Significance level α . digits Integer indicating the number of decimal places to display. ... further arguments.

Value

Prints a list of matrices of time intervals, estimates, standard errors, test statistics, p-values, and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")
vcov_phi_vec <- matrix(</pre>
```

print.ctmeddelta 91

```
data = c(
   0.00843, 0.00040, -0.00151,
   -0.00600, -0.00033, 0.00110,
   0.00324, 0.00020, -0.00061,
   0.00040, 0.00374, 0.00016,
   -0.00022, -0.00273, -0.00016,
   0.00009, 0.00150, 0.00012,
   -0.00151, 0.00016, 0.00389,
   0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
   -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
   -0.00033, -0.00273, -0.00007,
   0.00031, 0.00287, 0.00013,
   -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
   -0.00119, 0.00013, 0.00297,
   0.00063, -0.00004, -0.00177,
   0.00324, 0.00009, -0.00050,
   -0.00374, -0.00014, 0.00063,
   0.00495, 0.00024, -0.00093,
   0.00020, 0.00150, 0.00000,
   -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
   -0.00093, 0.00012, 0.00223
 ),
 nrow = 9
)
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
print(delta)
# Range of time intervals ------
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 from = x^{*},
 to = "y",
 med = "m"
print(delta)
```

92 print.ctmedeffect

print.ctmedeffect

Print Method for Object of Class ctmedeffect

Description

Print Method for Object of Class ctmedeffect

Usage

```
## S3 method for class 'ctmedeffect'
print(x, digits = 4, ...)
```

Arguments

```
x an object of class ctmedeffect.digits Integer indicating the number of decimal places to display.... further arguments.
```

Value

Prints the effects.

Author(s)

Ivan Jacob Agaloos Pesigan

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
delta_t <- 1
# Time Interval of One ------
## Total Effect ------
total_dt <- Total(</pre>
 phi = phi,
 delta_t = delta_t
print(total_dt)
```

print.ctmedmc 93

```
direct_dt <- Direct(</pre>
 phi = phi,
 delta_t = delta_t,
 from = "x",
 to = "y",
 med = "m"
print(direct_dt)
## Indirect Effect ------
indirect_dt <- Indirect(</pre>
 phi = phi,
 delta_t = delta_t,
 from = "x",
 to = "y",
 med = "m"
)
print(indirect_dt)
```

print.ctmedmc

Print Method for Object of Class ctmedmc

Description

Print Method for Object of Class ctmedmc

Usage

```
## S3 method for class 'ctmedmc'
print(x, alpha = 0.05, digits = 4, ...)
```

Arguments

x an object of class ctmedmc. alpha Numeric vector. Significance level α . digits Integer indicating the number of decimal places to display. . . . further arguments.

Value

Prints a list of matrices of time intervals, estimates, standard errors, number of Monte Carlo replications, and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

94 print.ctmedmc

```
set.seed(42)
phi <- matrix(</pre>
  data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
    0.00495, 0.00024, -0.00093,
    0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
  ),
 nrow = 9
)
# Specific time interval ------
mc <- MCMed(</pre>
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m",
```

print.ctmedmcphi 95

print.ctmedmcphi

Print Method for Object of Class ctmedmcphi

Description

Print Method for Object of Class ctmedmcphi

Usage

```
## S3 method for class 'ctmedmcphi'
print(x, digits = 4, ...)
```

Arguments

x an object of class ctmedmcphi.

digits Integer indicating the number of decimal places to display.

... further arguments.

Value

Prints a list of drift matrices.

Author(s)

Ivan Jacob Agaloos Pesigan

96 print.ctmedmed

Examples

```
set.seed(42)
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) \leftarrow rownames(phi) \leftarrow c("x", "m", "y")
mc <- MCPhi(</pre>
  phi = phi,
  vcov_phi_vec = 0.1 * diag(9),
  R = 100L # use a large value for R in actual research
)
print(mc)
```

print.ctmedmed

Print Method for Object of Class ctmedmed

Description

Print Method for Object of Class ctmedmed

Usage

```
## S3 method for class 'ctmedmed'
print(x, digits = 4, ...)
```

Arguments

x an object of class ctmedmed.digits Integer indicating the number of decimal places to display.... further arguments.

Value

Prints a matrix of effects.

Author(s)

Ivan Jacob Agaloos Pesigan

print.ctmedtraj 97

Examples

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
# Specific time interval ------
med <- Med(
 phi = phi,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
print(med)
# Range of time intervals ------
med <- Med(
 phi = phi,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
print(med)
```

print.ctmedtraj

Print Method for Object of Class ctmedtraj

Description

Print Method for Object of Class ctmedtraj

Usage

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

Arguments

```
x an object of class ctmedtraj.
```

... further arguments.

98 summary.ctmeddelta

Value

Prints a data frame of simulated data.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
traj <- Trajectory(</pre>
  mu0 = c(3, 3, -3),
  time = 150,
  phi = phi,
  med = "m"
)
print(traj)
```

summary.ctmeddelta

Summary Method for an Object of Class ctmeddelta

Description

Summary Method for an Object of Class ctmeddelta

Usage

```
## S3 method for class 'ctmeddelta'
summary(object, alpha = 0.05, ...)
```

Arguments

```
object Object of class ctmeddelta. 
 alpha Numeric vector. Significance level \alpha. 
 additional arguments.
```

summary.ctmeddelta 99

Value

Returns a data frame of effects, time intervals, estimates, standard errors, test statistics, p-values, and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
    -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
    0.00644, 0.00031, -0.00119,
    -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
    0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
    0.00495, 0.00024, -0.00093,
    0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
    0.00024, 0.00214, 0.00012,
    -0.00061, 0.00012, 0.00156,
    0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
  ),
  nrow = 9
)
```

100 summary.ctmedmc

```
# Specific time interval -----
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
)
summary(delta)
# Range of time intervals ------
delta <- DeltaMed(</pre>
 phi = phi,
 vcov_phi_vec = vcov_phi_vec,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
)
summary(delta)
```

summary.ctmedmc

Summary Method for an Object of Class ctmedmc

Description

Summary Method for an Object of Class ctmedmc

Usage

```
## S3 method for class 'ctmedmc'
summary(object, alpha = 0.05, ...)
```

Arguments

object Object of class ctmedmc. alpha Numeric vector. Significance level α .

... additional arguments.

Value

Returns a data frame of effects, time intervals, estimates, standard errors, number of Monte Carlo replications, and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

summary.ctmedmc 101

```
set.seed(42)
phi <- matrix(</pre>
  data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
vcov_phi_vec <- matrix(</pre>
  data = c(
    0.00843, 0.00040, -0.00151,
    -0.00600, -0.00033, 0.00110,
    0.00324, 0.00020, -0.00061,
    0.00040, 0.00374, 0.00016,
    -0.00022, -0.00273, -0.00016,
    0.00009, 0.00150, 0.00012,
    -0.00151, 0.00016, 0.00389,
    0.00103, -0.00007, -0.00283,
   -0.00050, 0.00000, 0.00156,
    -0.00600, -0.00022, 0.00103,
   0.00644, 0.00031, -0.00119,
   -0.00374, -0.00021, 0.00070,
    -0.00033, -0.00273, -0.00007,
    0.00031, 0.00287, 0.00013,
    -0.00014, -0.00170, -0.00012,
   0.00110, -0.00016, -0.00283,
    -0.00119, 0.00013, 0.00297,
    0.00063, -0.00004, -0.00177,
    0.00324, 0.00009, -0.00050,
    -0.00374, -0.00014, 0.00063,
    0.00495, 0.00024, -0.00093,
    0.00020, 0.00150, 0.00000,
    -0.00021, -0.00170, -0.00004,
   0.00024, 0.00214, 0.00012,
   -0.00061, 0.00012, 0.00156,
   0.00070, -0.00012, -0.00177,
    -0.00093, 0.00012, 0.00223
  ),
 nrow = 9
)
# Specific time interval ------
mc <- MCMed(</pre>
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m",
```

102 summary.ctmedmed

```
R = 100L # use a large value for R in actual research
)
summary(mc)

# Range of time intervals ------
mc <- MCMed(
   phi = phi,
   vcov_phi_vec = vcov_phi_vec,
   delta_t = 1:5,
   from = "x",
   to = "y",
   med = "m",
   R = 100L # use a large value for R in actual research
)
summary(mc)</pre>
```

summary.ctmedmed

Summary Method for an Object of Class ctmedmed

Description

Summary Method for an Object of Class ctmedmed

Usage

```
## S3 method for class 'ctmedmed'
summary(object, digits = 4, ...)
```

Arguments

object an object of class ctmedmed.

digits Integer indicating the number of decimal places to display.

... further arguments.

Value

Returns a matrix of effects.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
colnames(phi) \leftarrow rownames(phi) \leftarrow c("x", "m", "y")
# Specific time interval ------
med <- Med(</pre>
 phi = phi,
 delta_t = 1,
 from = "x",
 to = "y",
 med = "m"
)
summary(med)
# Range of time intervals ------
med <- Med(
 phi = phi,
 delta_t = 1:5,
 from = "x",
 to = "y",
 med = "m"
)
summary(med)
```

summary.ctmedposteriorphi

Summary Method for Object of Class ctmedposteriorphi

Description

Summary Method for Object of Class ctmedposteriorphi

Usage

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

Arguments

```
object an object of class ctmedposteriorphi.
... further arguments.
```

104 summary.ctmedtraj

Value

Returns a list of the posterior means (in matrix form) and covariance matrix.

Author(s)

Ivan Jacob Agaloos Pesigan

summary.ctmedtraj

Summary Method for an Object of Class ctmedtraj

Description

Summary Method for an Object of Class ctmedtraj

Usage

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

Arguments

```
object an object of class ctmedtraj.
... further arguments.
```

Value

Returns a data frame of simulated data.

Author(s)

Ivan Jacob Agaloos Pesigan

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")

traj <- Trajectory(
  mu0 = c(3, 3, -3),
  time = 150,
  phi = phi,</pre>
```

Total 105

```
med = "m"
)
summary(traj)
```

Total

Total Effect Matrix Over a Specific Time Interval

Description

This function computes the total effects matrix over a specific time interval Δt using the first-order stochastic differential equation model's drift matrix Φ .

Usage

Total(phi, delta_t)

Arguments

phi

Numeric matrix. The drift matrix (Φ) , phi should have row and column names pertaining to the variables in the system.

delta_t

Numeric. Time interval (Δt).

Details

The total effect matrix over a specific time interval Δt is given by

$$Total_{\Delta t} = \exp(\Delta t \mathbf{\Phi})$$

where Φ denotes the drift matrix, and Δt the time interval.

Linear Stochastic Differential Equation Model:

The measurement model is given by

$$\mathbf{y}_{i,t} = \boldsymbol{\nu} + \boldsymbol{\Lambda} \boldsymbol{\eta}_{i,t} + \boldsymbol{\varepsilon}_{i,t}, \quad ext{with} \quad \boldsymbol{\varepsilon}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \boldsymbol{\Theta}\right)$$

where $\mathbf{y}_{i,t}$, $\eta_{i,t}$, and $\varepsilon_{i,t}$ are random variables and ν , Λ , and Θ are model parameters. $\mathbf{y}_{i,t}$ represents a vector of observed random variables, $\eta_{i,t}$ a vector of latent random variables, and $\varepsilon_{i,t}$ a vector of random measurement errors, at time t and individual t. ν denotes a vector of intercepts, Λ a matrix of factor loadings, and Θ the covariance matrix of ε .

An alternative representation of the measurement error is given by

$$\boldsymbol{\varepsilon}_{i,t} = \boldsymbol{\Theta}^{\frac{1}{2}} \mathbf{z}_{i,t}, \quad \text{with} \quad \mathbf{z}_{i,t} \sim \mathcal{N}\left(\mathbf{0}, \mathbf{I}\right)$$

where $\mathbf{z}_{i,t}$ is a vector of independent standard normal random variables and $\left(\Theta^{\frac{1}{2}}\right)\left(\Theta^{\frac{1}{2}}\right)' = \Theta$. The dynamic structure is given by

$$\mathrm{d}oldsymbol{\eta}_{i,t} = \left(oldsymbol{\iota} + oldsymbol{\Phi}oldsymbol{\eta}_{i,t}
ight)\mathrm{d}t + oldsymbol{\Sigma}^{rac{1}{2}}\mathrm{d}\mathbf{W}_{i,t}$$

Total

where ι is a term which is unobserved and constant over time, Φ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, Σ is the matrix of volatility or randomness in the process, and $\mathrm{d}W$ is a Wiener process or Brownian motion, which represents random fluctuations.

Value

Returns an object of class ctmedeffect which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("Total").output The matrix of total effects.
```

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), TotalCentral(), TotalStd(), Trajectory()
```

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
)
colnames(phi) <- rownames(phi) <- c("x", "m", "y")
delta_t <- 1
Total(</pre>
```

TotalCentral 107

```
phi = phi,
  delta_t = delta_t
)
phi <- matrix(
  data = c(
    -6, 5.5, 0, 0,
    1.25, -2.5, 5.9, -7.3,
    0, 0, -6, 2.5,
    5, 0, 0, -6
  ),
  nrow = 4
)
colnames(phi) <- rownames(phi) <- paste0("y", 1:4)
Total(
  phi = phi,
  delta_t = delta_t
)</pre>
```

TotalCentral

Total Effect Centrality

Description

Total Effect Centrality

Usage

```
TotalCentral(phi, delta_t, tol = 0.01)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ) , phi should have row and column names
	pertaining to the variables in the system.
delta_t	Vector of positive numbers. Time interval (Δt) .
tol	Numeric. Smallest possible time interval to allow.

Details

The total effect centrality of a variable is the sum of the total effects of a variable on all other variables at a particular time interval.

Value

Returns an object of class ctmedmed which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("TotalCentral").output A matrix of total effect centrality.
```

108 TotalCentral

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalStd(), Trajectory()
```

```
phi <- matrix(</pre>
 data = c(
   -0.357, 0.771, -0.450,
   0.0, -0.511, 0.729,
   0, 0, -0.693
 ),
 nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
# Specific time interval ------
TotalCentral(
 phi = phi,
 delta_t = 1
# Range of time intervals ------
total_central <- TotalCentral(</pre>
 phi = phi,
 delta_t = 1:30
plot(total_central)
# Methods -----
# TotalCentral has a number of methods including
# print, summary, and plot
total_central <- TotalCentral(</pre>
```

TotalStd 109

```
phi = phi,
  delta_t = 1:5
)
print(total_central)
summary(total_central)
plot(total_central)
```

TotalStd

Standardized Total Effect Matrix Over a Specific Time Interval

Description

This function computes the standardized total effects matrix over a specific time interval Δt using the first-order stochastic differential equation model's drift matrix Φ and process noise covariance matrix Σ .

Usage

```
TotalStd(phi, sigma, delta_t)
```

Arguments

phi	Numeric matrix. The drift matrix (Φ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix (Σ) .
delta_t	Numeric. Time interval (Δt).

Details

The standardized total effect matrix over a specific time interval Δt is given by

$$\operatorname{Total}_{\Delta t}^{*} = \mathbf{S} \left(\exp \left(\Delta t \mathbf{\Phi} \right) \right) \mathbf{S}^{-1}$$

where Φ denotes the drift matrix, ${\bf S}$ a diagonal matrix with model-implied standard deviations on the diagonals and Δt the time interval.

Value

Returns an object of class ctmedeffect which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("TotalStd").output The matrix of total effects.
```

110 TotalStd

Author(s)

Ivan Jacob Agaloos Pesigan

References

Bollen, K. A. (1987). Total, direct, and indirect effects in structural equation models. Sociological Methodology, 17, 37. doi:10.2307/271028

Deboeck, P. R., & Preacher, K. J. (2015). No need to be discrete: A method for continuous time mediation analysis. Structural Equation Modeling: A Multidisciplinary Journal, 23 (1), 61–75. doi:10.1080/10705511.2014.973960

Ryan, O., & Hamaker, E. L. (2021). Time to intervene: A continuous-time approach to network analysis and centrality. Psychometrika, 87 (1), 214–252. doi:10.1007/s11336021097670

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), Trajectory()
```

```
phi <- matrix(</pre>
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
  ),
  nrow = 3
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
sigma <- matrix(</pre>
  data = c(
    0.24455556, 0.02201587, -0.05004762,
    0.02201587, 0.07067800, 0.01539456,
    -0.05004762, 0.01539456, 0.07553061
  ),
  nrow = 3
)
delta_t <- 1
TotalStd(
  phi = phi,
  sigma = sigma,
  delta_t = delta_t
```

Trajectory 111

	Trajectory	Simulate Trajectories of Variables	
--	------------	------------------------------------	--

Description

This function simulates trajectories of variables without measurement error or process noise. Total corresponds to the total effect and Direct corresponds to the portion of the total effect where the indirect effect is removed.

Usage

```
Trajectory(mu0, time, phi, med)
```

Arguments

mu0 Numeric vector. Initial values of the variables.
 time Positive integer. Number of time points.
 phi Numeric matrix. The drift matrix (Φ). phi should have row and column names pertaining to the variables in the system.
 med Character vector. Name/s of the mediator variable/s in phi.

Value

Returns an object of class ctmedtraj which is a list with the following elements:

```
call Function call.args Function arguments.fun Function used ("Trajectory").output A data frame of simulated data.
```

See Also

```
Other Continuous Time Mediation Functions: BootMed(), DeltaBeta(), DeltaBetaStd(), DeltaIndirectCentral(), DeltaMed(), DeltaMedStd(), DeltaTotalCentral(), Direct(), DirectStd(), ExpCov(), ExpMean(), Indirect(), IndirectCentral(), IndirectStd(), MCBeta(), MCBetaStd(), MCIndirectCentral(), MCMed(), MCMedStd(), MCPhi(), MCTotalCentral(), Med(), MedStd(), PosteriorBeta(), PosteriorIndirectCentral(), PosteriorMed(), PosteriorTotalCentral(), Total(), TotalCentral(), TotalStd()
```

```
phi <- matrix(
  data = c(
    -0.357, 0.771, -0.450,
    0.0, -0.511, 0.729,
    0, 0, -0.693
),
  nrow = 3</pre>
```

Trajectory Trajectory

```
colnames(phi) <- rownames(phi) <- c("x", "m", "y")</pre>
traj <- Trajectory(</pre>
 mu0 = c(3, 3, -3),
 time = 150,
 phi = phi,
 med = "m"
)
plot(traj)
# Methods -----
# Trajectory has a number of methods including
# print, summary, and plot
traj <- Trajectory(</pre>
 mu0 = c(3, 3, -3),
 time = 25,
 phi = phi,
 med = "m"
)
print(traj)
summary(traj)
plot(traj)
```

Index

* Continuous Time Mediation Functions	BootMed, 3
BootMed, 3	* cTMed
DeltaBeta, 8	BootMed, 3
DeltaBetaStd, 11	DeltaBeta, 8
DeltaIndirectCentral, 15	DeltaBetaStd, 11
DeltaMed, 18	DeltaIndirectCentral, 15
DeltaMedStd, 22	DeltaMed, 18
DeltaTotalCentral, 26	DeltaMedStd, 22
Direct, 29	DeltaTotalCentral, 26
DirectStd, 32	Direct, 29
ExpCov, 34	DirectStd, 32
ExpMean, 36	ExpCov, 34
Indirect, 38	ExpMean, 36
<pre>IndirectCentral, 40</pre>	Indirect, 38
IndirectStd, 42	<pre>IndirectCentral, 40</pre>
MCBeta, 44	IndirectStd, 42
MCBetaStd, 47	MCBeta, 44
MCIndirectCentral, 51	MCBetaStd, 47
MCMed, <u>55</u>	MCIndirectCentral, 51
MCMedStd, 58	MCMed, 55
MCPhi, 63	MCMedStd, 58
MCTotalCentral, 65	MCPhi, 63
Med, 68	MCTotalCentral, 65
MedStd, 71	Med, 68
PosteriorBeta, 79	MedStd, 71
PosteriorIndirectCentral, 81	PosteriorBeta, 79
PosteriorMed, 84	PosteriorIndirectCentral, 81
PosteriorTotalCentral, 87	PosteriorMed, 84
Total, 105	PosteriorTotalCentral, 87
TotalCentral, 107	Total, 105
TotalStd, 109	TotalCentral, 107
Trajectory, 111	TotalStd, 109
* beta	Trajectory, 111
DeltaBeta, 8	* delta
DeltaBetaStd, 11	DeltaBeta, 8
MCBeta, 44	DeltaBetaStd, 11
MCBetaStd, 47	DeltaIndirectCentral, 15
PosteriorBeta, 79	DeltaMed, 18
* boot	DeltaMedStd, 22

114 INDEX

DeltaTotalCentral, 26	PosteriorIndirectCentral, 81
* effects	PosteriorTotalCentral, 87
Direct, 29	TotalCentral, 107
DirectStd, 32	* path
Indirect, 38	BootMed, 3
IndirectCentral, 40	DeltaMed, 18
IndirectStd, 42	DeltaMedStd, 22
Med, 68	MCMed, 55
MedStd, 71	MCMedStd, 58
Total, 105	Med, 68
TotalCentral, 107	MedStd, 71
TotalStd, 109	PosteriorMed, 84
Trajectory, 111	Trajectory, 111
* expectations	* posterior
ExpCov, 34	PosteriorBeta, 79
ExpMean, 36	PosteriorIndirectCentral, 81
* mc	PosteriorMed, 84
MCBeta, 44	PosteriorTotalCentral, 87
MCBetaStd, 47	
MCIndirectCentral, 51	BootMed, 3, 10, 13, 17, 20, 24, 28, 31, 33, 35,
MCMed, 55	37, 39, 41, 43, 46, 49, 53, 57, 61, 64,
MCMedStd, 58	67, 70, 72, 80, 83, 85, 88, 106, 108,
MCPhi, 63	110, 111
MCTotalCentral, 65	
* methods	confint.ctmeddelta,4
confint.ctmeddelta,4	confint.ctmedmc, 6
confint.ctmedmc, 6	- 1
plot.ctmeddelta, 73	DeltaBeta, 4, 8, 13, 17, 20, 24, 28, 31, 33, 35,
plot.ctmedmc, 75	37, 39, 41, 43, 46, 49, 53, 57, 61, 64,
plot.ctmedmed, 76	67, 70, 72, 80, 83, 85, 88, 106, 108,
plot.ctmedtraj,78	110, 111
print.ctmeddelta, 90	DeltaBetaStd, 4, 10, 11, 17, 20, 24, 28, 31,
print.ctmedeffect, 92	33, 35, 37, 39, 41, 43, 46, 49, 53, 57,
print.ctmedmc, 93	61, 64, 67, 70, 72, 80, 83, 85, 88,
print.ctmedmcphi, 95	106, 108, 110, 111
print.ctmedmed, 96	DeltaIndirectCentral, 4, 10, 13, 15, 20, 24, 28, 31, 33, 35, 37, 39, 41, 43, 46, 49,
print.ctmedtraj, 97	53, 57, 61, 64, 67, 70, 72, 80, 83, 85,
summary.ctmeddelta,98	88, 106, 108, 110, 111
summary.ctmedmc, 100	DeltaMed, 4, 10, 13, 17, 18, 24, 28, 31, 33, 35,
summary.ctmedmed, 102	37, 39, 41, 43, 46, 49, 53, 57, 61, 64,
summary.ctmedposteriorphi, 103	67, 70, 72, 80, 83, 85, 88, 106, 108,
summary.ctmedtraj, 104	110, 111
* network	DeltaMedStd, 4, 10, 13, 17, 20, 22, 28, 31, 33,
DeltaIndirectCentral, 15	35, 37, 39, 41, 43, 46, 49, 53, 57, 61,
DeltaTotalCentral, 26	64, 67, 70, 72, 80, 83, 85, 88, 106,
IndirectCentral, 40	108, 110, 111
MCIndirectCentral, 51	DeltaTotalCentral, 4, 10, 13, 17, 20, 24, 26,
MCTotalCentral, 65	31, 33, 35, 37, 39, 41, 43, 46, 49, 53,
	21,22,22,27,27,11,12,10,17,22,

INDEX 115

```
57, 61, 64, 67, 70, 72, 80, 83, 85, 88,
                                                                   57, 61, 64, 67, 70, 72, 80, 83, 85, 88,
          106, 108, 110, 111
                                                                   106, 108, 110, 111
Direct, 4, 10, 13, 17, 20, 24, 28, 29, 33, 35,
                                                         MCMed, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35, 37,
          37, 39, 41, 43, 46, 49, 53, 57, 61, 64,
                                                                   39, 41, 43, 46, 49, 53, 55, 61, 64, 67,
          67, 70, 72, 80, 83, 85, 88, 106, 108,
                                                                   70, 72, 80, 83, 85, 88, 106, 108, 110,
          110, 111
                                                                   111
Direct(), 3, 19, 56, 69, 85
                                                         MCMedStd, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35,
                                                                   37, 39, 41, 43, 46, 49, 53, 57, 58, 64,
DirectStd, 4, 10, 13, 17, 20, 24, 28, 31, 32,
                                                                   67, 70, 72, 80, 83, 85, 88, 106, 108,
          35, 37, 39, 41, 43, 46, 49, 53, 57, 61,
                                                                   110, 111
          64, 67, 70, 72, 80, 83, 85, 88, 106,
          108, 110, 111
                                                         MCPhi, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35, 37,
                                                                   39, 41, 43, 46, 49, 53, 57, 61, 63, 67,
DirectStd(), 23, 60, 71
                                                                   70, 72, 80, 83, 85, 88, 106, 108, 110,
                                                                   111
ExpCov, 4, 10, 13, 17, 20, 24, 28, 31, 33, 34,
                                                         MCTotalCentral, 4, 10, 13, 17, 20, 24, 28, 31,
          37, 39, 41, 43, 46, 49, 53, 57, 61, 64,
                                                                   33, 35, 37, 39, 41, 43, 46, 49, 53, 57,
          67, 70, 72, 80, 83, 85, 88, 106, 108,
                                                                   61, 64, 65, 70, 72, 80, 83, 85, 88,
          110, 111
                                                                   106, 108, 110, 111
ExpMean, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35,
                                                         Med, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35, 37,
          36, 39, 41, 43, 46, 49, 53, 57, 61, 64,
                                                                   39, 41, 43, 46, 49, 53, 57, 61, 64, 67,
          67, 70, 72, 80, 83, 85, 88, 106, 108,
                                                                   68, 72, 80, 83, 85, 88, 106, 108, 110,
          110, 111
                                                                   111
                                                         MedStd, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35,
Indirect, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35,
                                                                   37, 39, 41, 43, 46, 49, 53, 57, 61, 64,
          37, 38, 41, 43, 46, 49, 53, 57, 61, 64.
                                                                   67, 70, 71, 80, 83, 85, 88, 106, 108,
          67, 70, 72, 80, 83, 85, 88, 106, 108,
                                                                   110. 111
          110.111
Indirect(), 3, 19, 56, 69, 85
                                                         plot.ctmeddelta, 73
IndirectCentral, 4, 10, 13, 17, 20, 24, 28,
                                                         plot.ctmedmc, 75
          31, 33, 35, 37, 39, 40, 43, 46, 49, 53,
                                                         plot.ctmedmed, 76
          57, 61, 64, 67, 70, 72, 80, 83, 85, 88,
                                                         plot.ctmedtraj, 78
          106, 108, 110, 111
                                                         PosteriorBeta, 4, 10, 13, 17, 20, 24, 28, 31,
IndirectCentral(), 16, 52
                                                                   33, 35, 37, 39, 41, 43, 46, 49, 53, 57,
IndirectStd, 4, 10, 13, 17, 20, 24, 28, 31, 33,
                                                                   61, 64, 67, 70, 72, 79, 83, 85, 88,
          35, 37, 39, 41, 42, 46, 49, 53, 57, 61,
                                                                   106, 108, 110, 111
          64, 67, 70, 72, 80, 83, 85, 88, 106,
                                                         PosteriorIndirectCentral, 4, 10, 13, 17,
          108, 110, 111
                                                                   20, 24, 28, 31, 33, 35, 37, 39, 41, 43,
IndirectStd(), 23, 60, 71
                                                                   46, 49, 53, 57, 61, 64, 67, 70, 72, 80,
                                                                   81, 85, 88, 106, 108, 110, 111
MCBeta, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35,
                                                         PosteriorMed, 4, 10, 13, 17, 20, 24, 28, 31,
          37, 39, 41, 43, 44, 49, 53, 57, 61, 64,
                                                                   33, 35, 37, 39, 41, 43, 46, 49, 53, 57,
          67, 70, 72, 80, 83, 85, 88, 106, 108,
                                                                   61, 64, 67, 70, 72, 80, 83, 84, 88,
          110.111
                                                                   106, 108, 110, 111
MCBetaStd, 4, 10, 13, 17, 20, 24, 28, 31, 33,
                                                         PosteriorTotalCentral, 4, 10, 13, 17, 20,
          35, 37, 39, 41, 43, 46, 47, 53, 57, 61,
                                                                   24, 28, 31, 33, 35, 37, 39, 41, 43, 46,
          64, 67, 70, 72, 80, 83, 85, 88, 106,
                                                                   49, 53, 57, 61, 64, 67, 70, 72, 80, 83,
          108, 110, 111
                                                                   85, 87, 106, 108, 110, 111
MCIndirectCentral, 4, 10, 13, 17, 20, 24, 28,
                                                         print.ctmeddelta, 90
          31, 33, 35, 37, 39, 41, 43, 46, 49, 51,
                                                         print.ctmedeffect, 92
```

116 INDEX

```
print.ctmedmc, 93
print.ctmedmcphi, 95
print.ctmedmed, 96
print.ctmedtraj, 97
summary.ctmeddelta,98
summary.ctmedmc, 100
summary.ctmedmed, 102
summary.ctmedposteriorphi, 103
summary.ctmedtraj, 104
Total, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35, 37,
         39, 41, 43, 46, 49, 53, 57, 61, 64, 67,
         70, 72, 80, 83, 85, 88, 105, 108, 110,
         111
Total(), 3, 9, 19, 45, 56, 69, 79, 85
TotalCentral, 4, 10, 13, 17, 20, 24, 28, 31,
         33, 35, 37, 39, 41, 43, 46, 49, 53, 57,
         61, 64, 67, 70, 72, 80, 83, 85, 88,
         106, 107, 110, 111
TotalCentral(), 26, 66, 82, 88
TotalStd, 4, 10, 13, 17, 20, 24, 28, 31, 33, 35,
         37, 39, 41, 43, 46, 49, 53, 57, 61, 64,
         67, 70, 72, 80, 83, 85, 88, 106, 108,
         109, 111
TotalStd(), 12, 23, 48, 60, 71
Trajectory, 4, 10, 13, 17, 20, 24, 28, 31, 33,
         35, 37, 39, 41, 43, 46, 49, 53, 57, 61,
         64, 67, 70, 72, 80, 83, 85, 88, 106,
         108, 110, 111
```