

Package ‘cTMed’

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Title Continuous Time Mediation

Version 0.0.0.9000

Description Calculates standard errors and confidence intervals
for the indirect effect in continuous time mediation models.

URL <https://github.com/jeksterslab/cTMed>,
<https://jeksterslab.github.io/cTMed/>

BugReports <https://github.com/jeksterslab/cTMed/issues>

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confint.ctmeddelta	<i>Delta Method Confidence Intervals</i>
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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 considered.
- level the confidence level required.
- ... additional arguments.

Value

Returns a matrix of confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```

data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Specific time-interval -----
delta <- DeltaMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m"
)
confint(delta)

# Range of time-intervals -----
delta <- DeltaMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m"
)
confint(delta)

```

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.

<code>parm</code>	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 considered.
<code>level</code>	the confidence level required.
<code>...</code>	additional arguments.

Value

Returns a matrix of confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Specific time-interval -----
mc <- MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # use a large value for R in actual research
)
confint(mc)

# Range of time-intervals -----
mc <- MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # use a large value for R in actual research
)
confint(mc)
```

Description

The data was simulated using `simStateSpace::SimSSMVARFixed()` from a discrete-time vector autoregressive model given by

Usage

deboeck2015

Format

Dataframe with Five Columns:

id Individual ID.

time Time variable.

x X variable.

m M variable.

y Y variable.

Details

$$\mathbf{y}_{i,t} = \beta \mathbf{y}_{i,t-1} + \boldsymbol{\varepsilon}_{i,t}$$

where $\mathbf{y}_{i,t}$ and $\mathbf{y}_{i,t+1}$ represents a vector of observed variables X , M , and Y for individual i at time t and $t + 1$, $\boldsymbol{\varepsilon}_{i,t}$ a vector of normally distributed random noise with mean vector of zero and covariance matrix Ψ given by

$$\Psi = \begin{pmatrix} 0.10 & 0 & 0 \\ 0 & 0.10 & 0 \\ 0 & 0 & 0.10 \end{pmatrix}, \quad \text{and}$$

β is a matrix of lagged parameters given by

$$\beta = \begin{pmatrix} 0.70 & 0 & 0 \\ 0.50 & 0.60 & 0 \\ -0.10 & 0.40 & 0.50 \end{pmatrix}.$$

The mean vector $\boldsymbol{\mu}_0$ and covariance matrix Σ_0 of the initial condition are given by

$$\boldsymbol{\mu}_0 = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \quad \text{and}$$

$$\Sigma_0 = \begin{pmatrix} 1 & 0.20 & 0.20 \\ 0.20 & 1 & 0.20 \\ 0.20 & 0.20 & 1 \end{pmatrix}.$$

References

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](https://doi.org/10.1080/10705511.2014.973960)

deboeck2015phi

Drift Matrix

Description

Parameter estimates and sampling variance-covariance matrix of the continuous-time vector autoregressive model drift matrix using the data set deboeck2015. The model was fitted using the dynr package.

Usage

deboeck2015phi

Format

List with Two Elements:

dynr Results using the dynr package.

ctsem Results using the ctsem package.

The dynr element is a list with the following elements:

phi The estimated drift matrix Φ .

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

The ctsem element is a list with the following elements:

posterior Posterior distribution.

posterior_phi Posterior distribution of the drift matrix Φ .

phi Posterior mean of the drift matrix Φ .

vcov Posterior variance-covariance matrix of $\text{vec}(\Phi)$.

References

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](https://doi.org/10.1080/10705511.2014.973960)

Ou, L., Hunter, M. D., & Chow, S.-M. (2019). What's for dynr: A package for linear and nonlinear dynamic modeling in R. *The R Journal*, 11(1), 91. [doi:10.32614/rj2019012](https://doi.org/10.32614/rj2019012)

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 Φ .

Usage

```
DeltaMed(phi, vcov_phi_vec, delta_t, from, to, med, ncores = 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 $\text{vec}(\Phi)$.
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.

Details

See [Total\(\)](#), [Direct\(\)](#), and [Indirect\(\)](#) for more details.

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:

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

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

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

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

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

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

Linear Stochastic Differential Equation Model:

The measurement model is given by

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

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\mathbf{\Lambda}$, 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, $\mathbf{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of $\boldsymbol{\varepsilon}$.

An alternative representation of the measurement error is given by

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

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

The dynamic structure is given by

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

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

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 with length of `length(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: [Direct\(\)](#), [Indirect\(\)](#), [MCMed\(\)](#), [MCPhi\(\)](#), [Med\(\)](#), [PosteriorMed\(\)](#), [TestPhi\(\)](#), [Total\(\)](#)

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# 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(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m"
)

# Methods -----
# DeltaMed 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 Φ .

Usage

```
Direct(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 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

$$\text{Direct}_{\Delta t, i, j, \mathbf{m}} = \exp(\Delta t \mathbf{D} \Phi \mathbf{D})_{i, j}$$

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

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

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\mathbf{\Lambda}$, 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, $\mathbf{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of $\boldsymbol{\varepsilon}$.

An alternative representation of the measurement error is given by

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

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

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

where $\boldsymbol{\iota}$ is a term which is unobserved and constant over time, $\boldsymbol{\Phi}$ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, $\boldsymbol{\Sigma}$ is the matrix of volatility or randomness in the process, and $d\mathbf{W}$ 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.

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](https://doi.org/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](https://doi.org/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](https://doi.org/10.1007/s11336021097670)

See Also

Other Continuous Time Mediation Functions: [DeltaMed\(\)](#), [Indirect\(\)](#), [MCMed\(\)](#), [MCPPhi\(\)](#), [Med\(\)](#), [PosteriorMed\(\)](#), [TestPhi\(\)](#), [Total\(\)](#)

Examples

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

```

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 Φ .

Usage

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

Arguments

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

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

$$\text{Indirect}_{\Delta t} = \exp(\Delta t \Phi)_{i,j} - \exp(\Delta t \mathbf{D}_m \Phi \mathbf{D}_m)_{i,j}$$

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

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

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\mathbf{\Lambda}$, 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, $\mathbf{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of $\boldsymbol{\varepsilon}$.

An alternative representation of the measurement error is given by

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

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

The dynamic structure is given by

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

where $\boldsymbol{\iota}$ 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, $\boldsymbol{\Sigma}$ is the matrix of volatility or randomness in the process, and $d\mathbf{W}$ 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").

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](https://doi.org/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](https://doi.org/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](https://doi.org/10.1007/s11336021097670)

See Also

Other Continuous Time Mediation Functions: [DeltaMed\(\)](#), [Direct\(\)](#), [MCMed\(\)](#), [MCPHi\(\)](#), [Med\(\)](#), [PosteriorMed\(\)](#), [TestPhi\(\)](#), [Total\(\)](#)

Examples

```
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
Indirect(
  phi = phi,
  delta_t = delta_t,
  from = "x",
  to = "y",
  med = "m"
)
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)
Indirect(
  phi = phi,
  delta_t = delta_t,
  from = "y2",
  to = "y4",
  med = c("y1", "y3")
)
```

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} at a particular time-interval Δt using the first-order stochastic differential equation model drift matrix Φ .

Usage

```
MCMed(
  phi,
  vcov_phi_vec,
  delta_t,
  from,
  to,
  med,
  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 $\text{vec}(\Phi)$.
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. Check the generated Φ and generate different values if the test fails. The test includes the following: <ul style="list-style-type: none"> • test that the largest eigen value of Φ is less than one, and • test that the diagonal values of Φ are between 0 to negative infinity.
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.

Details

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

Monte Carlo Method:

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

$$\hat{\boldsymbol{\theta}} \sim \mathcal{N}(\boldsymbol{\theta}, \mathbb{V}(\hat{\boldsymbol{\theta}}))$$

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

$$\hat{\boldsymbol{\theta}}^* \sim \mathcal{N}(\hat{\boldsymbol{\theta}}, \hat{\mathbb{V}}(\hat{\boldsymbol{\theta}})).$$

Let $\mathbf{g}(\hat{\boldsymbol{\theta}})$ be a parameter that is a function of the estimated parameters. A sampling distribution of $\mathbf{g}(\hat{\boldsymbol{\theta}})$, which we refer to as $\mathbf{g}(\hat{\boldsymbol{\theta}}^*)$, 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 $100(1 - \alpha)\%$ are the confidence intervals.

Linear Stochastic Differential Equation Model:

The measurement model is given by

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

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

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

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

The dynamic structure is given by

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

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

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.

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](https://doi.org/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](https://doi.org/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](https://doi.org/10.1007/s11336021097670)

See Also

Other Continuous Time Mediation Functions: [DeltaMed\(\)](#), [Direct\(\)](#), [Indirect\(\)](#), [MCPHi\(\)](#), [Med\(\)](#), [PosteriorMed\(\)](#), [TestPhi\(\)](#), [Total\(\)](#)

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Specific time-interval -----
MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # use a large value for R in actual research
)

# Range of time-intervals -----
mc <- MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
```

```

    delta_t = 1:20,
    from = "x",
    to = "y",
    med = "m",
    R = 5 # use a large value for R in actual research
)

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

```

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 $\text{vec}(\Phi)$.
R	Positive integer. Number of replications.
test_phi	Logical. Check the generated Φ and generate different values if the test fails. The test includes the following: <ul style="list-style-type: none"> • test that the largest eigen value of Φ is less than one, and • test that the diagonal values of Φ are between 0 to negative infinity.
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.

Details

Monte Carlo Method:

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

$$\hat{\boldsymbol{\theta}} \sim \mathcal{N}(\boldsymbol{\theta}, \mathbb{V}(\hat{\boldsymbol{\theta}}))$$

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

$$\hat{\boldsymbol{\theta}}^* \sim \mathcal{N}(\hat{\boldsymbol{\theta}}, \hat{\mathbb{V}}(\hat{\boldsymbol{\theta}})).$$

Linear Stochastic Differential Equation Model:

The measurement model is given by

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

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

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

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

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

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

Value

Returns a list of simulated drift matrices.

Author(s)

Ivan Jacob Agaloos Pesigan

See Also

Other Continuous Time Mediation Functions: [DeltaMed\(\)](#), [Direct\(\)](#), [Indirect\(\)](#), [MCMed\(\)](#), [Med\(\)](#), [PosteriorMed\(\)](#), [TestPhi\(\)](#), [Total\(\)](#)

Examples

```

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")
MCPhi(
  phi = phi,
  vcov_phi_vec = 0.1 * diag(9),
  R = 5
)
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)
MCPhi(
  phi = phi,
  vcov_phi_vec = 0.1 * diag(16),
  R = 5,
  test_phi = FALSE
)

```

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 Φ .

Usage

```
Med(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	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.

Details

See [Total\(\)](#), [Direct\(\)](#), and [Indirect\(\)](#) for more details.

Linear Stochastic Differential Equation Model:

The measurement model is given by

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

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\mathbf{\Lambda}$, 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, $\mathbf{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of $\boldsymbol{\varepsilon}$.

An alternative representation of the measurement error is given by

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

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

The dynamic structure is given by

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

where $\boldsymbol{\iota}$ is a term which is unobserved and constant over time, $\boldsymbol{\Phi}$ is the drift matrix which represents the rate of change of the solution in the absence of any random fluctuations, $\boldsymbol{\Sigma}$ is the matrix of volatility or randomness in the process, and $d\mathbf{W}$ 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

See Also

Other Continuous Time Mediation Functions: [DeltaMed\(\)](#), [Direct\(\)](#), [Indirect\(\)](#), [MCMed\(\)](#), [MCPhi\(\)](#), [PosteriorMed\(\)](#), [TestPhi\(\)](#), [Total\(\)](#)

Examples

```
# -----
# Example 1 -----
# -----
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")

# 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 = 1:20,
  from = "x",
  to = "y",
  med = "m"
)
plot(med)

# -----
# Example 2 -----
# -----
```

```

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)

# Specific time-interval -----
Med(
  phi = phi,
  delta_t = 1,
  from = "y2",
  to = "y4",
  med = c("y1", "y3")
)

# Range of time-intervals -----
med <- Med(
  phi = phi,
  delta_t = seq(from = 0, to = 5, length.out = 500),
  from = "y2",
  to = "y4",
  med = c("y1", "y3")
)

# Methods -----
# Med has a number of methods including
# print, summary, and plot
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, ...)

```

Arguments

x	Object of class ctmeddelta.
alpha	Numeric. Significance level
...	Additional arguments.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Range of time-intervals -----
delta <- DeltaMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  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, ...)
```

Arguments

x	Object of class ctmedmc.
alpha	Numeric. Significance level
...	Additional arguments.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```

data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Range of time-intervals -----
mc <- MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # 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

Usage

```

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

```

Arguments

x Object of class ctmedmed.
 ... Additional arguments.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```

# -----
# Example 1 -----
# -----
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")

  # Range of time-intervals -----
  med <- Med(
    phi = phi,
    delta_t = 1:20,
    from = "x",
    to = "y",
    med = "m"
  )
  plot(med)

  # -----
  # Example 2 -----
  # -----
  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)

  # Range of time-intervals -----
  med <- Med(
    phi = phi,
    delta_t = seq(from = 0, to = 5, length.out = 500),
    from = "y2",
    to = "y4",
    med = c("y1", "y3")
  )
  plot(med)

```

PosteriorMed

*Posterior Distribution of Total, Direct, and Indirect Effects of X on Y
Through M Over a Specific Time-Interval*

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} at a particular time-interval Δt using the posterior distribution of the first-order stochastic differential equation model drift matrix Φ .

Usage

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

Arguments

<code>phi</code>	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.
<code>delta_t</code>	Numeric. Time interval (Δt).
<code>from</code>	Character string. Name of the independent variable X in <code>phi</code> .
<code>to</code>	Character string. Name of the dependent variable Y in <code>phi</code> .
<code>med</code>	Character vector. Name/s of the mediator variable/s in <code>phi</code> .
<code>ncores</code>	Positive integer. Number of cores to use. If <code>ncores = NULL</code> , use a single core. Consider using multiple cores when number of replications R is a large value.

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 with length of `length(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: [DeltaMed\(\)](#), [Direct\(\)](#), [Indirect\(\)](#), [MCMed\(\)](#), [MCPPhi\(\)](#), [Med\(\)](#), [TestPhi\(\)](#), [Total\(\)](#)

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$ctsem$posterior_phi

# Specific time-interval -----
PosteriorMed(
  phi = phi,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m"
)

# Range of time-intervals -----
posterior <- PosteriorMed(
  phi = phi,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m"
)

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

print.ctmeddelta	<i>Print Method for Object of Class ctmeddelta</i>
------------------	--

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

Returns a matrix of time-interval, estimates, standard errors, test statistics, p-values, and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Specific time-interval -----
delta <- DeltaMed(
  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(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m"
)
print(delta)
```

print.ctmedeffect	<i>Print Method for Object of Class ctmedeffect</i>
-------------------	---

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

Returns the effects.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
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

# Time-Interval of One -----

## Total Effect -----
total_dt <- Total(
  phi = phi,
  delta_t = delta_t
)
print(total_dt)

## Direct Effect -----
```

```

direct_dt <- Direct(
  phi = phi,
  delta_t = delta_t,
  from = "x",
  to = "y",
  med = "m"
)
print(direct_dt)

## Indirect Effect -----
indirect_dt <- Indirect(
  phi = phi,
  delta_t = delta_t,
  from = "x",
  to = "y",
  med = "m"
)
print(indirect_dt)

```

print.ctmedmc	<i>Print Method for Object of Class ctmedmc</i>
---------------	---

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

Returns a matrix of estimates, standard errors, number of Monte Carlo replications, and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```

data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Specific time-interval -----
mc <- MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # use a large value for R in actual research
)
print(mc)

# Range of time-intervals -----
mc <- MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # use a large value for R in actual research
)
print(mc)

```

print.ctmedmcphi	<i>Print Method for Object of Class ctmedmcphi</i>
------------------	--

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

Returns the structure of the output.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
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")
mc <- MCPHi(
  phi = phi,
  vcov_phi_vec = 0.1 * diag(9),
  R = 5
)
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

Returns a matrix of effects.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```

# -----
# Example 1 -----
# -----
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")

# 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 = 1:20,
  from = "x",
  to = "y",
  med = "m"
)
print(med)

# -----
# Example 2 -----
# -----
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)

```

```

# Specific time-interval -----
med <- Med(
  phi = phi,
  delta_t = 1,
  from = "y2",
  to = "y4",
  med = c("y1", "y3")
)
print(med)

# Range of time-intervals -----
med <- Med(
  phi = phi,
  delta_t = 1:10,
  from = "y2",
  to = "y4",
  med = c("y1", "y3")
)
print(med)

```

summary.ctmeddelta	<i>Summary Method for an Object of Class ctmeddelta</i>
--------------------	---

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 α .
...	additional arguments.

Value

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

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Specific time-interval -----
delta <- DeltaMed(
  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(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:20,
  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 matrix of effects, time-interval, estimates, standard errors, test statistics, p-values, and confidence intervals.

Author(s)

Ivan Jacob Agaloos Pesigan

Examples

```
data("deboeck2015phi", package = "cTMed")
phi <- deboeck2015phi$dynr$phi
vcov_phi_vec <- deboeck2015phi$dynr$vcov

# Specific time-interval -----
mc <- MCMed(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # 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 = 1:20,
  from = "x",
  to = "y",
  med = "m",
  R = 5 # use a large value for R in actual research
)
summary(mc)
```

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

```
# -----
# Example 1 -----
# -----
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")

# Specific time-interval -----
med <- Med(
  phi = phi,
  delta_t = 1,
  from = "x",
  to = "y",
  med = "m"
)
summary(med)

# Range of time-intervals -----
med <- Med(
  phi = phi,
  delta_t = 1:20,
  from = "x",
  to = "y",
  med = "m"
)
summary(med)

# -----
# Example 2 -----
# -----
```

```

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)

# Specific time-interval -----
med <- Med(
  phi = phi,
  delta_t = 1,
  from = "y2",
  to = "y4",
  med = c("y1", "y3")
)
summary(med)

# Range of time-intervals -----
med <- Med(
  phi = phi,
  delta_t = 1:10,
  from = "y2",
  to = "y4",
  med = c("y1", "y3")
)
summary(med)

```

TestPhi

Test the Drift Matrix

Description

Both have to be true for the function to return TRUE.

- Test that the largest eigen value of Φ is less than one.
- Test that the diagonal values of Φ are between 0 to negative infinity.

Usage

```
TestPhi(phi)
```

Arguments

phi Numeric matrix. The drift matrix (Φ).

Author(s)

Ivan Jacob Agaloos Pesigan

See Also

Other Continuous Time Mediation Functions: [DeltaMed\(\)](#), [Direct\(\)](#), [Indirect\(\)](#), [MCMed\(\)](#), [MCPhi\(\)](#), [Med\(\)](#), [PosteriorMed\(\)](#), [Total\(\)](#)

Examples

```
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")
TestPhi(phi = phi)
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)
TestPhi(phi = phi)
```

Total	<i>Total Effect Matrix Over a Specific Time-Interval</i>
-------	--

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

$$\text{Total}_{\Delta t} = \exp(\Delta t \Phi)$$

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

Linear Stochastic Differential Equation Model:

The measurement model is given by

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

where $\mathbf{y}_{i,t}$, $\boldsymbol{\eta}_{i,t}$, and $\boldsymbol{\varepsilon}_{i,t}$ are random variables and $\boldsymbol{\nu}$, $\mathbf{\Lambda}$, 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, $\mathbf{\Lambda}$ a matrix of factor loadings, and $\boldsymbol{\Theta}$ the covariance matrix of $\boldsymbol{\varepsilon}$.

An alternative representation of the measurement error is given by

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

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

The dynamic structure is given by

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

where $\boldsymbol{\iota}$ 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, $\boldsymbol{\Sigma}$ is the matrix of volatility or randomness in the process, and $d\mathbf{W}$ 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

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See Also

Other Continuous Time Mediation Functions: [DeltaMed\(\)](#), [Direct\(\)](#), [Indirect\(\)](#), [MCMed\(\)](#), [MCPPhi\(\)](#), [Med\(\)](#), [PosteriorMed\(\)](#), [TestPhi\(\)](#)

Examples

```
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(
  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
)
```

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