

# Package ‘cTMed’

November 26, 2024

**Title** Continuous Time Mediation

**Version** 1.0.2

**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](https://doi.org/10.1080/10705511.2014.973960)> and Ryan and Hamaker (2021) <[doi:10.1007/s11336-021-09767-0](https://doi.org/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.

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

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

**License** GPL (>= 3)

**Encoding** UTF-8

**Roxygen** list(markdown = TRUE)

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**Suggests** knitr, rmarkdown, testthat, expm

**RoxygenNote** 7.3.2

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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 data frame of confidence intervals.

**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")
vcov_phi_vec <- matrix(
  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 -----
delta <- DeltaMed(
  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(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:5,
  from = "x",
  to = "y",
  med = "m"
)
confint(delta, level = 0.95)

```

**Description**

Monte Carlo Method Confidence Intervals

**Usage**

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

**Arguments**

<code>object</code>	Object of class <code>ctmedmc</code> .
<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 data frame of confidence intervals.

**Author(s)**

Ivan Jacob Agaloos Pesigan

**Examples**

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

# 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
)
confint(mc, level = 0.95)

```

## Description

This function computes the delta method sampling variance-covariance matrix for the elements of the matrix of lagged coefficients  $\beta$  over a specific time interval  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). 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 ( $\Delta t$ ).
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\(\)](#).

### Delta Method:

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

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

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

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

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

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

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

**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

**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: [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
vcov_phi_vec <- matrix(
  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(
  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  $\beta$  over a specific time interval  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
vcov_theta	Numeric matrix. The sampling variance-covariance matrix of $\text{vec}(\Phi)$ and $\text{vech}(\Sigma)$
delta_t	Numeric. Time interval ( $\Delta t$ ).
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  $\theta$  be a vector that combines  $\text{vec}(\Phi)$ , that is, the elements of the  $\Phi$  matrix in vector form sorted column-wise and  $\text{vech}(\Sigma)$ , that is, the unique elements of the  $\Sigma$  matrix in vector form sorted column-wise. Let  $\hat{\theta}$  be a vector that combines  $\text{vec}(\hat{\Phi})$  and  $\text{vech}(\hat{\Sigma})$ . By the multivariate central limit theory, the function  $g$  using  $\hat{\theta}$  as input can be expressed as:

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

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

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

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

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

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

## 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](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: [DeltaBeta\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
sigma <- matrix(
  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,
  ),
  nrow = 3
)
```

```

-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,
  sigma = sigma,
  vcov_theta = vcov_theta,
  delta_t = 1
)

# Range of time intervals -----
delta <- DeltaBetaStd(
  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  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). 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 ( $\Delta t$ ).
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 [IndirectCentral\(\)](#) more details.

### Delta Method:

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

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

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

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

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

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

that is,  $\hat{\mathbf{V}}(\hat{\boldsymbol{\theta}})$  for  $n^{-1}\mathbf{\Gamma}$ . Therefore, the sampling variance-covariance matrix of  $\mathbf{g}(\hat{\boldsymbol{\theta}})$  is given by

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

## 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

## 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\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
vcov_phi_vec <- matrix(
  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(

```



```

    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	<i>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</i>
----------	--

---

## 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  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

## Usage

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

## Arguments

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

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

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

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

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

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

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

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

## 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")
vcov_phi_vec <- matrix(
  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(
  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 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 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  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

### Usage

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

### Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
vcov_theta	Numeric matrix. The sampling variance-covariance matrix of $\text{vec}(\Phi)$ and $\text{vech}(\Sigma)$
delta_t	Numeric. Time interval ( $\Delta t$ ).
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  $\theta$  be a vector that combines  $\text{vec}(\Phi)$ , that is, the elements of the  $\Phi$  matrix in vector form sorted column-wise and  $\text{vech}(\Sigma)$ , that is, the unique elements of the  $\Sigma$  matrix in vector form sorted column-wise. Let  $\hat{\theta}$  be a vector that combines  $\text{vec}(\hat{\Phi})$  and  $\text{vech}(\hat{\Sigma})$ . By the multivariate central limit theory, the function  $\mathbf{g}$  using  $\hat{\theta}$  as input can be expressed as:

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

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

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

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

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

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

### 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](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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
sigma <- matrix(
  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,
  ),
  nrow = 3
)
```

```

-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(
  phi = phi,
  sigma = sigma,
  vcov_theta = vcov_theta,
  delta_t = 1:5,
  from = "x",
  to = "y",
  med = "m"
)
plot(delta)

# Methods -----
# DeltaMedStd has a number of methods including
# print, summary, confint, and plot
print(delta)

```



```
summary(delta)
confint(delta, level = 0.95)
plot(delta)
```

---

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

---

## Description

This function computes the delta method sampling variance-covariance matrix for the total effect centrality over a specific time interval  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). 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 ( $\Delta t$ ).
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.

### Delta Method:

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

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

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

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

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

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

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

### 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

### 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()`, `Direct()`, `DirectStd()`, `ExpCov()`, `ExpMean()`, `Indirect()`, `IndirectCentral()`, `IndirectStd()`, `MCBeta()`, `MCBetaStd()`, `MCIndirectCentral()`, `MCMed()`, `MCMedStd()`, `MCPhi()`, `MCTotalCentral()`, `Med()`, `MedStd()`, `PosteriorBeta()`, `PosteriorIndirectCentral()`, `PosteriorMed()`, `PosteriorPhi()`, `PosteriorTotalCentral()`, `Total()`, `TotalCentral()`, `TotalStd()`, `Trajectory()`

**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")
vcov_phi_vec <- matrix(
  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 -----
DeltaTotalCentral(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1
)

# Range of time intervals -----
delta <- DeltaTotalCentral(

```

```

    phi = phi,
    vcov_phi_vec = vcov_phi_vec,
    delta_t = 1:5
  )
plot(delta)

# Methods -----
# 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  $\Delta t$  using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

### Usage

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

### Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval ( $\Delta t$ ).
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

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

where  $\Phi$  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  $\Phi$ ,  $j$  the column index of  $X$  in  $\Phi$ , and  $\Delta t$  the time interval.

### Linear Stochastic Differential Equation Model:

The measurement model is given by

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

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 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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBETA\(\)](#), [MCBETAStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
)
```

## 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  $\Delta t$  using the first-order stochastic differential equation model's drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
delta_t	Numeric. Time interval ( $\Delta t$ ).
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

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

where  $\Phi$  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  $\Phi$ ,  $j$  the column index of  $X$  in  $\Phi$ ,  $\mathbf{S}$  a diagonal matrix with model-implied standard deviations on the diagonals, and  $\Delta t$  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 ("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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

## 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")
sigma <- matrix(
  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
DirectStd(
  phi = phi,
  sigma = sigma,
  delta_t = delta_t,
  from = "x",
  to = "y",
  med = "m"
)
```



ExpCov

*Model-Implied State Covariance Matrix***Description**

The function returns the model-implied state covariance matrix for a particular time interval  $\Delta t$  given by

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

where

$$\begin{aligned} \boldsymbol{\beta}_{\Delta t} &= \exp(\Delta t \boldsymbol{\Phi}), \\ \boldsymbol{\Psi}_{\Delta t} &= \boldsymbol{\Phi}^\# (\exp(\Delta t \boldsymbol{\Phi}) - \mathbf{J}) \text{vec}(\boldsymbol{\Sigma}), \quad \text{and} \\ \boldsymbol{\Phi}^\# &= (\boldsymbol{\Phi} \otimes \mathbf{I}) + (\mathbf{I} \otimes \boldsymbol{\Phi}). \end{aligned}$$

Note that  $\mathbf{I}$  and  $\mathbf{J}$  are identity matrices.

**Usage**

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

**Arguments**

phi	Numeric matrix. The drift matrix ( $\boldsymbol{\Phi}$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\boldsymbol{\Sigma}$ ).
delta_t	Numeric. Time interval ( $\Delta t$ ).

**Details****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 numeric matrix.

**Author(s)**

Ivan Jacob Agaloos Pesigan

**See Also**

Other Continuous Time Mediation Functions: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBETA\(\)](#), [MCBETAStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
sigma <- matrix(
  data = c(
    0.24, 0.02, -0.05,
    0.02, 0.07, 0.02,
    -0.05, 0.02, 0.08
  ),
  nrow = 3
)
delta_t <- 1
ExpCov(
  phi = phi,
  sigma = sigma,
  delta_t = delta_t
)
```

**Description**

The function returns the model-implied state mean vector for a particular time interval  $\Delta t$  given by

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

where

$$\begin{aligned} \boldsymbol{\beta}_{\Delta t} &= \exp(\Delta t \boldsymbol{\Phi}), \\ \boldsymbol{\alpha}_{\Delta t} &= \boldsymbol{\Phi}^{-1} (\boldsymbol{\beta}_{\Delta t} - \mathbf{I}) \boldsymbol{\iota}. \end{aligned}$$

Note that  $\mathbf{I}$  is an identity matrix.

**Usage**

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

**Arguments**

phi	Numeric matrix. The drift matrix ( $\boldsymbol{\Phi}$ ). 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 ( $\boldsymbol{\iota}$ ).
delta_t	Numeric. Time interval ( $\Delta t$ ).

**Details****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 numeric matrix.

**Author(s)**

Ivan Jacob Agaloos Pesigan

**See Also**

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

**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")
iota <- c(.5, .3, .4)
delta_t <- 1
ExpMean(
  phi = phi,
  iota = iota,
  delta_t = delta_t
)
```

---

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  $\Delta t$  using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

**Usage**

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

**Arguments**

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval ( $\Delta t$ ).
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 indirect effect of the independent variable  $X$  on the dependent variable  $Y$  relative to some mediator variables  $\mathbf{m}$  over a specific time interval  $\Delta t$  is given by

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

where  $\Phi$  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  $\Phi$ ,  $j$  the column index of  $X$  in  $\Phi$ , and  $\Delta t$  the time interval.

**Linear Stochastic Differential Equation Model:**

The measurement model is given by

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

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 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

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\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBETA\(\)](#), [MCBETAStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
)

```

---

IndirectCentral	<i>Indirect Effect Centrality</i>
-----------------	-----------------------------------

---

## Description

Indirect Effect Centrality

## Usage

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

## Arguments

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

## 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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectStd\(\)](#), [MCBETA\(\)](#), [MCBETAStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

## 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")

# Specific time interval -----
IndirectCentral(
  phi = phi,
  delta_t = 1
)

# Range of time intervals -----
indirect_central <- IndirectCentral(
  phi = phi,
  delta_t = 1:30
)
plot(indirect_central)

# Methods -----
# IndirectCentral has a number of methods including
# print, summary, and plot
indirect_central <- IndirectCentral(
  phi = phi,
  delta_t = 1:5
)
```



```
print(indirect_central)
summary(indirect_central)
plot(indirect_central)
```

---

IndirectStd	<i>Standardized Indirect Effect of X on Y Through M Over a Specific Time Interval</i>
-------------	---

---

### 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  $\Delta t$  using the first-order stochastic differential equation model's drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

### Usage

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

### Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
delta_t	Numeric. Time interval ( $\Delta t$ ).
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 indirect effect of the independent variable  $X$  on the dependent variable  $Y$  relative to some mediator variables  $\mathbf{m}$  over a specific time interval  $\Delta t$  is given by

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

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

### 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").

**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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
sigma <- matrix(
  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	<i>Monte Carlo Sampling Distribution for the Elements of the Matrix of Lagged Coefficients Over a Specific Time Interval or a Range of Time Intervals</i>
--------	---

---

### Description

This function generates a Monte Carlo method sampling distribution for the elements of the matrix of lagged coefficients  $\beta$  over a specific time interval  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model drift matrix  $\Phi$ .

### Usage

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

### Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). 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 ( $\Delta t$ ).
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix $\Phi$ . If the test returns FALSE, the function generates a new drift matrix $\Phi$ 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  $\theta$  be  $\text{vec}(\Phi)$ , that is, the elements of the  $\Phi$  matrix in vector form sorted column-wise. Let  $\hat{\theta}$  be  $\text{vec}(\hat{\Phi})$ . Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

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

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,

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

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

## 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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**Examples**

```
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(
    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(
  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  $\beta$  over a specific time interval  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

## 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 ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
vcov_theta	Numeric matrix. The sampling variance-covariance matrix of $\text{vec}(\Phi)$ and $\text{vech}(\Sigma)$
delta_t	Numeric. Time interval ( $\Delta t$ ).
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix $\Phi$ . If the test returns FALSE, the function generates a new drift matrix $\Phi$ 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  $\theta$  be a vector that combines  $\text{vec}(\Phi)$ , that is, the elements of the  $\Phi$  matrix in vector form sorted column-wise and  $\text{vech}(\Sigma)$ , that is, the unique elements of the  $\Sigma$  matrix in vector form sorted column-wise. Let  $\hat{\theta}$  be a vector that combines  $\text{vec}(\hat{\Phi})$  and  $\text{vech}(\hat{\Sigma})$ . Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

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

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,

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

Let  $\mathbf{g}(\hat{\theta})$  be a parameter that is a function of the estimated parameters. A sampling distribution of  $\mathbf{g}(\hat{\theta})$ , which we refer to as  $\mathbf{g}(\hat{\theta}^*)$ , 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.

**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](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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
sigma <- matrix(
  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 -----
  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(
    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

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

## Usage

```

MCIndirectCentral(
  phi,
  vcov_phi_vec,
  delta_t,
  R,

```

```

    test_phi = TRUE,
    ncores = NULL,
    seed = NULL,
    tol = 0.01
)

```

### Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). 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 ( $\Delta t$ ).
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix $\Phi$ . If the test returns FALSE, the function generates a new drift matrix $\Phi$ 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  $\theta$  be  $\text{vec}(\Phi)$ , that is, the elements of the  $\Phi$  matrix in vector form sorted column-wise. Let  $\hat{\theta}$  be  $\text{vec}(\hat{\Phi})$ . Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

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

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,

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

Let  $\mathbf{g}(\hat{\theta})$  be a parameter that is a function of the estimated parameters. A sampling distribution of  $\mathbf{g}(\hat{\theta})$ , which we refer to as  $\mathbf{g}(\hat{\theta}^*)$ , 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.

**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](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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**Examples**

```
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(
  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(
  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 -----
# 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  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model drift matrix  $\Phi$ .

## Usage

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

## Arguments

<code>phi</code>	Numeric matrix. The drift matrix ( $\Phi$ ). <code>phi</code> should have row and column names pertaining to the variables in the system.
<code>vcov_phi_vec</code>	Numeric matrix. The sampling variance-covariance matrix of $\text{vec}(\Phi)$ .
<code>delta_t</code>	Numeric. Time interval ( $\Delta t$ ).
<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>R</code>	Positive integer. Number of replications.
<code>test_phi</code>	Logical. If <code>test_phi = TRUE</code> , the function tests the stability of the generated drift matrix $\Phi$ . If the test returns <code>FALSE</code> , the function generates a new drift matrix $\Phi$ and runs the test recursively until the test returns <code>TRUE</code> .

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

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

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,

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

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

### 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\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

## Examples

```
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(
    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 -----
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(
  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)

```

## 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  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

## 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 ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
vcov_theta	Numeric matrix. The sampling variance-covariance matrix of $\text{vec}(\Phi)$ and $\text{vech}(\Sigma)$
delta_t	Numeric. Time interval ( $\Delta t$ ).
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 $\Phi$ . If the test returns FALSE, the function generates a new drift matrix $\Phi$ 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  $\theta$  be a vector that combines  $\text{vec}(\Phi)$ , that is, the elements of the  $\Phi$  matrix in vector form sorted column-wise and  $\text{vech}(\Sigma)$ , that is, the unique elements of the  $\Sigma$  matrix in vector form sorted column-wise. Let  $\hat{\theta}$  be a vector that combines  $\text{vec}(\hat{\Phi})$  and  $\text{vech}(\hat{\Sigma})$ . Based on the asymptotic properties of maximum likelihood estimators, we can assume that estimators are normally distributed around the population parameters.

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

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,

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

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

## See Also

Other Continuous Time Mediation Functions: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBETA\(\)](#), [MCBETAStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCPHI\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

## 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")
sigma <- matrix(
  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,
  ),
  nrow = 3
)
```

```

-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 -----
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(
  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
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  $\Phi$  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 ( $\Phi$ ). 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. If test_phi = TRUE, the function tests the stability of the generated drift matrix $\Phi$ . If the test returns FALSE, the function generates a new drift matrix $\Phi$ 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.

## Details

### Monte Carlo Method:

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

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

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,

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

**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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**Examples**

```
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")
MCPhi(
  phi = phi,
  vcov_phi_vec = 0.1 * diag(9),
  R = 100L # use a large value for R in actual research
)
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 = 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  $\Delta t$  using the first-order stochastic differential equation model drift matrix  $\Phi$ .

### 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 ( $\Phi$ ). 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 vec ( $\Phi$ ).
delta_t	Numeric. Time interval ( $\Delta t$ ).
R	Positive integer. Number of replications.
test_phi	Logical. If test_phi = TRUE, the function tests the stability of the generated drift matrix $\Phi$ . If the test returns FALSE, the function generates a new drift matrix $\Phi$ 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 `TotalCentral()` for more details.

### Monte Carlo Method:

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

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

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,

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

Let  $g(\hat{\theta})$  be a parameter that is a function of the estimated parameters. A sampling distribution of  $g(\hat{\theta})$ , which we refer to as  $g(\hat{\theta}^*)$ , can be generated by using the simulated estimates to calculate  $g$ . The standard deviations of the simulated estimates are the standard errors. Percentiles corresponding to  $100(1 - \alpha)\%$  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](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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**Examples**

```
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(
    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 -----
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(
  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  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
delta_t	Vector of positive numbers. Time interval ( $\Delta t$ ).
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 `Total()`, `Direct()`, and `Indirect()` for more details.

### 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 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](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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [MedStd\(\)](#), [PosteriorBeta\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")

# 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(
  phi = phi,
  delta_t = 1:5,
  from = "x",
  to = "y",
  med = "m"
)
print(med)
summary(med)
plot(med)
```

---

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

---

## 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  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model's drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
delta_t	Numeric. Time interval ( $\Delta t$ ).
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

## 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()`, `MCPPhi()`, `MCTotalCentral()`, `Med()`, `PosteriorBeta()`, `PosteriorIndirectCentral()`, `PosteriorMed()`, `PosteriorPhi()`, `PosteriorTotalCentral()`, `Total()`, `TotalCentral()`, `TotalStd()`, `Trajectory()`

## 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")
sigma <- matrix(
  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(
```

```

    phi = phi,
    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(
  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

x	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.



**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")
vcov_phi_vec <- matrix(
  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(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  delta_t = 1:5,

```

```

    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

## Examples

```

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(

```

```

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(
  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

**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

**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")  
  
# Range of time intervals -----  
med <- Med(  
  phi = phi,  
  delta_t = 1:5,  
  from = "x",  
  to = "y",  
  med = "m"  
)  
plot(med)
```

---

plot.ctmedtraj	<i>Plot Method for an Object of Class ctmedtraj</i>
----------------	---

---

**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

**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")

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

plot(traj)
```

---

PosteriorBeta	<i>Posterior Sampling Distribution for the Elements of the Matrix of Lagged Coefficients Over a Specific Time Interval or a Range of Time Intervals</i>
---------------	---

---

## Description

This function generates a posterior sampling distribution for the elements of the matrix of lagged coefficients  $\beta$  over a specific time interval  $\Delta t$  or a range of time intervals using the first-order stochastic differential equation model drift matrix  $\Phi$ .

## Usage

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

## Arguments

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval ( $\Delta t$ ).
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

## 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: [DeltaBeta\(\)](#), [DeltaBetaStd\(\)](#), [DeltaIndirectCentral\(\)](#), [DeltaMed\(\)](#), [DeltaMedStd\(\)](#), [DeltaTotalCentral\(\)](#), [Direct\(\)](#), [DirectStd\(\)](#), [ExpCov\(\)](#), [ExpMean\(\)](#), [Indirect\(\)](#), [IndirectCentral\(\)](#), [IndirectStd\(\)](#), [MCBeta\(\)](#), [MCBetaStd\(\)](#), [MCIndirectCentral\(\)](#), [MCMed\(\)](#), [MCMedStd\(\)](#), [MCPhi\(\)](#), [MCTotalCentral\(\)](#), [Med\(\)](#), [MedStd\(\)](#), [PosteriorIndirectCentral\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

## 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")
vcov_phi_vec <- matrix(
  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(
    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(
    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  $\Delta t$  or a range of time intervals using the posterior distribution of the first-order stochastic differential equation model drift matrix  $\Phi$ .



**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 ( $\Phi$ ). Each matrix should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval ( $\Delta t$ ).
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](#)

**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\(\)](#), [PosteriorMed\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
vcov_phi_vec <- matrix(
  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(
```

```

    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(
  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  $\Delta t$  or a range of time intervals using the posterior distribution of the first-order stochastic differential equation model drift matrix  $\Phi$ .

## 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 ( $\Phi$ ). Each matrix should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval ( $\Delta t$ ).
from	Character string. Name of the independent variable $X$ in phi.

<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.
<code>tol</code>	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: `DeltaBeta()`, `DeltaBetaStd()`, `DeltaIndirectCentral()`, `DeltaMed()`, `DeltaMedStd()`, `DeltaTotalCentral()`, `Direct()`, `DirectStd()`, `ExpCov()`, `ExpMean()`, `Indirect()`, `IndirectCentral()`, `IndirectStd()`, `MCBeta()`, `MCBetaStd()`, `MCIndirectCentral()`, `MCMed()`, `MCMedStd()`, `MCPhi()`, `MCTotalCentral()`, `Med()`, `MedStd()`, `PosteriorBeta()`, `PosteriorIndirectCentral()`, `PosteriorPhi()`, `PosteriorTotalCentral()`, `Total()`, `TotalCentral()`, `TotalStd()`, `Trajectory()`

**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")
vcov_phi_vec <- matrix(
  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(
  phi = phi,
  vcov_phi_vec = vcov_phi_vec,
  R = 1000L
)$output

# 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 = 1:5,
    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)

```

---

PosteriorPhi

---

*Extract the Posterior Samples of the Drift Matrix*


---

## Description

The function extracts the posterior samples of the drift matrix from a fitted model from the `ctsem::ctStanFit()` function.

## Usage

```
PosteriorPhi(object)
```

## Arguments

`object`                      Object of class `ctStanFit`. Output of the `ctsem::ctStanFit()` function.

## Value

Returns an object of class `ctmedposteriorphi` which is a list drift matrices sampled from the posterior distribution.

## Author(s)

Ivan Jacob Agaloos Pesigan

**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\(\)](#)

---

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  $\Delta t$  or a range of time intervals using the posterior distribution of the first-order stochastic differential equation model drift matrix  $\Phi$ .

**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 ( $\Phi$ ). Each matrix should have row and column names pertaining to the variables in the system.
delta_t	Numeric. Time interval ( $\Delta t$ ).
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 ("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: [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\(\)](#), [PosteriorPhi\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")
vcov_phi_vec <- matrix(
  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(
  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(
  phi = phi,
  delta_t = 1:5
)

# Methods -----
# 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**

<code>x</code>	an object of class <code>ctmeddelta</code> .
<code>alpha</code>	Numeric vector. Significance level $\alpha$ .
<code>digits</code>	Integer indicating the number of decimal places to display.
<code>...</code>	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

**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")
vcov_phi_vec <- matrix(
  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 -----
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 = 1:5,
  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**

Prints 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 $\alpha$ .
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

## Examples

```

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(
    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(
  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
)
print(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
)
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**

Prints a list of drift matrices.

**Author(s)**

Ivan Jacob Agaloos Pesigan

**Examples**

```
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")  
mc <- MCPHi(  
  phi = phi,  
  vcov_phi_vec = 0.1 * diag(9),  
  R = 100L # use a large value for R in actual research  
)  
print(mc)
```

---

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

---

**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

**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")

# 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	<i>Print Method for Object of Class ctmedtraj</i>
-----------------	---

---

## 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.

## Value

Prints a data frame of simulated data.

## 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")

traj <- Trajectory(
  mu0 = c(3, 3, -3),

```

```

    time = 150,
    phi = phi,
    med = "m"
  )

  print(traj)

```

---

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 $\alpha$ .
...	additional arguments.

## 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

## 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")
vcov_phi_vec <- matrix(
  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 -----
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 = 1:5,
  from = "x",
  to = "y",
  med = "m"
)
summary(delta)

```

---

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

---

**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 $\alpha$ .
...	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

**Examples**

```
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(
    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(
  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
)
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)

```

**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(
  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 = 1:5,
  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.

### 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

**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")

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

summary(traj)
```

---

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

---

**Description**

This function computes the total effects matrix over a specific time interval  $\Delta t$  using the first-order stochastic differential equation model's drift matrix  $\Phi$ .

**Usage**

```
Total(phi, delta_t)
```

**Arguments**

- phi                    Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
- delta\_t                Numeric. Time interval ( $\Delta t$ ).



## Details

The total effect matrix over a specific time interval  $\Delta t$  is given by

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

where  $\Phi$  denotes the drift matrix, and  $\Delta t$  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,  $\Phi$  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 ("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](https://doi.org/10.2307/271028)
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- 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: [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\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

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
)
```

---

TotalCentral	<i>Total Effect Centrality</i>
--------------	--------------------------------

---

Description

Total Effect Centrality

Usage

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

**Arguments**

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
delta_t	Vector of positive numbers. Time interval ( $\Delta t$ ).
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.

**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: [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\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalStd\(\)](#), [Trajectory\(\)](#)

**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")

# Specific time interval -----
TotalCentral(
  phi = phi,
  delta_t = 1
)

# Range of time intervals -----
total_central <- TotalCentral(
  phi = phi,
  delta_t = 1:30
)
plot(total_central)

# Methods -----
# TotalCentral has a number of methods including
# print, summary, and plot
total_central <- TotalCentral(
  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  $\Delta t$  using the first-order stochastic differential equation model's drift matrix  $\Phi$  and process noise covariance matrix  $\Sigma$ .

**Usage**

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

**Arguments**

phi	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
sigma	Numeric matrix. The process noise covariance matrix ( $\Sigma$ ).
delta_t	Numeric. Time interval ( $\Delta t$ ).

**Details**

The standardized total effect matrix over a specific time interval  $\Delta t$  is given by

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

where  $\Phi$  denotes the drift matrix,  $\mathbf{S}$  a diagonal matrix with model-implied standard deviations on the diagonals and  $\Delta t$  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.

**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: [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\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [Trajectory\(\)](#)

**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")
sigma <- matrix(
  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***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**

<b>mu0</b>	Numeric vector. Initial values of the variables.
<b>time</b>	Positive integer. Number of time points.
<b>phi</b>	Numeric matrix. The drift matrix ( $\Phi$ ). phi should have row and column names pertaining to the variables in the system.
<b>med</b>	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: [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\(\)](#), [PosteriorPhi\(\)](#), [PosteriorTotalCentral\(\)](#), [Total\(\)](#), [TotalCentral\(\)](#), [TotalStd\(\)](#)

**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")
```

```
traj <- Trajectory(
  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(
  mu0 = c(3, 3, -3),
  time = 25,
  phi = phi,
  med = "m"
)
print(traj)
summary(traj)
plot(traj)
```

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