

# Package ‘mstudentd’

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**Type** Package

**Title** Multivariate t Distribution

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**Description** Distance between multivariate t distributions, as presented by N. Bouh-  
lel and D. Rousseau (2023) <doi:10.1109/LSP.2023.3324594>.

**Depends** R (>= 3.3.0)

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**URL** <https://forgemia.inra.fr/imhorphen/mstudentd>

**BugReports** <https://forgemia.inra.fr/imhorphen/mstudentd/-/issues>

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mstudentd-package      *Tools for Multivariate  $t$  Distributions*

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## Description

This package provides tools for multivariate  $t$  distributions (MTD):

- Calculation of distances/divergences between MTD:
  - Renyi divergence, Bhattacharyya distance, Hellinger distance: [diststudent](#)
  - Kullback-Leibler divergence: [kldstudent](#)
- Tools for MTD:
  - Probability density: [dmtd](#)
  - Simulation from a MTD: [rmtd](#)
  - Plot of the density of a MTD with 2 variables: [plotmtd](#), [contourmtd](#)

## Author(s)

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## References

S. Kotz and Saralees Nadarajah (2004), *Multivariate  $t$  Distributions and Their Applications*, Cambridge University Press.

N. Bouhlef and D. Rousseau (2023), Exact Rényi and Kullback-Leibler Divergences Between Multivariate  $t$ -Distributions, *IEEE Signal Processing Letters*. doi:10.1109/LSP.2023.3324594 #’ @keywords internal

## See Also

Useful links:

- <https://forgemia.inra.fr/imhorphen/mstudentd>
- Report bugs at <https://forgemia.inra.fr/imhorphen/mstudentd/-/issues>

**Description**

Draws the contour plot of the probability density of the multivariate  $t$  distribution with 2 variables with location parameter  $\mu$  and scatter matrix  $\Sigma$ .

**Usage**

```
contourmtd(nu, mu, Sigma,
           xlim = c(mu[1] + c(-10, 10)*Sigma[1, 1]),
           ylim = c(mu[2] + c(-10, 10)*Sigma[2, 2]),
           zlim = NULL, npt = 30, nx = npt, ny = npt,
           main = "Multivariate t density",
           sub = NULL, nlevels = 10,
           levels = pretty(zlim, nlevels), tol = 1e-6, ...)
```

**Arguments**

<code>nu</code>	numeric. The degrees of freedom.
<code>mu</code>	length 2 numeric vector.
<code>Sigma</code>	symmetric, positive-definite square matrix of order 2. The scatter matrix.
<code>xlim, ylim</code>	x-and y- limits.
<code>zlim</code>	z- limits. If NULL, it is the range of the values of the density on the x and y values within <code>xlim</code> and <code>ylim</code> .
<code>npt</code>	number of points for the discretisation.
<code>nx, ny</code>	number of points for the discretisation among the x- and y- axes.
<code>main, sub</code>	main and sub title, as for <a href="#">title</a> .
<code>nlevels, levels</code>	arguments to be passed to the <a href="#">contour</a> function.
<code>tol</code>	tolerance (relative to largest variance) for numerical lack of positive-definiteness in $\Sigma$ , for the estimation of the density. see <a href="#">dmt</a> .
<code>...</code>	additional arguments to <a href="#">plot.window</a> , <a href="#">title</a> , <a href="#">Axis</a> and <a href="#">box</a> , typically <a href="#">graphical parameters</a> such as <code>cex.axis</code> .

**Value**

Returns invisibly the probability density function.

**Author(s)**

Pierre Santagostini, Nizar Bouhlel

## References

S. Kotz and Saralees Nadarajah (2004), *Multivariate  $t$  Distributions and Their Applications*, Cambridge University Press.

## See Also

[dmt](#): probability density of a multivariate  $t$  density

[plotmtd](#): 3D plot of a bivariate  $t$  density.

## Examples

```
nu <- 1
mu <- c(1, 4)
Sigma <- matrix(c(0.8, 0.2, 0.2, 0.2), nrow = 2)
contourmtd(nu, mu, Sigma)
```

---

diststudent

*Distance/Divergence between Centered Multivariate  $t$  Distributions*

---

## Description

Computes the distance or divergence (Renyi divergence, Bhattacharyya distance or Hellinger distance) between two random vectors distributed according to multivariate  $t$  distributions (MTD) with zero mean vector.

## Usage

```
diststudent(nu1, Sigma1, nu2, Sigma2,
            dist = c("renyi", "battacharyya", "hellinger"),
            bet = NULL, eps = 1e-06)
```

## Arguments

nu1	numeric. The degrees of freedom of the first distribution.
Sigma1	symmetric, positive-definite matrix. The correlation matrix of the first distribution.
nu2	numeric. The degrees of freedom of the second distribution.
Sigma2	symmetric, positive-definite matrix. The correlation matrix of the second distribution.
dist	character. The distance or divergence used. One of "renyi" (default), "battacharyya" or "hellinger".
bet	numeric, positive and not equal to 1. Order of the Renyi divergence. Ignored if distance="battacharyya" or distance="hellinger".
eps	numeric. Precision for the computation of the partial derivative of the Lauricella $D$ -hypergeometric function (see Details). Default: 1e-06.

### Details

Given  $X_1$ , a random vector of  $R^p$  distributed according to the MTD with parameters  $(\nu_1, \mathbf{0}, \Sigma_1)$  and  $X_2$ , a random vector of  $R^p$  distributed according to the MTD with parameters  $(\nu_2, \mathbf{0}, \Sigma_2)$ .

Let  $\delta_1 = \frac{\nu_1 + p}{2}\beta$ ,  $\delta_2 = \frac{\nu_2 + p}{2}(1 - \beta)$  and  $\lambda_1, \dots, \lambda_p$  the eigenvalues of the square matrix  $\Sigma_1 \Sigma_2^{-1}$  sorted in increasing order:

$$\lambda_1 < \dots < \lambda_{p-1} < \lambda_p$$

The Renyi divergence between  $X_1$  and  $X_2$  is:

$$D_R^\beta(\mathbf{X}_1 || \mathbf{X}_2) = \frac{1}{\beta - 1} \left[ \beta \ln \left( \frac{\Gamma\left(\frac{\nu_1 + p}{2}\right) \Gamma\left(\frac{\nu_2}{2}\right) \nu_2^{\frac{p}{2}}}{\Gamma\left(\frac{\nu_2 + p}{2}\right) \Gamma\left(\frac{\nu_1}{2}\right) \nu_1^{\frac{p}{2}}} \right) + \ln \left( \frac{\Gamma\left(\frac{\nu_2 + p}{2}\right)}{\Gamma\left(\frac{\nu_2}{2}\right)} \right) + \ln \left( \frac{\Gamma(\delta_1 + \delta_2 - \frac{p}{2})}{\Gamma(\delta_1 + \delta_2)} \right) - \frac{\beta}{2} \sum_{i=1}^p \ln \lambda_i + \ln F_D \right]$$

with  $F_D$  given by:

- If  $\frac{\nu_1}{\nu_2} \lambda_1 > 1$ :  $F_D = F_D^{(p)} \left( \delta_1, \underbrace{\frac{1}{2}, \dots, \frac{1}{2}}_p; \delta_1 + \delta_2; 1 - \frac{\nu_2}{\nu_1 \lambda_1}, \dots, 1 - \frac{\nu_2}{\nu_1 \lambda_p} \right)$
- If  $\frac{\nu_1}{\nu_2} \lambda_p < 1$ :  $F_D = \prod_{i=1}^p \left( \frac{\nu_1}{\nu_2} \lambda_i \right)^{\frac{1}{2}} F_D^{(p)} \left( \delta_2, \underbrace{\frac{1}{2}, \dots, \frac{1}{2}}_p; \delta_1 + \delta_2; 1 - \frac{\nu_1}{\nu_2} \lambda_1, \dots, 1 - \frac{\nu_1}{\nu_2} \lambda_p \right)$
- If  $\frac{\nu_1}{\nu_2} \lambda_1 < 1$  and  $\frac{\nu_1}{\nu_2} \lambda_p > 1$ :  

$$F_D = \left( \frac{\nu_2}{\nu_1} \frac{1}{\lambda_p} \right)^{\delta_2} \prod_{i=1}^p \left( \frac{\nu_1}{\nu_2} \lambda_i \right)^{\frac{1}{2}} F_D^{(p)} \left( \delta_2, \underbrace{\frac{1}{2}, \dots, \frac{1}{2}}_p, \delta_1 + \delta_2 - \frac{p}{2}; \delta_1 + \delta_2; 1 - \frac{\lambda_1}{\lambda_p}, \dots, 1 - \frac{\lambda_{p-1}}{\lambda_p}, 1 - \frac{\nu_2}{\nu_1} \frac{1}{\lambda_p} \right)$$

where  $F_D^{(p)}$  is the Lauricella  $D$ -hypergeometric function defined for  $p$  variables:

$$F_D^{(p)}(a; b_1, \dots, b_p; g; x_1, \dots, x_p) = \sum_{m_1 \geq 0} \dots \sum_{m_p \geq 0} \frac{(a)_{m_1 + \dots + m_p} (b_1)_{m_1} \dots (b_p)_{m_p}}{(g)_{m_1 + \dots + m_p}} \frac{x_1^{m_1}}{m_1!} \dots \frac{x_p^{m_p}}{m_p!}$$

Its computation uses the [lauricella](#) function.

The Bhattacharyya distance is given by:

$$D_B(\mathbf{X}_1 || \mathbf{X}_2) = \frac{1}{2} D_R^{1/2}(\mathbf{X}_1 || \mathbf{X}_2)$$

And the Hellinger distance is given by:

$$D_H(\mathbf{X}_1 || \mathbf{X}_2) = 1 - \exp \left( -\frac{1}{2} D_R^{1/2}(\mathbf{X}_1 || \mathbf{X}_2) \right)$$

### Value

A numeric value: the Renyi divergence between the two distributions, with two attributes `attr(, "epsilon")` (precision of the result of the Lauricella  $D$ -hypergeometric function, see Details) and `attr(, "k")` (number of iterations).

**Author(s)**

Pierre Santagostini, Nizar Bouhlef

**References**

N. Bouhlef and D. Rousseau (2023), Exact Rényi and Kullback-Leibler Divergences Between Multivariate  $t$ -Distributions, IEEE Signal Processing Letters. doi:[10.1109/LSP.2023.3324594](https://doi.org/10.1109/LSP.2023.3324594)

**Examples**

```
nu1 <- 2
Sigma1 <- matrix(c(2, 1.2, 0.4, 1.2, 2, 0.6, 0.4, 0.6, 2), nrow = 3)
nu2 <- 4
Sigma2 <- matrix(c(1, 0.3, 0.1, 0.3, 1, 0.4, 0.1, 0.4, 1), nrow = 3)

# Renyi divergence
diststudent(nu1, Sigma1, nu2, Sigma2, bet = 0.25)
diststudent(nu2, Sigma2, nu1, Sigma1, bet = 0.25)

# Bhattacharyya distance
diststudent(nu1, Sigma1, nu2, Sigma2, dist = "bhattacharyya")
diststudent(nu2, Sigma2, nu1, Sigma1, dist = "bhattacharyya")

# Hellinger distance
diststudent(nu1, Sigma1, nu2, Sigma2, dist = "hellinger")
diststudent(nu2, Sigma2, nu1, Sigma1, dist = "hellinger")
```

---

dmtd

*Density of a Multivariate  $t$  Distribution*


---

**Description**

Density of the multivariate ( $p$  variables)  $t$  distribution (MTD) with degrees of freedom  $\nu$ , mean vector  $\mu$  and correlation matrix  $\Sigma$ .

**Usage**

```
dmtd(x, nu, mu, Sigma, tol = 1e-6)
```

**Arguments**

<code>x</code>	length $p$ numeric vector.
<code>nu</code>	numeric. The degrees of freedom.
<code>mu</code>	length $p$ numeric vector. The mean vector.
<code>Sigma</code>	symmetric, positive-definite square matrix of order $p$ . The correlation matrix.
<code>tol</code>	tolerance (relative to largest variance) for numerical lack of positive-definiteness in $\Sigma$ .

**Details**

The density function of a multivariate  $t$  distribution with  $p$  variables is given by:

$$f(\mathbf{x}|\nu, \boldsymbol{\mu}, \Sigma) = \frac{\Gamma\left(\frac{\nu+p}{2}\right) |\Sigma|^{-1/2}}{\Gamma\left(\frac{\nu}{2}\right) (\nu\pi)^{p/2}} \left(1 + \frac{1}{\nu}(\mathbf{x} - \boldsymbol{\mu})^T \Sigma^{-1}(\mathbf{x} - \boldsymbol{\mu})\right)^{-\frac{\nu+p}{2}}$$

When  $p = 1$  (univariate case) it becomes:

$$f(x|\nu, \mu, \sigma^2) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right) \sqrt{\nu\pi}\sigma} \left(1 + \frac{(x - \mu)^2}{\nu\sigma^2}\right)^{-\frac{\nu+1}{2}}$$

**Value**

The value of the density.

**Author(s)**

Pierre Santagostini, Nizar Bouhlel

**References**

S. Kotz and Saralees Nadarajah (2004), *Multivariate  $t$  Distributions and Their Applications*, Cambridge University Press.

**Examples**

```
nu <- 1
mu <- c(0, 1, 4)
Sigma <- matrix(c(0.8, 0.3, 0.2, 0.3, 0.2, 0.1, 0.2, 0.1, 0.2), nrow = 3)
dmt(d(c(0, 1, 4), nu, mu, Sigma)
dmt(d(c(1, 2, 3), nu, mu, Sigma)

# Univariate
dmt(1, 3, 0, 1)
dt(1, 3)
```

---

kldstudent

---

*Kullback-Leibler Divergence between Centered Multivariate  $t$  Distributions*


---

**Description**

Computes the Kullback-Leibler divergence between two random vectors distributed according to multivariate  $t$  distributions (MTD) with zero location vector.

**Usage**

```
kldstudent(nu1, Sigma1, nu2, Sigma2, eps = 1e-06)
```

**Arguments**

nu1	numeric. The degrees of freedom of the first distribution.
Sigma1	symmetric, positive-definite matrix. The scatter matrix of the first distribution.
nu2	numeric. The degrees of freedom of the second distribution.
Sigma2	symmetric, positive-definite matrix. The scatter matrix of the second distribution.
eps	numeric. Precision for the computation of the partial derivative of the Lauricella $D$ -hypergeometric function (see Details). Default: 1e-06.

**Details**

Given  $X_1$ , a random vector of  $\mathbb{R}^p$  distributed according to the centered MTD with parameters  $(\nu_1, 0, \Sigma_1)$  and  $X_2$ , a random vector of  $\mathbb{R}^p$  distributed according to the MCD with parameters  $(\nu_2, 0, \Sigma_2)$ .

Let  $\lambda_1, \dots, \lambda_p$  the eigenvalues of the square matrix  $\Sigma_1 \Sigma_2^{-1}$  sorted in increasing order:

$$\lambda_1 < \dots < \lambda_{p-1} < \lambda_p$$

The Kullback-Leibler divergence of  $X_1$  from  $X_2$  is given by:

$$D_{KL}(\mathbf{X}_1 \parallel \mathbf{X}_2) = \ln \left( \frac{\Gamma\left(\frac{\nu_1+p}{2}\right) \Gamma\left(\frac{\nu_2}{2}\right) \nu_2^{\frac{p}{2}}}{\Gamma\left(\frac{\nu_2+p}{2}\right) \Gamma\left(\frac{\nu_1}{2}\right) \nu_1^{\frac{p}{2}}}\right) + \frac{\nu_2 - \nu_1}{2} \left[ \psi\left(\frac{\nu_1+p}{2}\right) - \psi\left(\frac{\nu_1}{2}\right) \right] - \frac{1}{2} \sum_{i=1}^p \ln \lambda_i - \frac{\nu_2+p}{2} \times D$$

where  $\psi$  is the digamma function (see [Special](#)) and  $D$  is given by:

- If  $\frac{\nu_1}{\nu_2} \lambda_1 > 1$ :

$$D = \prod_{i=1}^p \left( \frac{\nu_2}{\nu_1} \frac{1}{\lambda_i} \right)^{\frac{1}{2}} \frac{\partial}{\partial a} \left\{ F_D^{(p)} \left( \frac{\nu_1+p}{2}, \underbrace{\frac{1}{2}, \dots, \frac{1}{2}}_p; a + \frac{\nu_1+p}{2}; 1 - \frac{\nu_2}{\nu_1} \frac{1}{\lambda_1}, \dots, 1 - \frac{\nu_2}{\nu_1} \frac{1}{\lambda_p} \right) \right\} \Bigg|_{a=0}$$

- If  $\frac{\nu_1}{\nu_2} \lambda_p < 1$ :

$$D = \frac{\partial}{\partial a} \left\{ F_D^{(p)} \left( a, \underbrace{\frac{1}{2}, \dots, \frac{1}{2}}_p; a + \frac{\nu_1+p}{2}; 1 - \frac{\nu_1}{\nu_2} \lambda_1, \dots, 1 - \frac{\nu_1}{\nu_2} \lambda_p \right) \right\} \Bigg|_{a=0}$$

- If  $\frac{\nu_1}{\nu_2} \lambda_1 < 1$  and  $\frac{\nu_1}{\nu_2} \lambda_p > 1$ :

$$D = -\ln \left( \frac{\nu_1}{\nu_2} \lambda_p \right) + \frac{\partial}{\partial a} \left\{ F_D^{(p)} \left( a, \underbrace{\frac{1}{2}, \dots, \frac{1}{2}}_p, a + \frac{\nu_1}{2}; a + \frac{\nu_1+p}{2}; 1 - \frac{\lambda_1}{\lambda_p}, \dots, 1 - \frac{\lambda_{p-1}}{\lambda_p}, 1 - \frac{\nu_2}{\nu_1} \frac{1}{\lambda_p} \right) \right\} \Bigg|_{a=0}$$

$F_D^{(p)}$  is the Lauricella  $D$ -hypergeometric function defined for  $p$  variables:

$$F_D^{(p)}(a; b_1, \dots, b_p; g; x_1, \dots, x_p) = \sum_{m_1 \geq 0} \dots \sum_{m_p \geq 0} \frac{(a)_{m_1+\dots+m_p} (b_1)_{m_1} \dots (b_p)_{m_p}}{(g)_{m_1+\dots+m_p}} \frac{x_1^{m_1}}{m_1!} \dots \frac{x_p^{m_p}}{m_p!}$$

**Value**

A numeric value: the Kullback-Leibler divergence between the two distributions, with two attributes `attr(, "epsilon")` (precision of the partial derivative of the Lauricella  $D$ -hypergeometric function, see Details) and `attr(, "k")` (number of iterations).

**Author(s)**

Pierre Santagostini, Nizar Bouhlef

**References**

N. Bouhlef and D. Rousseau (2023), Exact Rényi and Kullback-Leibler Divergences Between Multivariate t-Distributions, IEEE Signal Processing Letters. doi:[10.1109/LSP.2023.3324594](https://doi.org/10.1109/LSP.2023.3324594)

**Examples**

```
nu1 <- 2
Sigma1 <- matrix(c(2, 1.2, 0.4, 1.2, 2, 0.6, 0.4, 0.6, 2), nrow = 3)
nu2 <- 4
Sigma2 <- matrix(c(1, 0.3, 0.1, 0.3, 1, 0.4, 0.1, 0.4, 1), nrow = 3)

kldstudent(nu1, Sigma1, nu2, Sigma2)
kldstudent(nu2, Sigma2, nu1, Sigma1)
```

---

lauricella

*Lauricella D-Hypergeometric Function*

---

**Description**

Computes the Lauricella  $D$ -hypergeometric Function function.

**Usage**

```
lauricella(a, b, g, x, eps = 1e-06)
```

**Arguments**

a	numeric.
b	numeric vector.
g	numeric.
x	numeric vector. x must have the same length as b.
eps	numeric. Precision for the nested sums (default 1e-06).

**Details**

If  $n$  is the length of the  $b$  and  $x$  vectors, the Lauricella  $D$ -hypergeometric Function function is given by:

$$F_D^{(n)}(a, b_1, \dots, b_n, g; x_1, \dots, x_n) = \sum_{m_1 \geq 0} \dots \sum_{m_n \geq 0} \frac{(a)_{m_1 + \dots + m_n} (b_1)_{m_1} \dots (b_n)_{m_n} x_1^{m_1} \dots x_n^{m_n}}{(g)_{m_1 + \dots + m_n} m_1! \dots m_n!}$$

where  $(x)_p$  is the Pochhammer symbol (see [pochhammer](#)).

If  $|x_i| < 1, i = 1, \dots, n$ , this sum converges. Otherwise there is an error.

The `eps` argument gives the required precision for its computation. It is the `attr(, "epsilon")` attribute of the returned value.

Sometimes, the convergence is too slow and the required precision cannot be reached. If this happens, the `attr(, "epsilon")` attribute is the precision that was really reached.

**Value**

A numeric value: the value of the Lauricella function, with two attributes `attr(, "epsilon")` (precision of the result) and `attr(, "k")` (number of iterations).

**Author(s)**

Pierre Santagostini, Nizar Bouhlel

**References**

N. Bouhlel and D. Rousseau, Exact Rényi and Kullback-Leibler Divergences Between Multivariate t-Distributions. IEEE Signal Processing Letters Processing Letters, vol. 26 no. 7, July 2019. [doi:10.1109/LSP.2019.2915000](https://doi.org/10.1109/LSP.2019.2915000)

---

Inpochhammer

*Logarithm of the Pochhammer Symbol*

---

**Description**

Computes the logarithm of the Pochhammer symbol.

**Usage**

`Inpochhammer(x, n)`

**Arguments**

<code>x</code>	numeric.
<code>n</code>	positive integer.

**Details**

The Pochhammer symbol is given by:

$$(x)_n = \frac{\Gamma(x+n)}{\Gamma(x)} = x(x+1)\dots(x+n-1)$$

So, if  $n > 0$ :

$$\log((x)_n) = \log(x) + \log(x+1) + \dots + \log(x+n-1)$$

If  $n = 0$ ,  $\log((x)_n) = \log(1) = 0$

**Value**

Numeric value. The logarithm of the Pochhammer symbol.

**Author(s)**

Pierre Santagostini, Nizar Bouhlel

**See Also**

[pochhammer\(\)](#)

**Examples**

```
lnpochhammer(2, 0)
lnpochhammer(2, 1)
lnpochhammer(2, 3)
```

---

plotmtd

*Plot of the Bivariate t Density*

---

**Description**

Plots the probability density of the multivariate  $t$  distribution with 2 variables with location parameter  $\mu$  and scatter matrix  $\Sigma$ .

**Usage**

```
plotmtd(nu, mu, Sigma, xlim = c(mu[1] + c(-10, 10)*Sigma[1, 1]),
        ylim = c(mu[2] + c(-10, 10)*Sigma[2, 2]), n = 101,
        xvals = NULL, yvals = NULL, xlab = "x", ylab = "y",
        zlab = "f(x,y)", col = "gray", tol = 1e-6, ...)
```

**Arguments**

<code>nu</code>	numeric. The degrees of freedom.
<code>mu</code>	length 2 numeric vector. The mean vector.
<code>Sigma</code>	symmetric, positive-definite square matrix of order 2. The correlation matrix.
<code>xlim, ylim</code>	x-and y- limits.
<code>n</code>	A one or two element vector giving the number of steps in the x and y grid, passed to <a href="#">plot3d.function</a> .
<code>xvals, yvals</code>	The values at which to evaluate x and y. If used, <code>xlim</code> and/or <code>ylim</code> are ignored.
<code>xlab, ylab, zlab</code>	The axis labels.
<code>col</code>	The color to use for the plot. See <a href="#">plot3d.function</a> .
<code>tol</code>	tolerance (relative to largest variance) for numerical lack of positive-definiteness in <code>Sigma</code> , for the estimation of the density. see <a href="#">dmtd</a> .
<code>...</code>	Additional arguments to pass to <a href="#">plot3d.function</a> .

**Value**

Returns invisibly the probability density function.

**Author(s)**

Pierre Santagostini, Nizar Bouhlel

**References**

S. Kotz and Saralees Nadarajah (2004), *Multivariate  $t$  Distributions and Their Applications*, Cambridge University Press.

**See Also**

[dmtd](#): probability density of a multivariate  $t$  density

[contourmtd](#): contour plot of a bivariate  $t$  density.

[plot3d.function](#): plot a function of two variables.

**Examples**

```
nu <- 1
mu <- c(1, 4)
Sigma <- matrix(c(0.8, 0.2, 0.2, 0.2), nrow = 2)
plotmtd(nu, mu, Sigma)
```

---

pochhammer	<i>Pochhammer Symbol</i>
------------	--------------------------

---

**Description**

Computes the Pochhammer symbol.

**Usage**

pochhammer(x, n)

**Arguments**

x	numeric.
n	positive integer.

**Details**

The Pochhammer symbol is given by:

$$(x)_n = \frac{\Gamma(x+n)}{\Gamma(x)} = x(x+1)\dots(x+n-1)$$

**Value**

Numeric value. The value of the Pochhammer symbol.

**Author(s)**

Pierre Santagostini, Nizar Bouhlel

**Examples**

```
pochhammer(2, 0)
pochhammer(2, 1)
pochhammer(2, 3)
```

---

rmtd

---

*Simulate from a Multivariate t Distribution*


---

**Description**

Produces one or more samples from the multivariate ( $p$  variables)  $t$  distribution (MTD) with degrees of freedom  $\nu$ , mean vector  $\mu$  and correlation matrix  $\Sigma$ .

**Usage**

```
rmtd(n, nu, mu, Sigma, tol = 1e-6)
```

**Arguments**

n	integer. Number of observations.
nu	numeric. The degrees of freedom.
mu	length $p$ numeric vector. The mean vector
Sigma	symmetric, positive-definite square matrix of order $p$ . The correlation matrix.
tol	tolerance for numerical lack of positive-definiteness in Sigma (for <code>mvrnorm</code> , see Details).

**Details**

A sample from a MTD with parameters  $\nu$ ,  $\mu$  and  $\Sigma$  can be generated using:

$$X = \mu + \frac{Y}{\sqrt{\frac{u}{\nu}}}$$

where  $Y$  is a random vector distributed among a centered Gaussian density with covariance matrix  $\Sigma$  (generated using `mvrnorm`) and  $u$  is distributed among a Chi-squared distribution with  $\nu$  degrees of freedom.

**Value**

A matrix with  $p$  columns and  $n$  rows.

**Author(s)**

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**References**

S. Kotz and Saralees Nadarajah (2004), *Multivariate  $t$  Distributions and Their Applications*, Cambridge University Press.

**See Also**

[dmtd](#): probability density of a MTD.

**Examples**

```
nu <- 3
mu <- c(0, 1, 4)
Sigma <- matrix(c(1, 0.6, 0.2, 0.6, 1, 0.3, 0.2, 0.3, 1), nrow = 3)
x <- rmtd(10000, nu, mu, Sigma)
head(x)
dim(x)
mu; colMeans(x)
nu/(nu-2)*Sigma; var(x)
```

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