

Package ‘DPQ’

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Title Density, Probability, Quantile ('DPQ') Computations

Version 0.5-9

Date 2024-08-23

VersionNote Last CRAN: 0.5-8 on 2023-11-30; 0.5-7 on 2023-11-03

Description Computations for approximations and alternatives for the 'DPQ' (Density (pdf), Probability (cdf) and Quantile) functions for probability distributions in R.

Primary focus is on (central and non-central) beta, gamma and related distributions such as the chi-squared, F, and t.

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For several distribution functions, provide functions implementing formulas from Johnson, Kotz, and Kemp (1992) <doi:10.1002/bimj.4710360207> and Johnson, Kotz, and Balakrishnan (1995) for discrete or continuous distributions respectively.

This is for the use of researchers in these numerical approximation implementations, notably for my own use in order to improve standard R `pbeta()`, `qgamma()`, ..., etc: {"`dpq"-functions}.

Depends R (>= 4.0.0)

Imports stats, graphics, methods, utils, sfsmisc (>= 1.1-14)

Suggests Rmpfr, DPQmpfr (>= 0.3-1), gmp, MASS, mgcv, scatterplot3d, interp, cobs

SuggestsNote MASS::fractions() in ex | mgcv, scatt..., ..., cobs: some tests/

License GPL (>= 2)

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NeedsCompilation yes

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DPQ-package

*Density, Probability, Quantile ('DPQ') Computations***Description**

Computations for approximations and alternatives for the 'DPQ' (Density (pdf), Probability (cdf) and Quantile) functions for probability distributions in R. Primary focus is on (central and non-central) beta, gamma and related distributions such as the chi-squared, F, and t. – For several distribution functions, provide functions implementing formulas from Johnson, Kotz, and Kemp (1992) <doi:10.1002/bimj.4710360207> and Johnson, Kotz, and Balakrishnan (1995) for discrete or continuous distributions respectively. This is for the use of researchers in these numerical approximation implementations, notably for my own use in order to improve standard R `pbeta()`, `qgamma()`, ..., etc: {"dpq"-functions}.

Details

The DESCRIPTION file:

```

Package:      DPQ
Title:        Density, Probability, Quantile ('DPQ') Computations
Version:      0.5-9
Date:         2024-08-23
VersionNote:  Last CRAN: 0.5-8 on 2023-11-30; 0.5-7 on 2023-11-03
Authors@R:    c(person("Martin", "Maechler", role=c("aut", "cre"), email="maechler@stat.math.ethz.ch", comment = c(ORCID
Description:  Computations for approximations and alternatives for the 'DPQ' (Density (pdf), Probability (cdf) and Quantile
Depends:      R (>= 4.0.0)
Imports:      stats, graphics, methods, utils, sfsmisc (>= 1.1-14)
Suggests:    Rmpfr, DPQmpfr (>= 0.3-1), gmp, MASS, mgcv, scatterplot3d, interp, cobs
SuggestsNote: MASS::fractions() in ex | mgcv, scatt..., ..., cobs: some tests/
License:      GPL (>= 2)
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URL:          https://specfun.r-forge.r-project.org/, https://r-forge.r-project.org/R/?group_id=611, https://r-forge.r-project.org
BugReports:   https://r-forge.r-project.org/tracker/?atid=2462&group_id=611
Author:       Martin Maechler [aut, cre] (<https://orcid.org/0000-0002-8685-9910>), Morten Welinder [ctb] (pgamma C o
Maintainer:   Martin Maechler <maechler@stat.math.ethz.ch>

```

Index of help topics:

```

.D_0          Distribution Utilities "dpq"
Bern          Bernoulli Numbers
DPQ-package   Density, Probability, Quantile ('DPQ')
              Computations
Ixpq         Normalized Incomplete Beta Function "Like"
              'pbeta()'
M_LN2        Numerical Utilities - Functions, Constants
alqdiv       Compute log(gamma(b)/gamma(a+b)) when b >= 8

```

b_chi	Compute $E[\chi_{\text{nu}}]/\sqrt{\text{nu}}$ useful for t- and chi-Distributions
bd0	Binomial Deviance - Auxiliary Functions for 'dgamma()' Etc
bpser	'pbeta()' 'bpser' series computation
chebyshevPoly	Chebyshev Polynomial Evaluation
dbinom_raw	R's C Mathlib (Rmath) dbinom_raw() Binomial Probability pure R Function
dgamma.R	Gamma Density Function Alternatives
dhyperBinMolenaar	HyperGeometric (Point) Probabilities via Molenaar's Binomial Approximation
dnbinomR	Pure R Versions of R's C (Mathlib) dnbinom() Negative Binomial Probabilities
dnchisqR	Approximations of the (Noncentral) Chi-Squared Density
dntJKBf1	Non-central t-Distribution Density - Algorithms and Approximations
dpsifn	Psi Gamma Functions Workhorse from R's API
dtWV	Asymptotic Noncentral t Distribution Density by Viechtbauer
expm1x	Accurate $\exp(x) - 1 - x$ (for smallish $ x $)
format01prec	Format Numbers in $[0,1]$ with "Precise" Result
frexp	Base-2 Representation and Multiplication of Numbers
gam1d	Compute $1/\Gamma(x+1) - 1$ Accurately
gamln1	Compute $\log(\Gamma(x+1))$ Accurately in $[-0.2, 1.25]$
gammaVer	Gamma Function Versions
hyper2binomP	Transform Hypergeometric Distribution Parameters to Binomial Probability
lbetaM	(Log) Beta and Ratio of Gammas Approximations
lfastchoose	R versions of Simple Formulas for Logarithmic Binomial Coefficients
lgamma1p	Accurate 'log(gamma(a+1))'
lgammaAsymp	Asymptotic Log Gamma Function
log1mexp	Compute $\log(1 - \exp(-a))$ and $\log(1 + \exp(x))$ Numerically Optimally
log1pmx	Accurate 'log(1+x) - x' Computation
logcf	Continued Fraction Approximation of Log-Related Power Series
logspace.add	Logspace Arithmetix - Addition and Subtraction
lssum	Compute Logarithm of a Sum with Signed Large Summands
lsum	Properly Compute the Logarithm of a Sum (of Exponentials)
newton	Simple R level Newton Algorithm, Mostly for Didactical Reasons
p111	Numerically Stable $p111(t) = (t+1)*\log(1+t) - t$

pbetaRv1	Pure R Implementation of Old pbeta()
pchisqV	Wienergerm Approximations to (Non-Central) Chi-squared Probabilities
phyper1molenaar	Molenaar's Normal Approximations to the Hypergeometric Distribution
phyperAllBin	Compute Hypergeometric Probabilities via Binomial Approximations
phyperApprAS152	Normal Approximation to cumulative Hyperbolic Distribution - AS 152
phyperBin.1	HyperGeometric Distribution via Approximate Binomial Distribution
phyperBinMolenaar	HyperGeometric Distribution via Molenaar's Binomial Approximation
phyperIbeta	Pearson's incomplete Beta Approximation to the Hyperbolic Distribution
phyperPeizer	Peizer's Normal Approximation to the Cumulative Hyperbolic
phyperR	R-only version of R's original phyper() algorithm
phyperR2	Pure R version of R's C level phyper()
phypers	The Four (4) Symmetric 'phyper()' Calls
pl2curves	Plot 2 Noncentral Distribution Curves for Visual Comparison
pnbetaAppr2	Noncentral Beta Probabilities
pnchi1sq	(Probabilities of Non-Central Chi-squared Distribution for Special Cases
pnchisq	(Approximate) Probabilities of Non-Central Chi-squared Distribution
pnormAsymp	Asymptotic Approximation of (Extreme Tail) 'pnorm()'
pnormL_LD10	Bounds for 1-Phi(.) - Mill's Ratio related Bounds for pnorm()
pntR	Non-central t Probability Distribution - Algorithms and Approximations
pow	X to Power of Y - R C API 'R_pow()'
pow1p	Accurate $(1+x)^y$, notably for small $ x $
ppoisErr	Direct Computation of 'ppois()' Poisson Distribution Probabilities
pt_Witkovsky_Tab1	Viktor Witosky's Table_1 pt() Examples
qbetaAppr	Compute (Approximate) Quantiles of the Beta Distribution
qbinomR	Pure R Implementation of R's qbinom() with Tuning Parameters
qchisqAppr	Compute Approximate Quantiles of the Chi-Squared Distribution
qgammaAppr	Compute (Approximate) Quantiles of the Gamma Distribution
qnbinomR	Pure R Implementation of R's qnbinom() with

	Tuning Parameters
qnchisqAppr	Compute Approximate Quantiles of Noncentral Chi-Squared Distribution
qnormAppr	Approximations to 'qnorm()', i.e., z_{α}
qnormAsymp	Asymptotic Approximation to Outer Tail of qnorm()
qnormR	Pure R version of R's 'qnorm()' with Diagnostics and Tuning Parameters
qntR	Pure R Implementation of R's qt() / qnt()
qpoisR	Pure R Implementation of R's qpois() with Tuning Parameters
qtAppr	Compute Approximate Quantiles of the (Non-Central) t-Distribution
qtR	Pure R Implementation of R's C-level t-Distribution Quantiles 'qt()'
qtU	'uniroot()'-based Computing of t-Distribution Quantiles
r_pois	Compute Relative Size of i-th term of Poisson Distribution Series
rexp1	TOMS 708 Approximation $\text{REXP}(x)$ of $\expm1(x) = \exp(x) - 1$
stirlerr	Stirling's Error Function - Auxiliary for Gamma, Beta, etc

Further information is available in the following vignettes:

Noncentral-Chisq	Noncentral Chi-Squared Probabilities – Algorithms in R (source)
comp-beta	Computing Beta(a,b) for Large Arguments (source)
log1pmx-etc	log1pmx, bd0, stirlerr - Probability Computations in R (source)
qnorm-asymp	Asymptotic Tail Formulas For Gaussian Quantiles (source)

An important goal is to investigate diverse algorithms and approximations of R's own density ($d^*(\cdot)$), probability ($p^*(\cdot)$), and quantile ($q^*(\cdot)$) functions, notably in “border” cases where the traditional published algorithms have shown to be suboptimal, not quite accurate, or even useless.

Examples are border cases of the beta distribution, or **non-central** distributions such as the non-central chi-squared and t-distributions.

Author(s)

Principal author and maintainer: Martin Maechler <maechler@stat.math.ethz.ch>

See Also

The package [DPQmpfr](#), which builds on this package and on [Rmpfr](#).

Examples

```
## Show problem in R's non-central t-distrib. density (and approximations):
example(dntJKBf)
```

algdiv *Compute log(gamma(b)/gamma(a+b)) when b >= 8*

Description

Computes

$$\text{algdiv}(a, b) := \log \frac{\Gamma(b)}{\Gamma(a+b)} = \log \Gamma(b) - \log \Gamma(a+b) = \text{lgamma}(b) - \text{lgamma}(a+b)$$

in a numerically stable way.

This is an auxiliary function in R's (TOMS 708) implementation of `pbeta()`, aka the incomplete beta function ratio.

Usage

`algdiv(a, b)`

Arguments

`a, b` numeric vectors which will be recycled to the same length.

Details

Note that this is also useful to compute the Beta function

$$B(a, b) = \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)}.$$

Clearly,

$$\log B(a, b) = \log \Gamma(a) + \text{algdiv}(a, b) = \log \Gamma(a) - \log Q_{ab}(a, b)$$

In our `./tests/qbeta-dist.R` we look into computing $\log(pB(p, q))$ accurately for $p \ll q$.

We are proposing a nice solution there.

How is this related to `algdiv()` ?

Additionally, we have defined

$$Q_{ab} = Q_{a,b} := \frac{\Gamma(a+b)\Gamma(b)}{\Gamma(a+b)},$$

such that $\log Q_{ab}(a, b) := \log Q_{ab}(a, b)$ fulfills simply

$$\log Q_{ab}(a, b) = -\text{algdiv}(a, b)$$

see [logQab_asy](#).

Value

a numeric vector of length $\max(\text{length}(a), \text{length}(b))$ (if neither is of length 0, in which case the result has length 0 as well).

Author(s)

Didonato, A. and Morris, A., Jr, (1992); `algdiv()`'s C version from the R sources, authored by the R core team; C and R interface: Martin Maechler

References

Didonato, A. and Morris, A., Jr, (1992) Algorithm 708: Significant digit computation of the incomplete beta function ratios, *ACM Transactions on Mathematical Software* **18**, 360–373.

See Also

`gamma`, `beta`; my own `logQab_asy()`.

Examples

```
Qab <- algdiv(2:3, 8:14)
cbind(a = 2:3, b = 8:14, Qab) # recycling with a warning

## algdiv() and my logQab_asy() give *very* similar results for largish b:
all.equal( - algdiv(3, 100),
           logQab_asy(3, 100), tolerance=0) # 1.283e-16 !!
(lQab <- logQab_asy(3, 1e10))
## relative error
1 + lQab/ algdiv(3, 1e10) # 0 (64b F 30 Linux; 2019-08-15)

## in-and outside of "certified" argument range {b >= 8}:
a. <- c(1:3, 4*(1:8))/32
b. <- seq(1/4, 20, by=1/4)
ad <- t(outer(a., b., algdiv))
## direct computation:
f.algdiv <- function(a,b) lgamma(b) - lgamma(a+b)
ad.d <- t(outer(a., b., f.algdiv))

matplot(b., ad.d, type = "o", cex=3/4,
        main = quote(log(Gamma(b)/Gamma(a+b)) ~" vs. algdiv(a,b)"))
mtext(paste0("a[1:",length(a.),"] = ",
            paste0(paste(head(paste0(formatC(a.*32), "/32")), collapse=", ", ", ", ..., 1" )))
matlines(b., ad, type = "l", lwd=4, lty=1, col=adjustcolor(1:6, 1/2))
abline(v=1, lty=3, col="midnightblue")
# The larger 'b', the more accurate the direct formula wrt algdiv()
all.equal(ad[b. >= 1,], ad.d[b. >= 1,])# 1.5e-5
all.equal(ad[b. >= 2,], ad.d[b. >= 2,], tol=0)# 3.9e-9
all.equal(ad[b. >= 4,], ad.d[b. >= 4,], tol=0)# 4.6e-13
all.equal(ad[b. >= 6,], ad.d[b. >= 6,], tol=0)# 3.0e-15
all.equal(ad[b. >= 8,], ad.d[b. >= 8,], tol=0)# 2.5e-15 (not much better)
```

Bern

*Bernoulli Numbers***Description**

Return the n -th Bernoulli number B_n , (or B_n^+ , see the reference), where $B_1 = +\frac{1}{2}$.

Usage

```
Bern(n, verbose = getOption("verbose", FALSE))
```

Arguments

`n` integer, $n \geq 0$.
`verbose` logical indicating if computation should be traced.

Value

The number B_n of type `numeric`.

A side effect is the *caching* of computed Bernoulli numbers in the hidden `environment` `.bernoulliEnv`.

Author(s)

Martin Maechler

References

https://en.wikipedia.org/wiki/Bernoulli_number

See Also

`Bernoulli` in **Rmpfr** in arbitrary precision via Riemann's ζ function.

The next version of package **gmp** is to contain `BernoulliQ()`, providing exact Bernoulli numbers as big rationals (class "bigq").

Examples

```
(B.0.10 <- vapply(0:10, Bern, 1/2))
## [1] 1.00000000 +0.50000000 0.16666667 0.00000000 -0.03333333 0.00000000
## [7] 0.02380952 0.00000000 -0.03333333 0.00000000 0.07575758
if(requireNamespace("MASS")) {
  print( MASS::fractions(B.0.10) )
  ## 1 +1/2 1/6 0 -1/30 0 1/42 0 -1/30 0 5/66
}
```


Examples

```
with(bpser(100000, 11, (0:64)/64), # all 0 {last one "wrongly"}
      stopifnot(r == c(rep(0, 64), 1), err == 0))
bp1e5.11L <- bpser(100000, 11, (0:64)/64, log.p=TRUE)# -> 2 "underflow to -Inf" warnings!
pbe <- pbeta((0:64)/64, 100000, 11, log.p=TRUE)

## verbose=TRUE showing info on number of terms / iterations
ps11.5 <- bpser(100000, 11.5, (0:64)/64, log.p=TRUE, verbose=TRUE)
```

b_chi

*Compute $E[\chi_\nu]/\sqrt{\nu}$ useful for t- and chi-Distributions***Description**

$$b_\chi(\nu) := E[\chi(\nu)]/\sqrt{\nu} = \frac{\sqrt{2/\nu}\Gamma((\nu+1)/2)}{\Gamma(\nu/2)},$$

where $\chi(\nu)$ denotes a chi-distributed random variable, i.e., the square of a chi-squared variable, and $\Gamma(z)$ is the Gamma function, `gamma()` in R.

This is a relatively important auxiliary function when computing with non-central t distribution functions and approximations, specifically see Johnson et al.(1994), p.520, after (31.26a), e.g., our `pntJW39()`.

Its logarithm,

$$lb_\chi(\nu) := \log\left(\frac{\sqrt{2/\nu}\Gamma((\nu+1)/2)}{\Gamma(\nu/2)}\right),$$

is even easier to compute via `lgamma` and `log`, and I have used Maple to derive an asymptotic expansion in $\frac{1}{\nu}$ as well.

Note that $lb_\chi(\nu)$ also appears in the formula for the t-density (`dt`) and distribution (tail) functions.

Usage

```
b_chi      (nu, one.minus = FALSE, c1 = 341, c2 = 1000)
b_chiAsymp(nu, order = 2, one.minus = FALSE)
#lb_chi    (nu, ..... ) # not yet
lb_chiAsymp(nu, order)

c_dt(nu)    # warning("FIXME: current c_dt() is poor -- base it on lb_chi(nu) !")
c_dtAsymp(nu) # deprecated in favour of lb_chi(nu)
c_pt(nu)    # warning("use better c_dt()") %--> FIXME deprecate even stronger ?
```

Arguments

nu	non-negative numeric vector of degrees of freedom.
one.minus	logical indicating if $1 - b()$ should be returned instead of $b()$.
c1, c2	boundaries for different approximation intervals used: for $0 < nu \leq c1$, internal $b1()$ is used, for $c1 < nu \leq c2$, internal $b2()$ is used, and for $c2 < nu$, the $b_chiAsymp()$ function is used, (and you can use that explicitly, also for smaller nu). FIXME: c1 and c2 were defined when the only asymptotic expansion known to me was the order = 2 one. A future version of b_chi will <i>very likely</i> use $b_chiAsymp(*, order)$ for higher orders, and the c1 and c2 arguments will change, possibly be abolished.
order	the polynomial order in $\frac{1}{\nu}$ of the asymptotic expansion of $b_\chi(\nu)$ for $\nu \rightarrow \infty$. The default, order = 2 corresponds to the order you can get out of the Abramowitz and Stegun (6.1.47) formula. Higher order expansions were derived using Maple by Martin Maechler in 2002, see below, but implemented in $b_chiAsymp()$ only in 2018.

Details

One can see that $b_chi()$ has the properties of a CDF of a continuous positive random variable: It grows monotonely from $b_\chi(0) = 0$ to (asymptotically) one. Specifically, for large nu, $b_chi(nu) = b_chiAsymp(nu)$ and

$$1 - b_\chi(\nu) \sim \frac{1}{4\nu}.$$

More accurately, derived from Abramowitz and Stegun, 6.1.47 (p.257) for $a=1/2, b=0$,

$$\Gamma(z + 1/2)/\Gamma(z) \sim \sqrt{z} * (1 - 1/(8z) + 1/(128z^2) + O(1/z^3)),$$

and applied for $b_\chi(\nu)$ with $z = \nu/2$, we get

$$b_\chi(\nu) \sim 1 - (1/(4\nu)) * (1 - 1/(8\nu)) + O(\nu^{-3}),$$

which has been implemented in $b_chiAsymp(*, order=2)$ in 1999.

Even more accurately, Martin Maechler, used Maple to derive an asymptotic expansion up to order 15, here reported up to order 5, namely with $r := \frac{1}{4\nu}$,

$$b_\chi(\nu) = c_\chi(r) = 1 - r + \frac{1}{2}r^2 + \frac{5}{2}r^3 - \frac{21}{8}r^4 - \frac{399}{8}r^5 + O(r^6).$$

Value

a numeric vector of the same length as nu.

Author(s)

Martin Maechler

References

Johnson, Kotz, Balakrishnan (1995) *Continuous Univariate Distributions*, Vol 2, 2nd Edition; Wiley; Formula on page 520, after (31.26a)

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover. https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

See Also

The t-distribution (base R) page [pt](#); our [pntJW39\(\)](#).

Examples

```
curve(b_chi, 0, 20); abline(h=0:1, v=0, lty=3)
r <- curve(b_chi, 1e-10, 1e5, log="x")
with(r, lines(x, b_chi(x, one.minus=TRUE), col = 2))

## Zoom in to c1-region
rc1 <- curve(b_chi, 340.5, 341.5, n=1001)# nothing to see
e <- 1e-3; curve(b_chi, 341-e, 341+e, n=1001) # nothing
e <- 1e-5; curve(b_chi, 341-e, 341+e, n=1001) # see noise, but no jump
e <- 1e-7; curve(b_chi, 341-e, 341+e, n=1001) # see float "granularity"+"jump"

## Zoom in to c2-region
rc2 <- curve(b_chi, 999.5, 1001.5, n=1001) # nothing visible
e <- 1e-3; curve(b_chi, 1000-e, 1000+e, n=1001) # clear small jump
c2 <- 1500
e <- 1e-3; curve(b_chi(x,c2=c2), c2-e, c2+e, n=1001)# still
## - - - -
c2 <- 3000
e <- 1e-3; curve(b_chi(x,c2=c2), c2-e, c2+e, n=1001)# ok asymp clearly better!!
curve(b_chiAsymp, add=TRUE, col=adjustcolor("red", 1/3), lwd=3)
if(requireNamespace("Rmpfr")) {
  xm <- Rmpfr::seqMpfr(c2-e, c2+e, length.out=1000)
}
## - - - -
c2 <- 4000
e <- 1e-3; curve(b_chi(x,c2=c2), c2-e, c2+e, n=1001)# ok asymp clearly better!!
curve(b_chiAsymp, add=TRUE, col=adjustcolor("red", 1/3), lwd=3)

grCol <- adjustcolor("forest green", 1/2)
curve(b_chi, 1/2, 1e11, log="x")
curve(b_chiAsymp, add = TRUE, col = grCol, lwd = 3)
## 1-b(nu) ~ 1/(4 nu) a power function <==> linear in log-log scale:
curve(b_chi(x, one.minus=TRUE), 1/2, 1e11, log="xy")
curve(b_chiAsymp(x, one.minus=TRUE), add = TRUE, col = grCol, lwd = 3)
```

Description

Provides (evaluation of) Chebyshev polynomials, given their coefficients vector `coef` (using $2c_0$, i.e., $2*\text{coef}[1]$ as the base R `mathlib` `chebyshev*`(`)` functions. Specifically, the following sum is evaluated:

$$\sum_{j=0}^n c_j T_j(x)$$

where $c_0 := \text{coef}[1]$ and $c_j := \text{coef}[j+1]$ for $j \geq 1$. $n := \text{chebyshev_nc}(\text{coef}, .)$ is the maximal degree and hence one less than the number of terms, and $T_j()$ is the Chebyshev polynomial (of the first kind) of degree j .

Usage

```
chebyshevPoly(coef, nc = chebyshev_nc(coef, eta), eta = .Machine$double.eps/20)
```

```
chebyshev_nc(coef, eta = .Machine$double.eps/20)
chebyshevEval(x, coef,
              nc = chebyshev_nc(coef, eta), eta = .Machine$double.eps/20)
```

Arguments

<code>coef</code>	a numeric vector of coefficients for the Chebyshev polynomial.
<code>nc</code>	the maximal degree, i.e., one less than the number of polynomial terms to use; typically use the default.
<code>eta</code>	a positive number; typically keep the default.
<code>x</code>	for <code>chebyshevEval()</code> : numeric vector of abscissa values at which the polynomial should be evaluated. Typically <code>x</code> values are inside the interval $[-1, 1]$.

Value

`chebyshevPoly()` returns `function(x)` which computes the values of the underlying Chebyshev polynomial at `x`.

`chebyshev_nc()` returns an `integer`, and `chebyshevEval(x, coef)` returns a numeric “like” `x` with the values of the polynomial at `x`.

Author(s)

R Core team, notably Ross Ihaka; Martin Maechler provided the R interface.

References

https://en.wikipedia.org/wiki/Chebyshev_polynomials

See Also

`polyn.eval()` from CRAN package **sfsmisc**; as one example of many more.

Examples

```
## The first 5 (base) Chebyshev polynomials:
T0 <- chebyshevPoly(2) # !! 2, not 1
T1 <- chebyshevPoly(0:1)
T2 <- chebyshevPoly(c(0,0,1))
T3 <- chebyshevPoly(c(0,0,0,1))
T4 <- chebyshevPoly(c(0,0,0,0,1))
curve(T0(x), -1,1, col=1, lwd=2, ylim=c(-1,1))
abline(h=0, lty=2)
curve(T1(x), col=2, lwd=2, add=TRUE)
curve(T2(x), col=3, lwd=2, add=TRUE)
curve(T3(x), col=4, lwd=2, add=TRUE)
curve(T4(x), col=5, lwd=2, add=TRUE)

(Tv <- vapply(c(T0=T0, T1=T1, T2=T2, T3=T3, T4=T4),
             function(Tp) Tp(-1:1), numeric(3)))
x <- seq(-1,1, by = 1/64)
stopifnot(exprs = {
  all.equal(chebyshevPoly(1:5)(x),
            0.5*T0(x) + 2*T1(x) + 3*T2(x) + 4*T3(x) + 5*T4(x))
  all.equal(unnamed(Tv), rbind(c(1,-1), c(1:-1,0:1), rep(1,5)))# warning on rbind()
})
```

 dbinom_raw

R's C Mathlib (Rmath) dbinom_raw() Binomial Probability pure R Function

Description

A pure R implementation of R's C API ('Mathlib' specifically) `dbinom_raw()` function which computes binomial probabilities *and* is continuous in x , i.e., also “works” for non-integer x .

Usage

```
dbinom_raw(x, n, p, q = 1-p, log = FALSE,
           version = c("2008", "R4.4"),
           verbose = getOption("verbose"))
```

Arguments

x vector with values typically in $0:n$, but here allowed to non-integer values.
 n called size in R's `dbinom()`.
 p called prob in R's `dbinom()`, the success probability, hence in $[0, 1]$.

q	mathematically the same as $1 - p$, but may be (much) more accurate, notably when small.
log	logical indicating if the <code>log()</code> of the resulting probability should be returned; useful notably in case the probability itself would underflow to zero.
version	a <code>character</code> string; originally, "2008" was the only option. Still the default currently, this <i>may change</i> in the future.
verbose	integer indicating the amount of verbosity of diagnostic output, 0 means no output, 1 more, etc.

Value

numeric vector of the same length as `x` which may have to be thought of recycled along `n`, `p` and/or `q`.

Author(s)

R Core and Martin Maechler

See Also

Note that our CRAN package **Rmpfr** provides `dbinom`, an mpfr-accurate function to be used instead of R's or this pure R version relying `bd0()` and `stirlerr()` where the latter currently only provides accurate double precision accuracy.

Examples

```
for(n in c(3, 10, 27, 100, 500, 2000, 5000, 1e4, 1e7, 1e10)) {
  x <- if(n <= 2000) 0:n else round(seq(0, n, length.out=2000))
  p <- 3/4
  stopifnot(all.equal(dbinom_raw(x, n, p, q=1-p) -> dbin,
                     dbinom(x, n, p, tolerance = 1e-13)) # 1.636e-14 (Apple clang 14.0.3)
            stopifnot(all.equal(dbin, dbinom_raw(x, n, p, q=1-p, version = "R4.4") -> dbin44,
                                tolerance = 1e-13))
            cat("n = ", n, ": ", (aeq <- all.equal(dbin44, dbin, tolerance = 0)), "\n")
            if(n < 3000) stopifnot(is.character(aeq)) # check that dbin44 is "better" ?!
  }

n <- 1024 ; x <- 0:n
plot(x, dbinom_raw(x, n, p, q=1-p) - dbinom(x, n, p), type="l", main = "|db_r(x) - db(x)|")
plot(x, dbinom_raw(x, n, p, q=1-p) / dbinom(x, n, p) - 1, type="b", log="y",
     main = "rel.err. |db_r(x) / db(x) - 1|")
```

dchisqApprox

*Approximations of the (Noncentral) Chi-Squared Density***Description**

Compute the density function $f(x, *)$ of the (noncentral) chi-squared distribution.

Usage

```
dnchisqR      (x, df, ncp, log = FALSE,
              eps = 5e-15, termSml = 1e-10, ncplLarge = 1000)
dnchisqBessel(x, df, ncp, log = FALSE)
dchisqAsym    (x, df, ncp, log = FALSE)
dnoncentchisq(x, df, ncp, kmax = floor(ncp/2 + 5 * (ncp/2)^0.5))
```

Arguments

x	non-negative numeric vector.
df	degrees of freedom (parameter), a positive number.
ncp	non-centrality parameter δ ;
log	logical indicating if the result is desired on the log scale.
eps	positive convergence tolerance for the series expansion: Terms are added while $\text{term} * q > (1-q) * \text{eps}$, where q is the term's multiplication factor.
termSml	positive tolerance: in the series expansion, terms are added to the sum as long as they are not smaller than $\text{termSml} * \text{sum}$ even when convergence according to eps had occurred. This was not part of the original C code, but was added later for safeguarding against infinite loops, from PR#14105 , e.g., for <code>dchisq(2000, 2, 1000)</code> .
ncplLarge	in the case where mid underflows to 0, when log is true, or $\text{ncp} \geq \text{ncplLarge}$, use a central approximation. In theory, an optimal choice of ncplLarge would not be arbitrarily set at 1000 (hardwired in R's <code>dchisq()</code> here), but possibly also depend on x or df .
kmax	the number of terms in the sum for <code>dnoncentchisq()</code> .

Details

`dnchisqR()` is a pure R implementation of R's own C implementation in the sources, 'R/src/nmath/dnchisq.c', additionally exposing the three "tuning parameters" `eps`, `termSml`, and `ncplLarge`.

`dnchisqBessel()` implements Fisher(1928)'s exact closed form formula based on the Bessel function $I_{\nu u}$, i.e., R's `besselI()` function; specifically formula (29.4) in Johnson et al. (1995).

`dchisqAsym()` is the simple asymptotic approximation from Abramowitz and Stegun's formula 26.4.27, p. 942.

`dnoncentchisq()` uses the (typically defining) infinite series expansion directly, with truncation at `kmax`, and terms t_k which are products of a Poisson probability and a central chi-square density, i.e., $t_k := \text{dpois}(k, \text{lambda} = \text{ncp}/2) * \text{dchisq}(x, \text{df} = 2*k + \text{df})$ for $k = 0, 1, \dots, \text{kmax}$.

Value

numeric vector similar to `x`, containing the (logged if `log=TRUE`) values of the density $f(x, *)$.

Note

These functions are mostly of historical interest, notably as R's `dchisq()` was not always very accurate in the noncentral case, i.e., for $n_{cp} > 0$.

Note

R's `dchisq()` is typically more uniformly accurate than the approximations nowadays, apart from `dnchisqR()` which should behave the same. There may occasionally exist small differences between `dnchisqR(x, *)` and `dchisq(x, *)` for the same parameters.

Author(s)

Martin Maechler, April 2008

References

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover. https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

Johnson, N.L., Kotz, S. and Balakrishnan, N. (1995) *Continuous Univariate Distributions Vol-2*, 2nd ed.; Wiley; chapter 29, Section 3 *Distribution*, (29.4), p. 436.

See Also

R's own `dchisq()`.

Examples

```
x <- sort(outer(c(1,2,5), 2^(-4:5)))
fRR <- dchisq (x, 10, 2)
f.R <- dnchisqR(x, 10, 2)
all.equal(fRR, f.R, tol = 0) # 64bit Lnx (F 30): 1.723897e-16
stopifnot(all.equal(fRR, f.R, tol = 4e-15))
```

dgamma-utils

Binomial Deviance – Auxiliary Functions for dgamma() Etc

Description

The “binomial deviance” function $\text{bd0}(x, M) := D_0(x, M) := M \cdot d_0(x/M)$, where $d_0(r) := r \log(r) + 1 - r$.

Mostly, pure R transcriptions of the C code utility functions for `dgamma()`, `dbinom()`, `dpois()`, `dt()`, and similar “base” density functions by Catherine Loader.

These have extra arguments with defaults that correspond to R's Mathlib C code hardwired cutoffs and tolerances.

Usage

```

dpois_raw(x, lambda, log=FALSE,
          version,
          small.x__lambda = .Machine$double.eps,
          ## the defaults for version will probably change in the future
          bd0.delta = 0.1,
          ## optional arguments of log1pmx() :
          tol_logcf = 1e-14, eps2 = 0.01, minL1 = -0.79149064, trace.lcf = verbose,
          logCF = if (is.numeric(x)) logcf else logcFR,
          verbose = FALSE)

dpois_simpl(x, lambda, log=FALSE)
dpois_simpl0(x, lambda, log=FALSE)

bd0(x, np,
    delta = 0.1, maxit = as.integer(-1100 / log2(delta)),
    s0 = .Machine$double.xmin,
    verbose = getOption("verbose"))
bd0C(x, np, delta = 0.1, maxit = 1000L, version = "R4.0", verbose = getOption("verbose"))
# "simple" log1pmx() based versions :
bd0_p11d1(x, M, tol_logcf = 1e-14, ...)
bd0_p11d(x, M, tol_logcf = 1e-14, ...)
bd0_l1pm(x, M, tol_logcf = 1e-14, ...)

ebd0(x, M, verbose = getOption("verbose"), ...) # experimental, may disappear !!
ebd0C(x, M, verbose = getOption("verbose"))

```

Arguments

<code>x</code>	<code>numeric</code> (or number-alike such as "mpfr").
<code>lambda, np, M</code>	each <code>numeric</code> (or number-alike ..); distribution parameters.
<code>log</code>	logical indicating if the log-density should be returned, otherwise the density at <code>x</code> .
<code>verbose</code>	logical indicating if some information about the computations are to be printed.
<code>small.x__lambda</code>	positive number; for <code>dpois_raw(x, lambda)</code> , when <code>x/lambda</code> is not larger than <code>small.x__lambda</code> , the direct log poisson formula is used instead of <code>ebd0()</code> , <code>bd0()</code> or <code>stirlerr()</code> .
<code>delta, bd0.delta</code>	a non-negative number < 1 (practically required to be $\leq .99$), a cutoff for <code>bd0()</code> where a continued fraction series expansion is used when $ x - M < delta * (x + M)$.
<code>tol_logcf, eps2, minL1, trace.lcf, logCF, ...</code>	optional tuning arguments passed to <code>log1pmx()</code> , and to its options passed to <code>logcf()</code> .
<code>maxit</code>	the number of series expansion terms to be used in <code>bd0()</code> when $ x - M $ is small. The default is k such that $\delta^{2k} \leq 2^{-1022-52}$, i.e., will underflow to zero.

<code>s0</code>	the very small s_0 determining that <code>bd0()</code> = s already before the <code>locf</code> series expansion.
<code>version</code>	a character string specifying the version of <code>bd0()</code> to use.

Details

`bd0()`: Loader's "Binomial Deviance" function; for $x, M > 0$ (where the limit $x \rightarrow 0$ is allowed). In the case of `dbinom`, x are integers (and $M = np$), but in general x is real.

$$bd_0(x, M) := M \cdot D_0\left(\frac{x}{M}\right),$$

where $D_0(u) := u \log(u) + 1 - u = u(\log(u) - 1) + 1$. Hence

$$bd_0(x, M) = M \cdot \left(\frac{x}{M}(\log\left(\frac{x}{M}\right) - 1) + 1\right) = x \log\left(\frac{x}{M}\right) - x + M.$$

A different way to rewrite this from Martyn Plummer, notably for important situation when $|x - M| \ll M$, is using $t := (x - M)/M$ (and $|t| \ll 1$ for that situation), equivalently, $\frac{x}{M} = 1 + t$. Using t ,

$$bd_0(x, M) = \log(1+t) - t \cdot M = M \cdot [(t+1)(\log(1+t) - 1) + 1] = M \cdot [(t+1) \log(1+t) - t] = M \cdot p_1 l_1(t),$$

and

$$p_1 l_1(t) := (t + 1) \log(1 + t) - t = \frac{t^2}{2} - \frac{t^3}{6} \dots$$

where the Taylor series expansion is useful for small $|t|$.

Note that `bd0(x, M)` now also works when x and/or M are arbitrary-accurate `mpfr`-numbers (package [Rmpfr](#)).

`bd0C()` interfaces to C code which corresponds to R's C Mathlib (`Rmath`) `bd0()`.

Value

a numeric vector "like" x ; in some cases may also be an (high accuracy) "mpfr"-number vector, using CRAN package [Rmpfr](#).

`ebd0()` (R code) and `ebd0C()` (interface to C code) are *experimental*, meant to be precision-extended version of `bd0()`, returning (y_h, y_l) (high- and low-part of y , the numeric result). In order to work for *long* vectors x, y_h, y_l need to be [list](#) components; hence we return a two-column [data.frame](#) with column names "yh" and "yl".

Author(s)

Martin Maechler

References

C. Loader (2000), see [dbinom](#)'s documentation.

Our package vignette *log1pmx, bd0, stirlerr - Probability Computations in R*.

See Also

[stirlerr](#) for Stirling's error function, complementing `bd0()` for computation of Gamma, Beta, Binomial and Poisson probabilities. [dgamma](#), [dpois](#).

Examples

```
x <- 800:1200
bd0x1k <- bd0(x, np = 1000)
plot(x, bd0x1k, type="l", ylab = "bd0(x, np=1000)")
bd0x1kC <- bd0C(x, np = 1000)
lines(x, bd0x1kC, col=2)
bd0.1d1 <- bd0_p11d1(x, 1000)
bd0.1d <- bd0_p11d(x, 1000)
bd0.1pm <- bd0_11pm(x, 1000)
stopifnot(exprs = {
  all.equal(bd0x1kC, bd0x1k, tol=1e-14) # even tol=0 currently ..
  all.equal(bd0x1kC, bd0.1d1, tol=1e-14)
  all.equal(bd0x1kC, bd0.1d, tol=1e-14)
  all.equal(bd0x1kC, bd0.1pm, tol=1e-14)
})

str(log1pmx) ##--> play with { tol_logcf, eps2, minL1, trace.lcf, logCF }

ebd0x1k <- ebd0(x, 1000)
exC <- ebd0C(x, 1000)
stopifnot(all.equal(exC, ebd0x1k, tol=4e-16))
lines(x, rowSums(ebd0x1k), col=adjustcolor(4, 1/2), lwd=4)

x <- 0:250
dp <- dpois(x, 48, log=TRUE) # R's 'stats' pkg function
dp.r <- dpois_raw(x, 48, log=TRUE)
all.equal(dp, dp.r, tol = 0) # on Linux 64b, see TRUE
stopifnot(all.equal(dp, dp.r, tol = 1e-14))
## dpois_raw() versions:
(vers <- eval(formals(dpois_raw)$version))
mv <- sapply(vers, function(v) dpois_raw(x, 48, version=v))
matplot(x, mv, type="h", log="y", main="dpois_raw(x, 48, version=*)") # "fine"

if(all(mv[,"ebd0_C1"] == mv[,"ebd0_v1"])) {
  cat("versions 'ebd0_C1' and 'ebd0_v1' are identical for lambda=48\n")
  mv <- mv[, vers != "ebd0_C1"]
}
## now look at *relative* errors -- need "Rmpfr" for "truth"
if(requireNamespace("Rmpfr")) {

  dM <- Rmpfr::dpois(Rmpfr::mpfr(x, 256), 48)
  asN <- Rmpfr::asNumeric
  relE <- asN(mv / dM - 1)
  cols <- adjustcolor(1:ncol(mv), 1/2)

  mtit <- "relative Errors of dpois_raw(x, 48, version = * )"
  matplot(x, relE, type="l", col=cols, lwd=3, lty=1, main=mtit)
```

```

legend("topleft", colnames(mv), col=cols, lwd=3, bty="n")

matplot(x, abs(relE), ylim=pmax(1e-18, range(abs(relE))), type="l", log="y",
        main=mtit, col=cols, lwd=2, lty=1, yaxt="n")
sfsmisc::eaxis(2)
legend("bottomright", colnames(mv), col=cols, lwd=2, bty="n", ncol=3)
ee <- c(.5, 1, 2)* 2^-52; eC <- quote(epsilon[C])
abline(h=ee, lty=2, col="gray", lwd=c(1,2,1))
axis(4, at=ee[2:3], expression(epsilon[C], 2 * epsilon[C]), col="gray", las=1)
par(new=TRUE)
plot(x, asN(dM), type="h", col=adjustcolor("darkgreen", 1/3), axes=FALSE, ann=FALSE)
stopifnot(abs(relE) < 8e-13) # seen 2.57e-13
}# Rmpfr

```

dgamma.R

*Gamma Density Function Alternatives***Description**

dgamma.R() is aimed to be an R level “clone” of R’s C level implementation [dgamma](#) (from package [stats](#)).

Usage

```
dgamma.R(x, shape, scale = 1, log,
         dpois_r_args = list())
```

Arguments

x	non-negative numeric vector.
shape	non-negative shape parameter of the Gamma distribution.
scale	positive scale parameter; note we do not see the need to have a rate parameter as the standard R function.
log	logical indicating if the result is desired on the log scale.
dpois_r_args	a list of optional arguments for dpois_raw() ; not much checked, must be specified correctly.

Value

numeric vector of the same length as x (which may have to be thought of recycled along shape and/or scale).

Author(s)

Martin Maechler

See Also

(As R's C code) this depends crucially on the “workhorse” function `dpois_raw()`.

Examples

```
xy <- curve(dgamma(x, 12), 0, 30) # R's dgamma()
xyR <- curve(dgamma.R(x, 12, dpois_r_args = list(verbose=TRUE)), add=TRUE,
            col = adjustcolor(2, 1/3), lwd=3)
stopifnot(all.equal(xy, xyR, tolerance = 4e-15)) # seen 7.12e-16
## TODO: check *vectorization* in x --> add tests/*.R ___ TODO ___

## From R's <R>/tests/d-p-q-r-tst-2.R -- replacing dgamma() w/ dgamma.R()
## PR#17577 - dgamma(x, shape) for shape < 1 (=> +Inf at x=0) and very small x
stopifnot(exprs = {
  all.equal(dgamma.R(2^-1027, shape = .99, log=TRUE), 7.1127667376, tol=1e-10)
  all.equal(dgamma.R(2^-1031, shape = 1e-2, log=TRUE), 702.8889158, tol=1e-10)
  all.equal(dgamma.R(2^-1048, shape = 1e-7, log=TRUE), 710.30007699, tol=1e-10)
  all.equal(dgamma.R(2^-1048, shape = 1e-7, scale = 1e-315, log=TRUE),
            709.96858768, tol=1e-10)
})
## R's dgamma() gave all Inf in R <= 3.6.1 [and still there in 32-bit Windows !]
```

dhyperBinMolenaar *HyperGeometric (Point) Probabilities via Molenaar's Binomial Approximation*

Description

Compute hypergeometric (point) probabilities via Molenaar's binomial approximation, `hyper2binomP()`.

Usage

```
dhyperBinMolenaar(x, m, n, k, log = FALSE)
```

Arguments

`x` (vector of) the number of white balls drawn without replacement from an urn which contains both black and white balls.

`m` the number of white balls in the urn.

`n` the number of black balls in the urn.

`k` the number of balls drawn from the urn, hence in $0, 1, \dots, m + n$.

`log` **logical** indication if the logarithm `log(P)` should be returned (instead of `P`).

Value

a **numeric** vector, with the length the maximum of the lengths of `x`, `m`, `n`, `k`.

Author(s)

Martin Maechler

References

See those in [phyperBinMolenaar](#).

See Also

[hyper2binomP\(\)](#); R's own [dhyper\(\)](#) which uses more sophisticated computations.

Examples

```
## The function is simply defined as
function (x, m, n, k, log = FALSE)
  dbinom(x, size = k, prob = hyper2binomP(x, m, n, k), log = log)
```

 dnbinomR

Pure R Versions of R's C (Mathlib) dnbinom() Negative Binomial Probabilities

Description

Compute pure R implementations of R's C Mathlib (Rmath) [dnbinom\(\)](#) binomial probabilities, allowing to see the effect of the cutoff eps.

Usage

```
dnbinomR (x, size, prob, log = FALSE, eps = 1e-10)
dnbinom.mu(x, size, mu, log = FALSE, eps = 1e-10)
```

Arguments

x, size, prob, mu, log
 see R's [dnbinom\(\)](#).

eps
 non-negative number specifying the cutoff for “small x/size”, in which case the 2-term approximation from Abramowitz and Stegun, 6.1.47 (p.257) is preferable to the [dbinom\(\)](#) based evaluation.

Value

numeric vector of the same length as x which may have to be thought of recycled along size and prob or mu.

Author(s)

R Core and Martin Maechler

References

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover. https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

See Also

`dbinom_raw`; Note that our CRAN package **Rmpfr** provides `dnbinom`, `dbinom` and more, where mpfr-accurate functions are used instead of R's (and our pure R version of) `bd0()` and `stirlerr()`.

Examples

```
stopifnot( dnbinomR(0, 1, 1) == 1 )
size <- 1000 ; x <- 0:size
dnb <- dnbinomR(x, size, prob = 5/8, log = FALSE, eps = 1e-10)
plot(x, dnb, type="b")
all.equal(dnb, dnbinom(x, size, prob = 5/8)) ## mean rel. diff: 0.00017...

dnbm <- dnbinom.mu(x, size, mu = 123, eps = 1e-10)
all.equal(dnbm, dnbinom(x, size, mu = 123)) # Mean relative diff: 0.00069...
```

dnt

Non-central t-Distribution Density - Algorithms and Approximations

Description

`dntJKBf1` implements the summation formulas of Johnson, Kotz and Balakrishnan (1995), (31.15) on page 516 and (31.15') on p.519, the latter being typo-corrected for a missing factor $1/j!$.

`dntJKBf()` is `Vectorize(dntJKBf1, c("x", "df", "ncp"))`, i.e., works vectorized in all three main arguments `x`, `df` and `ncp`.

The functions `.dntJKBch1()` and `.dntJKBch()` are only there for didactical reasons allowing to check that indeed formula (31.15') in the reference is missing a $j!$ factor in the denominator.

The `dntJKBf*` functions are written to also work with arbitrary precise numbers of class `"mpfr"` (from package **Rmpfr**) as arguments.

Usage

```
dntJKBf1(x, df, ncp, log = FALSE, M = 1000)
dntJKBf (x, df, ncp, log = FALSE, M = 1000)

## The "checking" versions, only for proving correctness of formula:
.dntJKBch1(x, df, ncp, log = FALSE, M = 1000, check=FALSE, tol.check = 1e-7)
.dntJKBch (x, df, ncp, log = FALSE, M = 1000, check=FALSE, tol.check = 1e-7)
```

Arguments

x, df, ncp	see R's <code>dt()</code> ; note that each can be of class "mpfr".
log	as in <code>dt()</code> , a logical indicating if $\log(f(x, *))$ should be returned instead of $f(x, *)$.
M	the number of terms to be used, a positive integer.
check	logical indicating if checks of the formula equalities should be done.
tol.check	tolerance to be used for <code>all.equal()</code> when check is true.

Details

How to choose M optimally has not been investigated yet and is probably also a function of the precision of the first three arguments (see `getPrec` from **Rmpfr**).

Note that relatedly, R's source code 'R/src/nmath/dnt.c' has claimed from 2003 till 2014 but **wrongly** that the noncentral t density $f(x, *)$ was

$$f(x, df, ncp) = \frac{df^{df/2} \cdot \exp(-.5*ncp^2)}{(\sqrt{\pi}) \cdot \Gamma(df/2) \cdot (df+x^2)^{(df+1)/2}} \cdot \sum_{k=0}^{\infty} \frac{\Gamma((df+k+df)/2) \cdot ncp^k}{\prod(1:k) \cdot (2 \cdot x^2 / (df+x^2))^{k/2}} .$$

These functions (and this help page) prove that it was wrong.

Value

a number for `dntJKBf1()` and `.dntJKBch1()`.

a numeric vector of the same length as the maximum of the lengths of x, df, ncp for `dntJKBf()` and `.dntJKBch()`.

Author(s)

Martin Maechler

References

Johnson, N.L., Kotz, S. and Balakrishnan, N. (1995) Continuous Univariate Distributions Vol~2, 2nd ed.; Wiley; chapter 31, Section 5 *Distribution Function*, p.514 ff

See Also

R's `dt`; (an improved version of) Viechtbauer's proposal: `dtWV`.

Examples

```
tt <- seq(0, 10, length.out = 21)
ncp <- seq(0, 6, length.out = 31)
dt3R <- outer(tt, ncp, dt, df = 3)
dt3JKB <- outer(tt, ncp, dntJKBf, df = 3)
all.equal(dt3R, dt3JKB) # Lnx(64-b): 51 NA's in dt3R
```

```

x <- seq(-1,12, by=1/16)
fx <- dt(x, df=3, ncp=5)
re1 <- 1 - .dntJKBch(x, df=3, ncp=5) / fx ; summary(warnings()) # slow, with warnings
op <- options(warn = 2) # (=> warning == error, for now)
re2 <- 1 - dntJKBf(x, df=3, ncp=5) / fx # faster, no warnings
stopifnot(all.equal(re1[!is.na(re1)], re2[!is.na(re1)], tol=1e-6))
head( cbind(x, fx, re1, re2) , 20)
matplot(x, log10(abs(cbind(re1, re2))), type = "o", cex = 1/4)

## One of the numerical problems in "base R"'s non-central t-density:
options(warn = 0) # (factory def.)
x <- 2^seq(-12, 32, by=1/8) ; df <- 1/10
dtm <- cbind(dt(x, df=df, log=TRUE),
             dt(x, df=df, ncp=df/2, log=TRUE),
             dt(x, df=df, ncp=df, log=TRUE),
             dt(x, df=df, ncp=df*2, log=TRUE)) #.. quite a few warnings:
summary(warnings())
matplot(x, dtm, type="l", log = "x", xaxt="n",
        main = "dt(x, df=1/10, log=TRUE) central and noncentral")
sfsmisc::eaxis(1)
legend("right", legend=c("", paste0("ncp = df",c("/2", "", "*2"))),
      lty=1:4, col=1:4, bty="n")

(doExtras <- DPQ::doExtras()) # TRUE e.g. if interactive()
(ncp <- seq(0, 12, by = if(doExtras) 3/4 else 2))
names(ncp) <- nnMs <- paste0("ncp=", ncp)
tt <- seq(0, 5, by = 1)
dt3R <- outer(tt, ncp, dt, df = 3)
if(requireNamespace("Rmpfr")) withAutoprint({
  mt <- Rmpfr::mpfr(tt, 128)
  mcp <- Rmpfr::mpfr(ncp, 128)
  system.time(
    dt3M <- outer(mt, mcp, dntJKBf, df = 3,
                  M = if(doExtras) 1024 else 256)) # M=1024: 7 sec [10 sec on Winb]
  re1E <- Rmpfr::asNumeric(sfsmisc::relErrV(dt3M, dt3R))
  re1E[tt != 0, ncp != 0]
})

## all.equal(dt3R, dt3V, tol=0) # 1.2e-12

# ---- using MPFR high accuracy arithmetic (too slow for routine testing) ----
## no such kink here:
x. <- if(requireNamespace("Rmpfr")) Rmpfr::mpfr(x, 256) else x
system.time(dtJKB <- dntJKBf(x., df=df, ncp=df, log=TRUE)) # 43s, was 21s and only 7s ???
lines(x, dtJKB, col=adjustcolor(3, 1/2), lwd=3)
options(op) # reset to prev.

## Relative Difference / Approximation errors :
plot(x, 1 - dtJKB / dtm[,3], type="l", log="x")
plot(x, 1 - dtJKB / dtm[,3], type="l", log="x", xaxt="n", ylim=c(-1,1)*1e-3); sfsmisc::eaxis(1)
plot(x, 1 - dtJKB / dtm[,3], type="l", log="x", xaxt="n", ylim=c(-1,1)*1e-7); sfsmisc::eaxis(1)
plot(x, abs(1 - dtJKB / dtm[,3]), type="l", log="xy", axes=FALSE, main =

```

```

      "dt(*, 1/10, 1/10, log=TRUE) relative approx. error",
      sub= paste("Copyright (C) 2019 Martin Maechler --- ", R.version.string))
for(j in 1:2) sfsmisc::eaxis(j)

```

dot-D-utils

Distribution Utilities "dpq"

Description

Utility functions for "dpq"-computations, paralleling those in R's own C source '[<Rsource>/src/nmath/dpq.h](#)', ("dpq" := **d**ensity-**p**robability-**q**uantile).

Usage

```

.D_0(log.p) # prob/density == 0   (for log.p=FALSE)
.D_1(log.p) # prob           == 1   "   "

.DT_0(lower.tail, log.p) # == 0 when (lower.tail=TRUE, log.p=FALSE)
.DT_1(lower.tail, log.p) # == 1 when   "   "

.D_Lval(p, lower.tail) # p   {L}ower
.D_Cval(p, lower.tail) # 1-p {C}omplementary

.D_val(x, log.p) # x in pF(x,..)
.D_qIv(p, log.p) # p in qF(p,..)
.D_exp(x, log.p) # exp(x) unless log.p where it's x
.D_log(p, log.p) # p " " " " log(p)
.D_Clog(p, log.p) # 1-p " " " " log(1-p) == log1p(-)

.D_LExp(x, log.p) ## [log](1 - exp(-x)) == log1p(- .D_qIv(x)) even more stable

.DT_val(x, lower.tail, log.p) # := .D_val(.D_Lval(x, lower.tail), log.p) == x in pF
.DT_Cval(x, lower.tail, log.p) # := .D_val(.D_Cval(x, lower.tail), log.p) == 1-x in pF

.DT_qIv(p, lower.tail, log.p) # := .D_Lval(.D_qIv(p)) == p in qF
.DT_CIv(p, lower.tail, log.p) # := .D_Cval(.D_qIv(p)) == 1-p in qF

.DT_exp(x, lower.tail, log.p) # exp(x)
.DT_Cexp(x, lower.tail, log.p) # exp(1-x)

.DT_log(p, lower.tail, log.p) # log(p) in qF
.DT_Clog(p, lower.tail, log.p) # log(1-p) in qF
.DT_Log(p, lower.tail) # log(p) in qF(p,..,log.p=TRUE)

```

Arguments

<code>x</code>	numeric vector.
<code>p</code>	(log) probability-like numeric vector.
<code>lower.tail</code>	logical; if true, probabilities are $P[X \leq x]$, otherwise upper tail probabilities, $P[X > x]$.
<code>log.p</code>	logical; if true, probabilities p are given as $\log(p)$ in argument <code>p</code> .

Value

Typically a numeric vector “as” `x` or `p`, respectively.

Author(s)

Martin Maechler

See Also

[log1mexp\(\)](#) which is called from `.D_LExp()` and `.DT_Log()`.

Examples

```
FT <- c(FALSE, TRUE)
stopifnot(exprs = {
  .D_0(log.p = FALSE) == 0
  .D_0(log.p = TRUE) == log(0)
  identical(c(1,0), vapply(FT, .D_1, double(1)))
})

## all such functions in package DPQ:
eDPQ <- as.environment("package:DPQ")
ls.str(envir=eDPQ, pattern = "^[.]D", all.names=TRUE)
(nD <- local({ n <- names(eDPQ); n[startsWith(n, ".D")] }))
trimW <- function(ch) sub("+$", "", sub("^+", "", ch))
writeLines(vapply(sort(nD), function(nm) {
  B <- deparse(eDPQ[[nm]])
  sprintf("%31s := %s", trimW(sub("function ", nm, B[[1]])),
    paste(trimW(B[-1]), collapse=" "))
}, ""))

do.lowlog <- function(Fn, ...) {
  stopifnot(is.function(Fn),
    all(c("lower.tail", "log.p") %in% names(formals(Fn))))
  FT <- c(FALSE, TRUE) ; cFT <- c("F", "T")
  L <- lapply(FT, function(lo) sapply(FT, function(lg) Fn(..., lower.tail=lo, log.p=lg)))
  r <- simplify2array(L)
  `dimnames<-`(r, c(rep(list(NULL), length(dim(r)) - 2L),
    list(log.p = cFT, lower.tail = cFT)))
}
do.lowlog(.DT_0)
do.lowlog(.DT_1)
```

```

do.lowlog(.DT_exp, x = 1/4) ; do.lowlog(.DT_exp, x = 3/4)
do.lowlog(.DT_val, x = 1/4) ; do.lowlog(.DT_val, x = 3/4)
do.lowlog(.DT_Cexp, x = 1/4) ; do.lowlog(.DT_Cexp, x = 3/4)
do.lowlog(.DT_Cval, x = 1/4) ; do.lowlog(.DT_Cval, x = 3/4)
do.lowlog(.DT_Clog, p = (1:3)/4) # w/ warn
do.lowlog(.DT_log, p = (1:3)/4) # w/ warn
do.lowlog(.DT_qIv, p = (1:3)/4)

## unfinished: FIXME, the above is *not* really checking
stopifnot(exprs = {

})

```

dpsifn

Psi Gamma Functions Workhorse from R's API

Description

Log Gamma derivatives, Psi Gamma functions. `dpsifn()` is an R interface to the R API function `R_dpsifn()`.

Usage

```
dpsifn(x, m, deriv1 = 0L, k2 = FALSE)
```

Arguments

<code>x</code>	numeric vector.
<code>m</code>	number of derivatives to return, an integer ≥ 0 .
<code>deriv1</code>	“start” derivative
<code>k2</code>	a logical specifying if <code>k2 = 2</code> should be applied.

Details

`dpsifn()` is the underlying “workhorse” of R’s own [digamma](#), [trigamma](#) and (generalized) [psigamma](#) functions.

It is useful, e.g., when several derivatives of $\log \Gamma = \text{lgamma}$ are desired. It computes and returns length- m sequence $(-1)^{k+1} / \Gamma(k+1) \cdot \psi^{(k)}(x)$ for $k = n, n+1, \dots, n+m-1$, where $n = \text{deriv1}$, and $\psi^{(k)}(x)$ is the k -th derivative of $\psi(x)$, i.e., `psigamma(x, k)`. For more details, see the comments in ‘src/nmath/polygamma.c’.

Value

A numeric $l_x \times m$ [matrix](#) (where $l_x = \text{length}(x)$) of scaled $\psi^{(k)}(x)$ values. The matrix has [attributes](#)

<code>underflow</code>	of l_x integer counts of the number of under- and over-flows, in computing the corresponding i -th matrix column for $x[i]$.
<code>ierr</code>	length- l_x integer vector of error codes, where 0 is normal/successful.

Author(s)

Martin Maechler (R interface); R Core et al., see [digamma](#).

References

See those in [psigamma](#)

See Also

[digamma](#), [trigamma](#), [psigamma](#).

Examples

```
x <- seq(-3.5, 6, by=1/4)
dpx <- dpsifn(x, m = if(getRversion() >= "4.2") 7 else 5)
dpx # in R <= 4.2.1, see that sometimes the 'nz' (under-over-flow count) was uninitialized !!
j <- -1L+seq_len(nrow(dpx)); (fj <- (-1)^(j+1)*gamma(j+1))
## mdpsi <- cbind(di = digamma(x),      -dpx[1,],
##              tri= trigamma(x),      dpx[2,],
##              tetra=psigamma(x,2),  -2*dpx[3,],
##              penta=psigamma(x,3),   6*dpx[4,],
##              hexa =psigamma(x,4),  -24*dpx[5,],
##              hepta=psigamma(x,5),  120*dpx[6,],
##              octa =psigamma(x,6), -720*dpx[7,])
## cbind(x, ie=attr(dpx,"errorCode"), round(mdpsi, 4))
str(psig <- outer(x, j, psigamma))
dpsi <- t(fj * (`attributes<-`(dpx, list(dim=dim(dpx))))))
if(getRversion() >= "4.2") {
  print( all.equal(psig, dpsi, tol=0) )# -> see 1.185e-16
  stopifnot( all.equal(psig, dpsi, tol=1e-15) )
} else { # R <= 4.1.x; dpsifn(x, ..) *not* ok for x < 0
  i <- x >= 0
  print( all.equal(psig[i,], dpsi[i,], tol=0) )# -> see 1.95e-16
  stopifnot( all.equal(psig[i,], dpsi[i,], tol=1e-15) )
}
```

 dtWV

Asymptotic Noncentral t Distribution Density by Viechtbauer

Description

Compute the density function $f(x)$ of the t distribution with df degrees of freedom and non-centrality parameter ncp , according to Wolfgang Viechtbauer's proposal in 2002. This is an asymptotic formula for "large" $df = \nu$, or mathematically $\nu \rightarrow \infty$.

Usage

```
dtWV(x, df, ncp = 0, log = FALSE)
```

Arguments

x	numeric vector.
df	degrees of freedom (> 0 , maybe non-integer). $df = \text{Inf}$ is allowed.
ncp	non-centrality parameter δ ; If omitted, use the central t distribution.
log	logical; if TRUE, $\log(f(x))$ is returned instead of $f(x)$.

Details

The formula used is “asymptotic”: Resnikoff and Lieberman (1957), p.1 and p.25ff, proposed to use recursive polynomials for (*integer !*) degrees of freedom $f = 1, 2, \dots, 20$, and then, for $df = f > 20$, use the asymptotic approximation which Wolfgang Viechtbauer proposed as a first version of a non-central t density for \mathbb{R} (when `dt()` did not yet have an `ncp` argument).

Value

numeric vector of density values, properly recycled in (x, df, ncp) .

Author(s)

Wolfgang Viechtbauer (2002) post to R-help (<https://stat.ethz.ch/pipermail/r-help/2002-October/026044.html>), and Martin Maechler (log argument; tweaks, notably recycling).

References

Resnikoff, George J. and Lieberman, Gerald J. (1957) *Tables of the non-central t-distribution*; Technical report no. 32 (LIE ONR 32), April 1, 1957; Applied Math. and Stat. Lab., Stanford University. <https://statistics.stanford.edu/technical-reports/tables-non-central-t-distribution-density-functio>

See Also

`dt`, R's (C level) implementation of the (non-central) t density; `dntJKBf`, for Johnson et al.'s summation formula approximation.

Examples

```
tt <- seq(0, 10, len = 21)
ncp <- seq(0, 6, len = 31)
dt3R <- outer(tt, ncp, dt , df = 3)
dt3WV <- outer(tt, ncp, dtWV, df = 3)
all.equal(dt3R, dt3WV) # rel.err 0.00063
dt25R <- outer(tt, ncp, dt , df = 25)
dt25WV <- outer(tt, ncp, dtWV, df = 25)
all.equal(dt25R, dt25WV) # rel.err 1.1e-5

x <- -10:700
fx <- dt (x, df = 22, ncp =100)
lfx <- dt (x, df = 22, ncp =100, log=TRUE)
lfv <- dtWV(x, df = 22, ncp =100, log=TRUE)

head(lfx, 20) # shows that R's dt(*, log=TRUE) implementation is "quite suboptimal"
```

```
## graphics
opa <- par(no.readonly=TRUE)
par(mar=.1+c(5,4,4,3), mgp = c(2, .8,0))
plot(fx ~ x, type="l")
par(new=TRUE) ; cc <- c("red", adjustcolor("orange", 0.4))
plot(lfx ~ x, type = "o", pch=".", col=cc[1], cex=2, ann=FALSE, yaxt="n")
sfsmisc::eaxis(4, col=cc[1], col.axis=cc[1], small.args = list(col=cc[1]))
lines(x, lfV, col=cc[2], lwd=3)
dtt1 <- " dt"; dtt2 <- "(x, df=22, ncp=100"; dttL <- paste0(dtt2,", log=TRUE)")
legend("right", c(paste0(dtt1,dtt2,""), paste0(c(dtt1,"dtWV"), dttL)),
      lty=1, lwd=c(1,1,3), col=c("black", cc), bty = "n")
par(opa) # reset
```

expm1x

*Accurate $\exp(x) - 1 - x$ (for smallish $|x|$)***Description**

Compute $e^x - 1 - x = \exp(x) - 1 - x$ accurately, notably for small $|x|$.

The last two entries in `cutx[]` denote boundaries where `expm1x(x)` uses direct formulas. For `nC <- length(cutx)`, $\exp(x) - 1 - x$ is used for $\text{abs}(x) \geq \text{cutx}[nC]$, and when $\text{abs}(x) < \text{cutx}[nC]$ $\expm1(x) - x$ is used for $\text{abs}(x) \geq \text{cutx}[nC-1]$.

Usage

```
expm1x(x, cutx = c( 4.4e-8, 0.1, 0.385, 1.1, 2),
          k = c(2, 9, 12, 17))
```

```
expm1xTser(x, k)
```

Arguments

<code>x</code>	numeric-alike vector; goal is to work for <code>mpfr</code> -numbers too.
<code>cutx</code>	increasing positive numeric vector of cut points defining intervals in which the computations will differ.
<code>k</code>	for <code>exp1mx()</code> : increasing vector of integers with <code>length(k) == length(cutx) + 2</code> , denoting the order of Taylor polynomial approximation by <code>expm1xTser(. , k)</code> to <code>expm1x(.)</code> . <code>exp1mxTser()</code> : an integer ≥ 1 , where the Taylor polynomial approximation has degree $k + 1$.

Value

a vector like `x` containing (approximations to) $e^x - x - 1$.

Author(s)

Martin Maechler

See Also

`expm1(x)` for computing $e^x - 1$ is much more widely known, and part of the ISO C standards now.

Examples

```
## a symmetric set of negative and positive
x <- unique(c(2^-seq(-3/8, 54, by = 1/8), seq(7/8, 3, by = 1/128)))
x <- x0 <- sort(c(-x, 0, x)) # negative *and* positive

## Mathematically, expm1(x) = exp(x) - 1 - x >= 0 (and == 0 only at x=0):
em1x <- expm1(x)
stopifnot(em1x >= 0, identical(x == 0, em1x == 0))

plot(x, em1x, type='b', log="y")
lines(x, expm1(x)-x, col = adjustcolor(2, 1/2), lwd = 3) ## should nicely cover ..
lines(x, exp(x)-1-x, col = adjustcolor(4, 1/4), lwd = 5) ## should nicely cover ..
cuts <- c(4.4e-8, 0.10, 0.385, 1.1, 2)[-1] # *not* drawing 4.4e-8
v <- c(-rev(cuts), 0, cuts); stopifnot(!is.unsorted(v))
abline(v = v, lty = 3, col=adjustcolor("gray20", 1/2))

stopifnot(diff(em1x[x <= 0]) <= 0)
stopifnot(diff(em1x[x >= 0]) >= 0)

## direct formula - may be really "bad" :
expm1.0 <- function(x) exp(x) - 1 - x
## less direct formula - improved (but still not universally ok):
expm1.1 <- function(x) expm1(x) - x

ax <- abs(x) # ==> show negative and positive x on top of each other
plot(ax, em1x, type='l', log="xy", xlab = "|x| (for negative and positive x)")
lines(ax, expm1(x)-x, col = adjustcolor(2, 1/2), lwd = 3) ## see problem at very left
lines(ax, exp(x)-1-x, col = adjustcolor(4, 1/4), lwd = 5) ## see huge problems for |x| < ~10^{-7}
legend("topleft", c("expm1(x)", "expm1(x) - x", "exp(x) - 1 - x"), bty="n",
      col = c(1,2,4), lwd = c(1,3,5))

## ----- Relative error of Taylor series approximations :
twoP <- seq(-0.75, 54, by = 1/8)
x <- 2^-twoP
x <- sort(c(-x,x)) # negative *and* positive
e1xAll <- cbind(expm1.0 = expm1.0(x),
               expm1.1 = expm1.1(x),
               vapply(1:15, \k) expm1Tser(x, k=k), x))
colnames(e1xAll)[-1:2] <- paste0("k=", 1:15)
head(e1xAll)
## TODO plot !!
```

format01prec *Format Numbers in [0,1] with "Precise" Result*

Description

Format numbers in [0,1] with “precise” result, notably using “1-..” if needed.

Usage

```
format01prec(x, digits = getOption("digits"), width = digits + 2,
             eps = 1e-06, ...,
             FUN = function(x, ...) formatC(x, flag = "-", ...))
```

Arguments

x	numbers in [0,1]; (still works if not)
digits	number of digits to use; is used as FUN(*, digits = digits) or FUN(*, digits = digits - 5) depending on x or eps.
width	desired width (of strings in characters), is used as FUN(*, width = width) or FUN(*, width = width - 2) depending on x or eps.
eps	small positive number: Use '1-' for those x which are in $(1 - \text{eps}, 1]$. The author has claimed in the last millennium that (the default) 1e-6 is <i>optimal</i> .
...	optional further arguments passed to FUN(x, digits, width, ...).
FUN	a function used for format() ing; must accept both a digits and width argument.

Value

a [character](#) vector of the same length as x.

Author(s)

Martin Maechler, 14 May 1997

See Also

[formatC](#), [format.pval](#).

Examples

```
## Show that format01prec() does reveal more precision :
cbind(format      (1 - 2^-(16:24)),
       format01prec(1 - 2^-(16:24)))

## a bit more variety
e <- c(2^seq(-24,0, by=2), 10^-(7:1))
ee <- sort(unique(c(e, 1-e)))
```

```
noquote(ff <- format01prec(ee))
data.frame(ee, format01prec = ff)
```

fr_ld_exp

*Base-2 Representation and Multiplication of Numbers***Description**

Both are R versions of C99 (and POSIX) standard C (and C++) mathlib functions of the same name.

`frexp(x)` computes base-2 exponent e and “mantissa”, or *fraction* r , such that $x = r * 2^e$, where $r \in [0.5, 1)$ (unless when x is in $c(0, -\text{Inf}, \text{Inf}, \text{NaN})$ where $r == x$ and e is 0), and e is integer valued.

`ldexp(f, E)` is the *inverse* of `frexp()`: Given fraction or mantissa f and integer exponent E , it returns $x = f * 2^E$. Viewed differently, it’s the fastest way to multiply or divide (double precision) numbers with 2^E .

Usage

```
frexp(x)
ldexp(f, E)
```

Arguments

<code>x</code>	numeric (coerced to double) vector.
<code>f</code>	numeric fraction (vector), in $[0.5, 1)$.
<code>E</code>	integer valued, exponent of 2, i.e., typically in $(-1024-50):1024$, otherwise the result will underflow to 0 or overflow to $\pm \text{Inf}$.

Value

`frexp` returns a [list](#) with named components `r` (of type double) and `e` (of type integer).

Author(s)

Martin Maechler

References

On unix-alikes, typically `man frexp` and `man ldexp`

See Also

Vaguely relatedly, [log1mexp\(\)](#), [lsum](#), [logspace.add](#).

Examples

```

set.seed(47)
x <- c(0, 2^(-3:3), (-1:1)/0,
      rlnorm(2^12, 10, 20) * sample(c(-1,1), 512, replace=TRUE))
head(x, 12)
which(!(iF <- is.finite(x))) # 9 10 11
rF <- frexp(x)
sapply(rF, summary) # (nice only when x had no NA's ..)
data.frame(x=x[!iF], lapply(rF, `[`, !iF))
## by C.99/POSIX 'r' should be the same as 'x' for these,
##   x   r e
## 1 -Inf -Inf 0
## 2 NaN  NaN 0
## 3 Inf  Inf 0
## but on Windows, we've seen 3 NA's :
ar <- abs(rF$r)
ldx <- with(rF, ldexp(r, e))
stopifnot(exprs = {
  0.5 <= ar[iF & x != 0]
  ar[iF] < 1
  is.integer(rF$e)
  all.equal(x[iF], ldx[iF], tol= 4*.Machine$double.eps)
  ## but actually, they should even be identical, well at least when finite
  identical(x[iF], ldx[iF])
})

```

gam1d

*Compute $1/\Gamma(x+1) - 1$ Accurately***Description**

Computes $1/\Gamma(a + 1) - 1$ accurately in $[-0.5, 1.5]$ for numeric argument a ; For "mpfr" numbers, the precision is increased intermediately such that $a + 1$ should not lose precision.

FIXME: "Pure-R" implementation is in ‘~/R/Pkgs/DPQ/TODO_R_versions_gam1_etc.R’

Usage

```
gam1d(a, warnIf = TRUE, verbose = FALSE)
```

Arguments

<code>a</code>	a numeric or numeric-alike, typically inheriting from class "mpfr".
<code>warnIf</code>	logical if a warning should be signalled when a is not in the “proper” range $[-0.5, 1.5]$.
<code>verbose</code>	logical indicating if some output from C code execution should be printed to the console.

Details

<https://dlmf.nist.gov/> states the well-know Taylor series for

$$\frac{1}{\Gamma(z)} = \sum_{k=1}^{\infty} c_k z^k$$

with $c_1 = 1$, $c_2 = \gamma$, (Euler's gamma, $\gamma = 0.5772\dots$, with recursion $c_k = (\gamma c_{k-1} - \zeta(2)c_{k-2}\dots + (-1)^k \zeta(k-1)c_1)/(k-1)$).

Hence,

$$\frac{1}{\Gamma(z+1)} = z + 1 + \sum_{k=2}^{\infty} c_k (z+1)^k$$

$$\frac{1}{\Gamma(z+1)} - 1 = z + \gamma * (z+1)^2 + \sum_{k=3}^{\infty} c_k (z+1)^k$$

Consequently, for $\zeta_k := \zeta(k)$, $c_3 = (\gamma^2 - \zeta_2)/2$, $c_4 = \gamma^3/6 - \gamma\zeta_2/2 + \zeta_3/3$.

```
gam <- Const("gamma", 128)
z <- Rmpfr::zeta(mpfr(1:7, 128))
(c3 <- (gam^2 - z[2])/2) # -0.655878071520253881077019515145
(c4 <- (gam*c3 - z[2]*c2 + z[3])/3) # -0.04200263503409523552900393488
(c4 <- gam*(gam^2/6 - z[2]/2) + z[3]/3)
(c5 <- (gam*c4 - z[2]*c3 + z[3]*c2 - z[4])/4) # 0.1665386113822914895017007951
(c5 <- (gam^4/6 - gam^2*z[2] + z[2]^2/2 + gam*z[3]*4/3 - z[4])/4)
```

Value

a numeric-alike vector like a.

Author(s)

Martin Maechler building on C code of TOMS 708

References

TOMS 708, see [pbeta](#)

See Also

[gamma](#).

Examples

```
g1 <- function(u) 1/gamma(u+1) - 1
u <- seq(-.5, 1.5, by=1/16); set.seed(1); u <- sample(u) # permuted (to check logic)

g11 <- vapply(u, gam1d, 1)
gam1d. <- gam1d(u)
stopifnot( all.equal(g1(u), g11) )
```

```

stopifnot( identical(g11, gam1d.) )

## Comparison of g1() and gam1d(), slightly extending the [-.5, 1.5] interval:
u <- seq(-0.525, 1.525, length.out = 2001)
mg1 <- cbind(g1 = g1(u), gam1d = gam1d(u))
clr <- adjustcolor(1:2, 1/2)
matplot(u, mg1, type = "l", lty = 1, lwd=1:2, col=clr) # *no* visual difference
## now look at *relative* errors
relErrV <- sfsmisc::relErrV
relE <- relErrV(mg1[, "gam1d"], mg1[, "g1"])
plot(u, relE, type = "l")
plot(u, abs(relE), type = "l", log = "y",
      main = "|rel.diff| gam1d() vs 'direct' 1/gamma(u+1) - 1")

## now {Rmpfr} for "truth" :
if(requireNamespace("Rmpfr")) withAutoprint({
  asN <- Rmpfr::asNumeric; mpfr <- Rmpfr::mpfr
  gam1M <- g1(mpfr(u, 512)) # "cheap": high precision avoiding "all" cancellation
  relE <- asN(relErrV(gam1M, gam1d(u)))
  plot(relE ~ u, type="l", ylim = c(-1,1) * 2.5e-15,
        main = expression("Relative Error of " ~ gam1d(u) %~~% frac(1, Gamma(u+1)) - 1))
  grid(lty = 3); abline(v = c(-.5, 1.5), col = adjustcolor(4, 1/2), lty=2, lwd=2)
})

if(requireNamespace("Rmpfr") && FALSE) {

## Comparison using Rmpfr; slightly extending the [-.5, 1.5] interval:
## {relErrV(), mpfr(), asN() defined above}

u <- seq(-0.525, 1.525, length.out = 2001)
gam1M <- gam1(mpfr(u, 128))
relE <- asN(relErrV(gam1M, gam1d(u)))

plot(relE ~ u, type="l", ylim = c(-1,1) * 2.5e-15,
      main = expression("Relative Error of " ~ gam1d(u) == frac(1, Gamma(u+1)) - 1))
grid(lty = 3); abline(v = c(-.5, 1.5), col = adjustcolor(4, 1/2), lty=2, lwd=2)

## what about the direct formula -- how bad is it really ?
relED <- asN(relErrV(gam1M, g1(u)))

plot(relE ~ u, type="l", ylim = c(-1,1) * 1e-14,
      main = expression("Relative Error of " ~ gam1d(u) == frac(1, Gamma(u+1)) - 1))
lines(relED ~ u, col = adjustcolor(2, 1/2), lwd = 2)
# mtext("comparing with direct formula 1/gamma(u+1) - 1")
legend("top", c("gam1d(u)", "1/gamma(u+1) - 1"), col = 1:2, lwd=1:2, bty="n")
## direct is clearly *worse* , but not catastrophic
}

```

Description

Computes $\log \Gamma(a + 1)$ accurately notably when $|a| \ll 1$. Specifically, it uses high (double precision) accuracy rational approximations for $-0.2 \leq a \leq 1.25$.

Usage

```
gamln1(a, warnIf = TRUE)
```

Arguments

a a numeric or numeric-alike, typically inheriting from class "mpfr".

warnIf logical if a [warning](#) should be signalled when **a** is not in the "proper" range $[-0.2, 1.25]$.

Details

It uses $-a * p(a)/q(a)$ for $a < 0.6$, where p and q are polynomials of degree 6 with coefficient vectors $p = [p_0 p_1 \dots p_6]$ and q ,

```
p <- c( .577215664901533, .844203922187225, -.168860593646662,
        -.780427615533591, -.402055799310489, -.0673562214325671,
        -.00271935708322958)
q <- c( 1, 2.88743195473681, 3.12755088914843, 1.56875193295039,
        .361951990101499, .0325038868253937, 6.67465618796164e-4)
```

Similarly, for $a \geq 0.6$, $x := a - 1$, the result is $x * r(x)/s(x)$, with 5th degree polynomials $r()$ and $s()$ and coefficient vectors

```
r <- c(.422784335098467, .848044614534529, .565221050691933,
        .156513060486551, .017050248402265, 4.97958207639485e-4)
s <- c( 1, 1.24313399877507, .548042109832463,
        .10155218743983, .00713309612391, 1.16165475989616e-4)
```

Value

a numeric-alike vector like **a**.

Author(s)

Martin Maechler building on C code of TOMS 708

References

TOMS 708, see [pbeta](#)

See Also

`lgamma1p()` for different algorithms to compute $\log \Gamma(a + 1)$, notably when outside the interval $[-0.2, 1.35]$. Package **DPQmpfr**'s `lgamma1pM()` provides very precise such computations. `lgamma()` (and `gamma()` (same page)).

Examples

```
lg1 <- function(u) lgamma(u+1) # the simple direct form
## The curve, zeros at u=0 & u=1:
curve(lg1, -.2, 1.25, col=2, lwd=2, n=999)
title("lgamma(x + 1)"); abline(h=0, v=0:1, lty=3)

u <- (-16:100)/80 ; set.seed(1); u <- sample(u) # permuted (to check logic)
g11 <- vapply(u, gamln1, numeric(1))
gamln1. <- gamln1(u)
stopifnot( identical(g11, gamln1.) )
stopifnot( all.equal(lg1(u), g11) )

u <- (-160:1000)/800
relE <- sfsmisc::relErrV(gamln1(u), lg1(u))
plot(u, relE, type="l", main = expression("rel.diff." ~ gamln1(u) %~~% lgamma(u+1)))
plot(u, abs(relE), type="l", log="y", yaxt="n",
      main = expression("|rel.diff." ~ gamln1(u) %~~% lgamma(u+1)))
sfsmisc::eaxis(2)

if(requireNamespace("DPQmpfr")) withAutoprint({
  ## Comparison using Rmpfr; extending the [-.2, 1.25] interval a bit
  u <- seq(-0.225, 1.31, length.out = 2000)
  lg1pM <- DPQmpfr::lgamma1pM(Rmpfr::mpfr(u, 128))
  relE <- Rmpfr::asNumeric(sfsmisc::relErrV(lg1pM, gamln1(u, warnIf=FALSE)))

  plot(relE ~ u, type="l", ylim = c(-1,1) * 2.3e-15,
        main = expression("relative error of " ~ gamln1(u) == log( Gamma(u+1) )))
  grid(lty = 3); abline(v = c(-.2, 1.25), col = adjustcolor(4, 1/2), lty=2, lwd=2)
  ## well... TOMS 708 gamln1() is good (if "only" 14 digits required

  ## what about the direct formula -- how bad is it really ?
  relED <- Rmpfr::asNumeric(sfsmisc::relErrV(lg1pM, lg1(u)))
  lines(relED ~ u, col = adjustcolor(2, 1/2))
  ## amazingly, the direct formula is partly (around -0.2 and +0.4) even better than gamln1() !

  plot(abs(relED) ~ u, type="l", log = "y", ylim = c(7e-17, 1e-14),
        main = expression("|relative error| of " ~ gamln1(u) == log( Gamma(u+1) )))
  grid(lty = 3); abline(v = c(-.2, 1.25), col = adjustcolor(4, 1/2), lty=2, lwd=2)
  relED <- Rmpfr::asNumeric(sfsmisc::relErrV(lg1pM, lg1(u)))
  lines(abs(relED) ~ u, col = adjustcolor(2, 1/2))
})
```

gammaVer

*Gamma Function Versions***Description**

Provide different variants or versions of computing the Gamma (Γ) function.

Usage

```
gammaVer(x, version, stirlerrV = c("R3", "R4..1", "R4.4_0"), traceLev = 0L)
```

Arguments

x	numeric vector of abscissa value for the Gamma function.
version	integer in {1,2,...,5} specifying which variant is desired.
stirlerrV	a string, specifying the <code>stirlerr()</code> version/variant to use.
traceLev	non-negative integer indicating the amount of diagnostic “tracing” output to the console during computation.

Details

All of these are good algorithms to compute $\Gamma(x)$ (for real x), and indeed correspond to the versions R’s implementation of `gamma(x)` over time. More specifically, the current version numbers correspond to

1. . TODO
2. .
3. .
4. Used in R from ... up to versions 4.3.z
5. Possibly to be used in R 4.4.z and newer.

The `stirlerrV` must be a string specifying the version of `stirlerr()` to be used:

“R3”: the historical version, used in all R version up to R 4.3.z.

“R4..1”: only started using `lgamma1p(n)` instead of `lgamma(n + 1.)` in `stirlerr(n)` for $n \leq 15$, in the direct formula.

“R4.4_0”: uses 10 cutoffs instead 4, and these are larger to gain accuracy.

Value

numeric vector as x

Author(s)

Martin Maechler

References

.... TODO

See Also

[gamma\(\)](#), R's own Gamma function.

Examples

```
xx <- seq(-4, 10, by=1/2)
gx <- sapply(1:5, gammaVer, x=xx)
gamx <- gamma(xx)
cbind(xx, gx, gamma=gamx)
apply(gx, 2, all.equal, target=gamx, tol = 0) # typically: {T,T,T,T, 1.357e-16}
stopifnot( apply(gx, 2, all.equal, target = gamx, tol = 1e-14))
# even 2e-16 (Lnx, 64b, R 4.2.1)
```

hyper2binomP	<i>Transform Hypergeometric Distribution Parameters to Binomial Probability</i>
--------------	---

Description

Transform the three parameters of the hypergeometric distribution function to the probability parameter of the “corresponding” binomial distribution.

Usage

```
hyper2binomP(x, m, n, k)
```

Arguments

x, m, n, k see [dhyper](#).

Value

a number, the binomial probability.

References

See those in [phyperBinMolenaar](#).

See Also

[phyper](#), [pbinom](#).

[dhyperBinMolenaar\(\)](#), [phyperBinMolenaar.1\(\)](#), [*.2\(\)](#), etc, all of which are crucially based on [hyper2binomP\(\)](#).

Examples

```

hyper2binomP(3,4,5,6) # 0.38856

## The function is simply defined as
function (x, m, n, k) {
  N <- m + n
  p <- m/N
  N.n <- N - (k - 1)/2
  (m - x/2)/N.n - k * (x - k * p - 1/2)/(6 * N.n^2)
}

```

Ixpq

*Normalized Incomplete Beta Function "Like" pbeta()***Description**

Computes the normalized incomplete beta function, in pure R code, derived from Nico Temme's Maple code for computing Table 1 in Gil et al (2023).

It uses a continued fraction, similarly to `bfrac()` in the TOMS 708 algorithm underlying R's `pbeta()`.

Usage

```
Ixpq(x, l_x, p, q, tol = 3e-16, it.max = 100L, plotIt = FALSE)
```

Arguments

<code>x</code>	numeric
<code>l_x</code>	$1 - x$; may be specified with higher precision (e.g., when $x \approx 1$, $1 - x$ suffers from cancellation).
<code>p, q</code>	the two shape parameters of the beta distribution.
<code>tol</code>	positive number, the convergence tolerance for the continued fraction computation.
<code>it.max</code>	maximal number of continued fraction steps.
<code>plotIt</code>	a logical , if true, plots show the relative approximation errors in each step.

Value

a vector like `x` or `l_x` with corresponding `pbeta(x, *)` values.

Author(s)

Martin Maechler; based on original Maple code by Nico Temme.

References

Gil et al. (2023)

See Also

[pbeta](#), [pbetaRv1\(\)](#), ..

Examples

```
x <- seq(0, 1, by=1/16)
r <- Ixpq(x, 1-x, p = 4, q = 7, plotIt = TRUE)
cbind(x, r)
## and "test" ___FIXME__
```

Ibeta

(Log) Beta and Ratio of Gammas Approximations

Description

Compute $\log(\text{beta}(a,b))$ in a simple (fast) or asymptotic way. The asymptotic case is based on the asymptotic Γ ([gamma](#)) ratios, provided in [Qab_terms\(\)](#) and [logQab_asy\(\)](#).

[lbeta_asy\(a,b, ..\)](#) is simply $\lgamma(a) - \logQab_asy(a, b, ..)$.

Usage

```
lbetaM (a, b, k.max = 5, give.all = FALSE)
lbeta_asy(a, b, k.max = 5, give.all = FALSE)
lbetaMM (a, b, cutAsy = 1e-2, verbose = FALSE)
```

```
betaI(a, n)
lbetaI(a, n)
```

```
logQab_asy(a, b, k.max = 5, give.all = FALSE)
Qab_terms(a, k)
```

Arguments

<code>a, b, n</code>	the Beta parameters, see beta ; <code>n</code> must be a positive integer and “small”.
<code>k.max, k</code>	for lbeta*() and logQab_asy() : the number of terms to be used in the series expansion of Qab_terms() , currently must be in 0, 1, .., 5.
<code>give.all</code>	logical indicating if all terms should be returned (as columns of a matrix) or just the result.
<code>cutAsy</code>	cutoff value from where to switch to asymptotic formula.
<code>verbose</code>	logical (or integer) indicating if and how much monitoring information should be printed to the console.

Details

All lbeta*() functions compute $\log(\text{beta}(a, b))$.

We use $Qab = Qab(a, b)$ for

$$Q_{a,b} := \frac{\Gamma(a+b)}{\Gamma(b)},$$

which is numerically challenging when b becomes large compared to a , or $a \ll b$.

With the beta function

$$B(a, b) = \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)} = \frac{\Gamma(a)}{Qab},$$

and hence

$$\log B(a, b) = \log \Gamma(a) + \log \Gamma(b) - \log \Gamma(a+b) = \log \Gamma(a) - \log Qab,$$

or in R, $\text{lbeta}(a, b) := \text{lgamma}(a) - \log Qab(a, b)$.

Indeed, typically everything has to be computed in log scale, as both $\Gamma(b)$ and $\Gamma(a+b)$ would overflow numerically for large b . Consequently, we use $\log Qab*()$, and for the large b case $\log Qab_asy()$ specifically,

$$\log Qab(a, b) := \log(Qab(a, b)).$$

The 5 polynomial terms in $Qab_terms()$ have been derived by the author in 1997, but not published, about getting asymptotic formula for Γ ratios, related to but *different* than formula (6.1.47) in Abramowitz and Stegun.

We also have a vignette about this, but really the problem has been addressed pragmatically by the authors of TOMS 708, see the 'References' in [pbeta](#), by their routine [algdiv\(\)](#) which also is available in our package **DPQ**, $\text{algdiv}(a, b) = -\log Qab(a, b)$. Note that this is related to computing [qbeta\(\)](#) in boundary cases. See also [algdiv\(\)](#) 'Details'.

Value

a fast or simple (approximate) computation of $\text{lbeta}(a, b)$.

Author(s)

Martin Maechler

References

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover. https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain; Formula (6.1.47), p.257

See Also

R's [beta](#) function; [algdiv\(\)](#).

Examples

```

(r <- logQab_asy(1, 50))
(rF <- logQab_asy(1, 50, give.all=TRUE))
r == rF # all TRUE: here, even the first approx. is good!
(r2 <- logQab_asy(5/4, 50))
(r2F <- logQab_asy(5/4, 50, give.all=TRUE))
r2 == r2F # TRUE only first entry "5"
(r2F.3 <- logQab_asy(5/4, 50, k=3, give.all=TRUE))

## Check relation to Beta(), Gamma() functions:
a <- 1.1 * 2^(-6:4)
b <- 1001.5
rDlgg <- lgamma(a+b) - lgamma(b) # suffers from cancellation for small 'a'
rDlgb <- lgamma(a) - lbeta(a, b) # (ditto)
ralgd <- - alqdiv(a,b)
rQasy <- logQab_asy(a, b)
cbind(a, rDlgg, rDlgb, ralgd, rQasy)
all.equal(rDlgg, rDlgb, tolerance = 0) # 3.0e-14
all.equal(rDlgb, ralgd, tolerance = 0) # 1.2e-16
all.equal(ralgd, rQasy, tolerance = 0) # 4.1e-10
all.equal(rQasy, rDlgg, tolerance = 0) # 3.5e-10

stopifnot(exprs = {
  all.equal(rDlgg, rDlgb, tolerance = 1e-12) # 3e-14 {from cancellations!}
  all.equal(rDlgb, ralgd, tolerance = 1e-13) # 1e-16
  all.equal(ralgd, rQasy, tolerance = 2e-9) # 4.1e-10
  all.equal(rQasy, rDlgg, tolerance = 2e-9) # 3.5e-10
  all.equal(lgamma(a)-lbeta(a, 2*b), logQab_asy(a, 2*b), tolerance =1e-10)# 1.4e-11
  all.equal(lgamma(a)-lbeta(a, b/2), logQab_asy(a, b/2), tolerance = 1e-7)# 1.2e-8
})
if(requireNamespace("Rmpfr")) withAutoprint({
  aM <- Rmpfr::mpfr(a, 512)
  bM <- Rmpfr::mpfr(b, 512)
  rT <- lgamma(aM+bM) - lgamma(bM) # "True" i.e. accurate values
  relE <- Rmpfr::asNumeric(sfsmisc::relErrV(rT, cbind(rDlgg, rDlgb, ralgd, rQasy)))
  cbind(a, signif(relE,4))
  ##      a      rDlgg      rDlgb      ralgd      rQasy
  ## 0.0171875 4.802e-12 3.921e-16 4.145e-17 -4.260e-16
  ## 0.0343750 1.658e-12 1.509e-15 -1.011e-17 1.068e-16
  ## 0.0687500 -2.555e-13 6.853e-16 -1.596e-17 -1.328e-16
  ## 0.1375000 1.916e-12 -7.782e-17 3.905e-17 -7.782e-17
  ## 0.2750000 1.246e-14 7.001e-17 7.001e-17 -4.686e-17
  ## 0.5500000 -2.313e-13 5.647e-17 5.647e-17 -6.040e-17
  ## 1.1000000 -9.140e-14 -1.298e-16 -1.297e-17 -1.297e-17
  ## 2.2000000 9.912e-14 2.420e-17 2.420e-17 -9.265e-17
  ## 4.4000000 1.888e-14 6.810e-17 -4.873e-17 -4.873e-17
  ## 8.8000000 -7.491e-15 1.004e-16 -1.638e-17 -4.118e-13
  ## 17.6000000 2.222e-15 1.207e-16 3.974e-18 -6.972e-10

## ==> logQab_asy() is very good _here_ as long as a << b
})

```

Description

Provide R versions of simple formulas for computing the logarithm of (the absolute value of) binomial coefficients, i.e., simpler, more direct formulas than what (the C level) code of R's `lchoose()` computes.

Usage

```
lfastchoose(n, k)
f05lchoose(n, k)
```

Arguments

n	a numeric vector.
k	a integer valued numeric vector.

Value

a numeric vector with the same attributes as `n + k`.

Author(s)

Martin Maechler

See Also

[lchoose](#).

Examples

```
lfastchoose # function(n, k) lgamma(n + 1) - lgamma(k + 1) - lgamma(n - k + 1)
f05lchoose # function(n, k) lfastchoose(n = floor(n + 0.5), k = floor(k + 0.5))

## interesting cases ?
```

<code>lgamma1p</code>	<i>Accurate</i> <code>log(gamma(a+1))</code>
-----------------------	--

Description

Compute

$$l\Gamma_1(a) := \log \Gamma(a + 1) = \log(a \cdot \Gamma(a)) = \log a + \log \Gamma(a),$$

which is “in principle” the same as `log(gamma(a+1))` or `lgamma(a+1)`, accurately also for (very) small a ($0 < a < 0.5$).

Usage

```
lgamma1p(a, tol_logcf = 1e-14, f.tol = 1, ...)
lgamma1p.(a, cutoff.a = 1e-6, k = 3)
lgamma1p_series(x, k)
lgamma1pC(x)
```

Arguments

<code>a, x</code>	a numeric vector.
<code>tol_logcf</code>	for <code>lgamma1p()</code> : a non-negative number passed to <code>logcf()</code> (and <code>log1pmx()</code> which calls <code>logcf()</code>).
<code>f.tol</code>	numeric (factor) used in <code>log1pmx(*, tol_logcf = f.tol * tol_logcf)</code> .
<code>...</code>	further optional arguments passed on to <code>log1pmx()</code> .
<code>cutoff.a</code>	for <code>lgamma1p.()</code> : a positive number indicating the cutoff to switch from ...
<code>k</code>	an integer, the number of terms in the series expansion used internally; currently for <code>lgamma1p.()</code> : $k \leq 3$ <code>lgamma1p_series()</code> : $k \leq 15$

Details

`lgamma1p()` is an R translation of the function (in Fortran) in Didonato and Morris (1992) which uses a 40-degree polynomial approximation.

`lgamma1p.(u)` for small $|u|$ uses up to 4 terms of

$$\Gamma(1 + u) = 1 + u * (-\gamma_E + a_0 u + a_1 u^2 + a_2 u^3) + O(u^5),$$

where $a_0 := (\psi'(1) + \psi(1)^2)/2 = (\pi^2/6 + \gamma_E^2)/2$, and a_1 and a_2 are similarly determined. Then `log1p(.)` of the $\Gamma(1 + u) - 1$ approximation above is used.

`lgamma1p_series(x, k)` is a Taylor series approximation of order k , directly of $l\Gamma_1(a) := \log \Gamma(a + 1)$ (mostly via Maple), which starts as $-\gamma_E x + \pi^2 x^2/12 + \dots$, where γ_E is Euler’s constant 0.5772156649.

`lgamma1pC()` is an interface to R’s C API (‘Mathlib’ / ‘Rmath.h’) function `lgamma1p()`.

Value

a numeric vector with the same attributes as `a`.

Author(s)

Morten Welinder (C code of Jan 2005, see R's bug issue [PR#7307](#)) for `lgamma1p()`.

Martin Maechler, notably for `lgamma1p_series()` which works with package **Rmpfr** but otherwise may be *much* less accurate than Morten's 40 term series!

References

Didonato, A. and Morris, A., Jr, (1992) Algorithm 708: Significant digit computation of the incomplete beta function ratios. *ACM Transactions on Mathematical Software*, **18**, 360–373; see also [pbeta](#).

See Also

Yet another algorithm, fully double precision accurate in $[-0.2, 1.25]$, is provided by [gamln1\(\)](#).
[log1pmx](#), [log1p](#), [pbeta](#).

Examples

```
curve(lgamma1p, -1.25, 5, n=1001, col=2, lwd=2)
abline(h=0, v=-1:0, lty=c(2,3,2), lwd=c(1, 1/2,1))
for(k in 1:15)
  curve(lgamma1p_series(x, k=k), add=TRUE, col=adjustcolor(paste0("gray",25+k*4), 2/3), lty = 3)

curve(lgamma1p, -0.25, 1.25, n=1001, col=2, lwd=2)
abline(h=0, v=0, lty=2)
for(k in 1:15)
  curve(lgamma1p_series(x, k=k), add=TRUE, col=adjustcolor("gray20", 2/3), lty = 3)

curve(-log(x*gamma(x)), 1e-30, .8, log="xy", col="gray50", lwd = 3,
      axes = FALSE, ylim = c(1e-30,1)) # underflows to zero at x ~ 1e-16
eaxGrid <- function(at.x = 10^(1-4*(0:8)), at.y = at.x) {
  sfsmisc::eaxis(1, sub10 = c(-2, 2), nintLog=16)
  sfsmisc::eaxis(2, sub10 = 2, nintLog=16)
  abline(h = at.y, v = at.x, col = "lightgray", lty = "dotted")
}
eaxGrid()
curve(-lgamma(1+x), add=TRUE, col="red2", lwd=1/2)# underflows even earlier
curve(-lgamma1p(x), add=TRUE, col="blue") -> lgxy
curve(-lgamma1p(x), add=TRUE, col=adjustcolor("forest green",1/4),
      lwd = 5, lty = 2)
for(k in 1:15)
  curve(-lgamma1p_series(x, k=k), add=TRUE, col=paste0("gray",80-k*4), lty = 3)
stopifnot(with(lgxy, all.equal(y, -lgamma1pC(x))))

if(requireNamespace("Rmpfr")) { # accuracy comparisons, originally from ../tests/qgamma-ex.R
  x <- 2^(-(500:11)/8)
  x. <- Rmpfr::mpfr(x, 200)
```

```

## versions of lgamma1p(x) := lgamma(1+x)
## lgamma1p(x) = log gamma(x+1) = log (x * gamma(x)) = log(x) + lgamma(x)
xct. <- log(x. * gamma(x.)) # using MPFR arithmetic .. no overflow/underflow ...
xc2. <- log(x.) + lgamma(x.) # (ditto)

AllEq <- function(target, current, ...)
  Rmpfr::all.equal(target, current, ...,
    formatFUN = function(x, ...) Rmpfr::format(x, digits = 9))
print(AllEq(xct., xc2., tol = 0)) # 2e-57
rr <- vapply(1:15, function(k) lgamma1p_series(x, k=k), x)
colnames(rr) <- paste0("k=", 1:15)
relEr <- Rmpfr::asNumeric(sfsmisc::relErrV(xct., rr))
## rel.error of direct simple computation:
relE.D <- Rmpfr::asNumeric(sfsmisc::relErrV(xct., lgamma(1+x)))

matplot(x, abs(relEr), log="xy", type="l", axes = FALSE,
  main = "|rel.Err(.)| for lgamma(1+x) =~= lgamma1p_series(x, k = 1:15)")
eaxGrid()
p2 <- -(53:52); twp <- 2^p2; labL <- lapply(p2, function(p) substitute(2^E, list(E=p)))
abline(h = twp, lty=3)
axis(4, at=twp, las=2, line=-1, labels=as.expression(labL), col=NA,col.ticks=NA)
legend("topleft", paste("k =", 1:15), ncol=3, col=1:6, lty=1:5, bty="n")
lines(x, abs(relE.D), col = adjustcolor(2, 2/3), lwd=2)
legend("top", "lgamma(1+x)", col=2, lwd=2)

## zoom in:
matplot(x, abs(relEr), log="xy", type="l", axes = FALSE,
  xlim = c(1e-5, 0.1), ylim = c(1e-17, 1e-10),
  main = "|rel.Err(.)| for lgamma(1+x) =~= lgamma1p_series(x, k = 1:15)")
eaxGrid(10^(-5:1), 10^-(17:10))
abline(h = twp, lty=3)
axis(4, at=twp, las=2, line=-1, labels=as.expression(labL), col=NA,col.ticks=NA)
legend("topleft", paste("k =", 1:15), ncol=3, col=1:6, lty=1:5, bty="n")
lines(x, abs(relE.D), col = adjustcolor(2, 2/3), lwd=2)
legend("right", "lgamma(1+x)", col=2, lwd=2)

} # Rmpfr only

```

lgammaAsymp

Asymptotic Log Gamma Function

Description

Compute an n -th order asymptotic approximation to log Gamma function, using Bernoulli numbers [Bern](#)(k) for k in $1, \dots, 2n$.

Usage

```
lgammaAsymp(x, n)
```

Arguments

x numeric vector
n integer specifying the approximation order.

Value

numeric vector with the same attributes (`length()` etc) as `x`, containing approximate `lgamma(x)` values.

Author(s)

Martin Maechler

See Also

`lgamma`; the n -th Bernoulli number `Bern(n)`, and also *exact* fractions Bernoulli numbers `BernoulliQ()` from package **gmp**.

Examples

```
## The function is currently
lgammaAsymp
```

log1mexp	<i>Compute $\log(1 - \exp(-a))$ and $\log(1 + \exp(x))$ Numerically Optimally</i>
----------	---

Description

Compute $f(a) = \log(1 - \exp(-a))$ quickly and numerically accurately.

`log1mexp()` is simple pure R code;

`log1mexpC()` is an interface to R C API ('Mathlib' / 'Rmath.h') function.

`log1pexpC()` is an interface to R's 'Mathlib' double function `log1pexp()` which computes $\log(1 + \exp(x))$, accurately, notably for large x , say, $x > 720$.

Usage

```
log1mexp(x)
log1mexpC(x)
log1pexpC(x)
```

Arguments

x numeric vector of positive values.

Author(s)

Martin Maechler

References

Martin Mächler (2012). Accurately Computing $\log(1 - \exp(-|a|))$; <https://CRAN.R-project.org/package=Rmpfr/vignettes/log1mexp-note.pdf>.

See Also

The `log1mexp()` function in CRAN package **copula**, and the corresponding vignette (in the ‘References’).

Examples

```
l1m.xy <- curve(log1mexp(x), -10, 10, n=1001)
stopifnot(with(l1m.xy, all.equal(y, log1mexpC(x))))

x <- seq(0, 710, length=1+710*2^4); stopifnot(diff(x) == 1/2^4)
l1pm <- cbind(log1p(exp(x)),
              log1pexpC(x))
matplot(x, l1pm, type="l", log="xy") # both look the same
iF <- is.finite(l1pm[,1])
stopifnot(all.equal(l1pm[iF,2], l1pm[iF,1], tol=1e-15))
```

log1pmx

*Accurate $\log(1+x) - x$ Computation***Description**

Compute

$$\log(1 + x) - x$$

accurately also for small x , i.e., $|x| \ll 1$.

Since April 2021, the pure R code version `log1pmx()` also works for "mpfr" numbers (from package **Rmpfr**).

`rlog1(x)`, provided mostly for reference and reproducibility, is used in TOMS Algorithm 708, see e.g. the reference of [lgamma1p](#). and computes *minus* `log1pmx(x)`, i.e., $x - \log(1 + x)$, using (argument reduction) and a rational approximation when $x \in [-0.39, 0.57]$.

Usage

```
log1pmx(x, tol_logcf = 1e-14, eps2 = 0.01, minL1 = -0.79149064,
        trace.lcf = FALSE,
        logCF = if(is.numeric(x)) logcf else logcfR.)
log1pmxC(x) # TODO in future: arguments (minL1, eps2, tol_logcf),
            # possibly with *different* defaults (!)
rlog1(x)
```

Arguments

<code>x</code>	numeric (or, for <code>log1pmx()</code> only, "mpfr" number) vector with values $x > -1$.
<code>tol_logcf</code>	a non-negative number indicating the tolerance (maximal relative error) for the auxiliary <code>logcf()</code> function.
<code>eps2</code>	non-negative cutoff where the algorithm switches from a few terms, to using <code>logcf()</code> explicitly. Note that for more accurate mpfr-numbers the default <code>eps = .01</code> is too large, even more so when the tolerance is lowered (from $1e-14$).
<code>minL1</code>	negative cutoff, called <code>minLog1Value</code> in Morten Welinder's C code for <code>log1pmx()</code> in 'R/src/nmath/pgamma.c', hard coded there to <code>-0.79149064</code> which seems not optimal for computation of <code>log1pmx()</code> , at least in some cases, and hence the default may be changed in the future . Also, for mpfr numbers, the default <code>-0.79149064</code> may well be far from optimal.
<code>trace.lcf</code>	<code>logical</code> used in <code>logcf(..., trace=trace.lcf)</code> .
<code>logCF</code>	the <code>function</code> to be used as <code>logcf()</code> . The default chooses the pure R <code>logcfR()</code> when <code>x</code> is not numeric, and chooses the C-based <code>logcf()</code> when <code>is.numeric(x)</code> is true.

Details

In order to provide full (double precision) accuracy, the computations happens differently in three regions for x ,

$$m_l = \text{minL1} = -0.79149064$$

is the first cutpoint,

$x < m_l$ **or** $x > 1$: use $\log_{1p}(x) := \log_{1p}(x) - x$,
 $|x| < \epsilon_2$: use $t(((2/9 * y + 2/7)y + 2/5)y + 2/3)y - x)$,
 $x \in [m_l, 1]$, **and** $|x| \geq \epsilon_2$: use $t(2y \log_{cf}(y, 3, 2) - x)$,

where $t := \frac{x}{2+x}$, and $y := t^2$.

Note that the formulas based on t are based on the (fast converging) formula

$$\log(1+x) = 2 \left(r + \frac{r^3}{3} + \frac{r^5}{5} + \dots \right),$$

where $r := x/(x+2)$, see the reference.

`log1pmxC()` is an interface to R C API ('Rmathlib') function.

Value

a numeric vector (with the same attributes as `x`).

Author(s)

A translation of Morten Welinder's C code of Jan 2005, see R's bug issue [PR#7307](#), parametrized and tuned by Martin Maechler.

References

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover.
https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

Formula (4.1.29), p.68.

Martin Mächler (2021). *log1pmx, ... Computing ... Probabilities in R*. (DPQ package vignette)

See Also

`logcf`, the auxiliary function, `lgamma1p` which calls `log1pmx`, `log1p`; also `expm1x()` which computes `expm1(x) - x` accurately, whereas `log1pmx(x)` computes `log1p(x) - x` accurately

Examples

```
(doExtras <- DPQ::doExtras()) # TRUE e.g. if interactive()
n1 <- if(doExtras) 1001 else 201
curve(log1pmx, -.9999, 7, n=n1); abline(h=0, v=-1:0, lty=3)
curve(log1pmx, -.1, .1, n=n1); abline(h=0, v=0, lty=3)
curve(log1pmx, -.01, .01, n=n1) -> l1xz2; abline(h=0, v=0, lty=3)
## C and R versions correspond closely:
with(l1xz2, stopifnot(all.equal(y, log1pmxC(x), tol = 1e-15)))

e <- if(doExtras) 2^-12 else 2^-8; by.p <- 1/(if(doExtras) 256 else 64)
xd <- c(seq(-1+e, 0+100*e, by=e), seq(by.p, 5, by=by.p)) # length 676 or 5476 if do.X.
plot(xd, log1pmx(xd), type="l", col=2, main = "log1pmx(x)")
abline(h=0, v=-1:0, lty=3)

## --- Compare rexp1() with log1pmx() -----
x <- seq(-0.5, 5/8, by=1/256)
all.equal(log1pmx(x), -rlog1(x), tol = 0) # 2.838e-16 {|rel.error| <= 1.33e-15}
stopifnot(all.equal(log1pmx(x), -rlog1(x), tol = 1e-14))
## much more closely:
x <- c(-1+1e-9, -1+1/256, -(127:50)/128, (-199:295)/512, 74:196/128)
if(is.unsorted(x)) stop("x must be sorted for plots")
rlog1.x <- rlog1(x)
summary(re1D <- sfsmisc::relErrV(log1pmx(x), -rlog1.x))
n.relD <- re1D * 2^53
table(n.relD)
## 64-bit Linux F36 (gcc 12.2.1):
## -6 -5 -4 -3 -2 -1 0 2 4 6 8 10 12 14
## 2 3 13 24 79 93 259 120 48 22 14 15 5 1
stopifnot(-10 <= n.relD, n.relD <= 20) # above Lnx: [-6, 14]

if(requireNamespace("Rmpfr")) {
  re1E <- Rmpfr::asNumeric(sfsmisc::relErrV(log1pmx(Rmpfr::mpfr(x,128)), -rlog1(x)))
  plot(x, pmax(2^-54, abs(re1E)), log="y", type="l", main = "|rel.Err| of rlog1(x)")
  r11.c <- c(-.39, 0.57, -.18, .18) # the cutoffs used inside rlog1()
  lc <- "gray"
  abline(v = r11.c, col=lc, lty=2)
  axis(3, at=r11.c, col=lc, cex.axis=3/4, mgp=c(2,.5,0))
  abline(h= (1:4)*2^-53, lty=3, col = (cg <- adjustcolor(1, 1/4)))
}
```

```

axis(4, at=(1:4)*2^-53, labels=expression(frac(epsilon[c],2), epsilon[c],
                                           frac(3,2)*epsilon[c], 2*epsilon[c]),
     cex.axis = 3/4, tcl=-1/4, las = 1, mgp=c(1.5,.5,0), col=cg)
## it seems the -.18 +.18 cutoffs should be slightly moved "outside"
}

## much more graphics etc in ../tests/dnbinom-tst.R (and the vignette, see above)

```

Description

Compute a continued fraction approximation to the series (infinite sum)

$$\sum_{k=0}^{\infty} \frac{x^k}{i+k \cdot d} = \frac{1}{i} + \frac{x}{i+d} + \frac{x^2}{i+2 \cdot d} + \frac{x^3}{i+3 \cdot d} + \dots$$

Needed as auxiliary function in `log1pmx()` and `lgamma1p()`.

Usage

```

logcfR(x, i, d, eps, maxit = 10000L, trace = FALSE)
logcfR(x, i, d, eps, maxit = 10000L, trace = FALSE)
logcf(x, i, d, eps, trace = FALSE)

```

Arguments

<code>x</code>	numeric vector of values typically less than 1. "mpfr" (of potentially high precision, package Rmpfr) work in <code>logcfR*(x,*)</code> .
<code>i</code>	positive numeric
<code>d</code>	non-negative numeric
<code>eps</code>	positive number, the convergence tolerance.
<code>maxit</code>	a positive integer, the maximal number of iterations or terms in the truncated series used.
<code>trace</code>	logical (or non-negative integer in the future) indicating if (and how much) diagnostic output should be printed to the console during the computations.

Details

`logcfR.()`: a pure R version where the iterations happen vectorized in `x`, only for those components `x[i]` they have not yet converged. This is particularly beneficial for not-very-short "mpfr" vectors `x`, and still conceptually equivalent to the `logcfR()` version.

`logcfR()`: a pure R version where each `x[i]` is treated separately, hence "properly" vectorized, but slowly so.

`logcf()`: only for numeric `x`, calls into (a clone of) R's own (non-API currently) `logcf()` C Rmathlib function.

Usage

```
logspace.add(lx, ly)
logspace.sub(lx, ly)
```

Arguments

`lx, ly` numeric vectors, typically of the same [length](#), but will be recycled to common length as with other R arithmetic.

Value

a [numeric](#) vector of the same length as `x+y`.

Note

This is really from R's C source code for [pgamma\(\)](#), i.e., '`<R>/src/nmath/pgamma.c`'

The function definitions are very simple, `logspace.sub()` using [log1mexp\(\)](#).

Author(s)

Morten Welinder (for R's [pgamma\(\)](#)); Martin Maechler

See Also

[lsum](#), [lssum](#); then [pgamma\(\)](#)

Examples

```
set.seed(12)
ly <- rnorm(100, sd= 50)
lx <- ly + abs(rnorm(100, sd=100)) # lx - ly must be positive for *.sub()
stopifnot(exprs = {
  all.equal(logspace.add(lx,ly),
            log(exp(lx) + exp(ly)), tol=1e-14)
  all.equal(logspace.sub(lx,ly),
            log(exp(lx) - exp(ly)), tol=1e-14)
})
```

Description

Properly compute $\log(x_1 + \dots + x_n)$ for given log absolute values $\text{l}xabs = \log(|x_1|), \dots, \log(|x_n|)$ and corresponding signs $\text{signs} = \text{sign}(x_1), \dots, \text{sign}(x_n)$. Here, x_i is of arbitrary sign.

Notably this works in many cases where the direct sum would have summands that had overflowed to $+\text{Inf}$ or underflowed to $-\text{Inf}$.

This is a (simpler, vector-only) version of `copula:::lssum()` (CRAN package **copula**).

Note that the *precision* is often not the problem for the direct summation, as R's `sum()` internally uses "long double" precision on most platforms.

Usage

```
lssum(lxabs, signs, l.off = max(lxabs), strict = TRUE)
```

Arguments

<code>lxabs</code>	n-vector of values $\log(x_1), \dots, \log(x_n)$.
<code>signs</code>	corresponding signs $\text{sign}(x_1), \dots, \text{sign}(x_n)$.
<code>l.off</code>	the offset to subtract and re-add; ideally in the order of <code>max(.)</code> .
<code>strict</code>	logical indicating if the function should stop on some negative sums.

Value

$$\log(x_1 + \dots + x_n) == \log(\text{sum}(x)) = \log(\text{sum}(\text{sign}(x) * |x|)) == \log(\text{sum}(\text{sign}(x) * \exp(\log(|x|)))) == \log(\exp(\log(x_0)))$$
Author(s)

Marius Hofert and Martin Maechler (for package **copula**).

See Also

`lsum()` which computes an exponential sum in log scale with *out* signs.

Examples

```
rSamp <- function(n, lmean, lsd = 1/4, roundN = 16) {
  lax <- sort((1+1e-14*rnorm(n))*round(roundN*rnorm(n, m = lmean, sd = lsd))/roundN)
  sx <- rep_len(c(-1,1), n)
  list(lax=lax, sx=sx, x = sx*exp(lax))
}

set.seed(101)
L1 <- rSamp(1000, lmean = 700) # here, lssum() is not needed (no under-/overflow)
summary(as.data.frame(L1))
ax <- exp(lax <- L1$lax)
hist(lax); rug(lax)
hist(ax); rug(ax)
sx <- L1$sx
```

```

table(sx)
(lsSimple <- log(sum(L1$x)))          # 700.0373
(lsS <- lssum(lxabs = lax, signs = sx))# ditto
lsS - lsSimple # even exactly zero (in 64b Fedora 30 Linux which has nice 'long double')
stopifnot(all.equal(700.037327351478, lsS, tol=1e-14), all.equal(lsS, lsSimple))

L2 <- within(L1, { lax <- lax + 10; x <- sx*exp(lax) }) ; summary(L2$x) # some -Inf, +Inf
(lsSimpl2 <- log(sum(L2$x)))          # NaN
(lsS2 <- lssum(lxabs = L2$lax, signs = L2$sx)) # 710.0373
stopifnot(all.equal(lsS2, lsS + 10, tol = 1e-14))

```

lsum

*Properly Compute the Logarithm of a Sum (of Exponentials)***Description**

Properly compute $\log(x_1 + \dots + x_n)$. for given $\log(x_1), \dots, \log(x_n)$. Here, $x_i > 0$ for all i .

If the inputs are denoted $l_i = \log(x_i)$ for $i = 1, 2, \dots, n$, we compute $\log(\sum(\exp(l[])))$, numerically stably.

Simple vector version of `copula::lsum()` (CRAN package **copula**).

Usage

```
lsum(lx, l.off = max(lx))
```

Arguments

lx	n-vector of values $\log(x_1), \dots, \log(x_n)$.
l.off	the offset to subtract and re-add; ideally in the order of the maximum of each column.

Value

$$\log(x_1 + \dots + x_n) = \log(\text{sum}(x)) = \log(\text{sum}(\exp(\log(x)))) = \log(\exp(\log(x_m a x)) * \text{sum}(\exp(\log(x) - \log(x_m a x)))) =$$
Author(s)

Originally, via paired programming: Marius Hofert and Martin Maechler.

See Also

`lssum()` which computes a sum in log scale with specified (typically alternating) signs.

Examples

```
## The "naive" version :
lsum0 <- function(lx) log(sum(exp(lx)))

lx1 <- 10*(-80:70) # is easy
lx2 <- 600:750     # lsum0() not ok [could work with rescaling]
lx3 <- -(750:900)  # lsum0() = -Inf - not good enough
m3 <- cbind(lx1,lx2,lx3)
lx6 <- lx5 <- lx4 <- lx3
lx4[149:151] <- -Inf ## = log(0)
lx5[150] <- Inf
lx6[1] <- NA_real_
m6 <- cbind(m3,lx4,lx5,lx6)
stopifnot(exprs = {
  all.equal(lsum(lx1), lsum0(lx1))
  all.equal((ls1 <- lsum(lx1)), 700.000045400960403, tol=8e-16)
  all.equal((ls2 <- lsum(lx2)), 750.458675145387133, tol=8e-16)
  all.equal((ls3 <- lsum(lx3)), -749.541324854612867, tol=8e-16)
  ## identical: matrix-version <==> vector versions
  identical(lsum(lx4), ls3)
  identical(lsum(lx4), lsum(head(lx4, -3))) # the last three were -Inf
  identical(lsum(lx5), Inf)
  identical(lsum(lx6), lx6[1])
  identical((lm3 <- apply(m3, 2, lsum)), c(lx1=ls1, lx2=ls2, lx3=ls3))
  identical(apply(m6, 2, lsum), c(lm3, lx4=ls3, lx5=Inf, lx6=lx6[1]))
})
```

newton

Simple R level Newton Algorithm, Mostly for Didactical Reasons

Description

Given the function $G()$ and its derivative $g()$, `newton()` uses the Newton method, starting at x_0 , to find a point x_p at which G is zero. $G()$ and $g()$ may each depend on the same parameter (vector) z .

Convergence typically happens when the stepsize becomes smaller than `eps`.

`keepAll = TRUE` to also get the vectors of consecutive values of x and $G(x, z)$;

Usage

```
newton(x0, G, g, z,
       xmin = -Inf, xmax = Inf, warnRng = TRUE,
       dxMax = 1000, eps = 0.0001, maxiter = 1000L,
       warnIter = missing(maxiter) || maxiter >= 10L,
       keepAll = NA)
```

Arguments

<code>x0</code>	numeric start value.
<code>G, g</code>	must be functions , mathematically of their first argument, but they can accept parameters; <code>g()</code> must be the derivative of <code>G</code> .
<code>z</code>	parameter vector for $G()$ and $g()$, to be kept fixed.
<code>xMin, xMax</code>	numbers defining the allowed range for <code>x</code> during the iterations; e.g., useful to set to 0 and 1 during quantile search.
<code>warnRng</code>	logical specifying if a warning should be signalled when start value <code>x0</code> is outside <code>[xMin, xMax]</code> and hence will be changed to one of the boundary values.
<code>dxMax</code>	maximal step size in x -space. (The default 1000 is quite arbitrary, do set a good maximal step size yourself!)
<code>eps</code>	positive number, the <i>absolute</i> convergence tolerance.
<code>maxiter</code>	positive integer, specifying the maximal number of Newton iterations.
<code>warnIter</code>	logical specifying if a warning should be signalled when the algorithm has not converged in <code>maxiter</code> iterations.
<code>keepAll</code>	logical specifying if the full sequence of <code>x</code> - and $G(x,*)$ values should be kept and returned: NA , the default: <code>newton</code> returns a small list of final “data”, with 4 components $x = x^*$, $G = G(x^*, z)$, <code>it</code> , and <code>converged</code> . TRUE : returns an extended list , in addition containing the vectors <code>x.vec</code> and <code>G.vec</code> . FALSE : returns only the x^* value.

Details

Because of the quadratic convergence at the end of the Newton algorithm, often x^* satisfies approximately $|G(x^*, z)| < eps^2$.

`newton()` can be used to compute the quantile function of a distribution, if you have a good starting value, and provide the cumulative probability and density functions as **R** functions `G` and `g` respectively.

Value

The result always contains the final `x`-value x^* , and typically some information about convergence, depending on the value of `keepAll`, see above:

<code>x</code>	the optimal x^* value (a number).
<code>G</code>	the function value $G(x^*, z)$, typically very close to zero.
<code>it</code>	the integer number of iterations used.
<code>convergence</code>	logical indicating if the Newton algorithm converged within <code>maxiter</code> iterations.
<code>x.vec</code>	the full vector of <code>x</code> values, $\{x_0, \dots, x^*\}$.
<code>G.vec</code>	the vector of function values (typically tending to zero), i.e., $G(x.vec, .)$ (even when $G(x, .)$ would not vectorize).

Author(s)

Martin Maechler, ca. 2004

References

Newton's Method on Wikipedia, https://en.wikipedia.org/wiki/Newton%27s_method.

See Also

`uniroot()` is much more sophisticated, works without derivatives and is generally faster than `newton()`.

`newton(.)` is currently crucially used (only) in our function `qchisqN()`.

Examples

```
## The most simple non-trivial case : Computing SQRT(a)
G <- function(x, a) x^2 - a
g <- function(x, a) 2*x

newton(1, G, g, z = 4 ) # z = a -- converges immediately
newton(1, G, g, z = 400) # bad start, needs longer to converge

## More interesting, and related to non-central (chisq, e.t.) computations:
## When is  $x * \log(x) < B$ , i.e., the inverse function of  $G = x * \log(x)$  :
x1x <- function(x, B) x*log(x) - B
dx1x <- function(x, B) log(x) + 1

Nx1x <- function(B) newton(B, G=x1x, g=dx1x, z=B, maxiter=Inf)$x
N1 <- function(B) newton(B, G=x1x, g=dx1x, z=B, maxiter = 1)$x
N2 <- function(B) newton(B, G=x1x, g=dx1x, z=B, maxiter = 2)$x

Bs <- c(outer(c(1,2,5), 10^(0:4)))
plot (Bs, vapply(Bs, Nx1x, pi), type = "l", log = "xy")
lines(Bs, vapply(Bs, N1 , pi), col = 2, lwd = 2, lty = 2)
lines(Bs, vapply(Bs, N2 , pi), col = 3, lwd = 3, lty = 3)

BL <- c(outer(c(1,2,5), 10^(0:6)))
plot (BL, vapply(BL, Nx1x, pi), type = "l", log = "xy")
lines(BL, BL, col="green2", lty=3)
lines(BL, vapply(BL, N1 , pi), col = 2, lwd = 2, lty = 2)
lines(BL, vapply(BL, N2 , pi), col = 3, lwd = 3, lty = 3)
## Better starting value from an approximate 1 step Newton:
iL1 <- function(B) 2*B / (log(B) + 1)
lines(BL, iL1(BL), lty=4, col="gray20") ## really better ==> use it as start

Nx1x <- function(B) newton(iL1(B), G=x1x, g=dx1x, z=B, maxiter=Inf)$x
N1 <- function(B) newton(iL1(B), G=x1x, g=dx1x, z=B, maxiter = 1)$x
N2 <- function(B) newton(iL1(B), G=x1x, g=dx1x, z=B, maxiter = 2)$x

plot (BL, vapply(BL, Nx1x, pi), type = "o", log = "xy")
lines(BL, iL1(BL), lty=4, col="gray20")
```

```

lines(BL, vapply(BL, N1 , pi), type = "o", col = 2, lwd = 2, lty = 2)
lines(BL, vapply(BL, N2 , pi), type = "o", col = 3, lwd = 2, lty = 3)
## Manual 2-step Newton
iL2 <- function(B) { lB <- log(B) ; B*(lB+1) / (lB * (lB - log(lB) + 1)) }
lines(BL, iL2(BL), col = adjustcolor("sky blue", 0.6), lwd=6)
##=> iL2() is very close to true curve
## relative error:
iLtrue <- vapply(BL, N1x, pi)
cbind(BL, iLtrue, iL2=iL2(BL), relErL2 = 1-iL2(BL)/iLtrue)
## absolute error (in log-log scale; always positive!):
plot(BL, iL2(BL) - iLtrue, type = "o", log="xy", axes=FALSE)
if(requireNamespace("sfsmisc")) {
  sfsmisc::eaxis(1)
  sfsmisc::eaxis(2, sub10=2)
} else {
  cat("no 'sfsmisc' package; maybe install.packages(\"sfsmisc\") ?\n")
  axis(1); axis(2)
}
## 1 step from iL2() seems quite good:
B. <- BL[-1] # starts at 2
NL2 <- lapply(B., function(B) newton(iL2(B), G=x1x, g=dx1x, z=B, maxiter=1))
str(NL2)
iL3 <- sapply(NL2, `[`, "x")
cbind(B., iLtrue[-1], iL2=iL2(B.), iL3, relE.3 = 1- iL3/iLtrue[-1])
x. <- iL2(B.)
all.equal(iL3, x. - x1x(x., B.) / dx1x(x.)) ## 7.471802e-8
## Algebraic simplification of one newton step :
all.equal((x.+B.)/(log(x.)+1), x. - x1x(x., B.) / dx1x(x.), tol = 4e-16)
iN1 <- function(x, B) (x+B) / (log(x) + 1)
B <- 12345
iN1(iN1(iN1(B, B),B),B)
N1x(B)

```

Description

The **DPQ** package provides some numeric constants used in some of its distribution computations.

`all_mpfr()` and `any_mpfr()` return **TRUE** iff all (or ‘any’, respectively) of their arguments inherit from **class** “mpfr” (from package **Rmpfr**).

`logr(x, a)` computes $\log(x / (x + a))$ in a numerically stable way.

`modf(x)` splits each `x` into integer part (as `trunc(x)`) and fractional (remainder) part in $(-1, 1)$ and corresponds to the R version of the C99 (and POSIX) standard C (and C++) mathlib functions of the same name.

Usage

```
## Numeric Constants : % mostly in ../R/beta-fns.R
M_LN2      # = log(2) = 0.693....
M_SQRT2    # = sqrt(2) = 1.4142...
M_cutoff   # := If |x| > |k| * M_cutoff, then log[ exp(-x) * k^x ] =~= -x
           # = 3196577161300663808 =~= 3.2e+18
M_minExp   # = log(2) * .Machine$double.min.exp # =~= -708.396..
G_half     # = sqrt(pi) = Gamma( 1/2 )

## Functions :
all_mpfr(...)
any_mpfr(...)
logr(x, a)  # == log(x / (x + a)) -- but numerically smart; x >= 0, a > -x
modf(x)
okLongDouble(lambda = 999, verbose = 0L, tol = 1e-15)
```

Arguments

...	numeric or "mpfr" numeric vectors.
x, a	number-like, not negative, now may be vectors of length(.) > 1.
lambda	a number, typically in the order of 500–10'000.
verbose	a non-negative integer, if not zero, okLongDouble() prints the intermediate long double computations' results.
tol	numerical tolerance used to determine the accuracy required for near equality in okLongDouble().

Details

all_mpfr(),

all_mpfr() : test if **all** or **any** of their arguments or of class "mpfr" (from package **Rmpfr**). The arguments are evaluated only until the result is determined, see the example.

logr() computes $\log(x/(x+a))$ in a numerically stable way.

Value

The numeric constant in the first case; a numeric (or "mpfr") vector of appropriate size in the 2nd case.

okLongDouble() returns a **logical**, **TRUE** iff the long double arithmetic with `expl()` and `logl()` seems to work accurately and consistently for `exp(-lambda)` and `log(lambda)`.

Author(s)

Martin Maechler

See Also

[.Machine](#)

Examples

```
(Ms <- ls("package:DPQ", pattern = "^M"))
lapply(Ms, function(nm) { cat(nm,": "); print(get(nm)) }) -> .tmp

logr(1:3, a=1e-10)

okLongDouble(verbose=TRUE) # verbose: show (C-level) computations
## typically TRUE, but not e.g. in a valgrinded R-devel of Oct.2019
## Here is typically the "boundary":
rr <- try(uniroot(function(x) okLongDouble(x) - 1/2,
                 c(11350, 11400), tol=1e-7, extendInt = "yes"))
str(rr, digits=9) ## seems somewhat platform dependent: now see
## $ root      : num 11376.563
## $ estim.prec: num 9.313e-08
## $ iter      : int 29

set.seed(2021); x <- runif(100, -7,7)
mx <- modf(x)
with(mx, head( cbind(x, i=mx$i, fr=mx$fr) )) # showing the first cases
with(mx, stopifnot( x == fr + i,
                   i == trunc(x),
                   sign(fr) == sign(x)))
```

p111

Numerically Stable $p111(t) = (t+1)\log(1+t) - t$*

Description

The binomial deviance function `bd0(x,M)` can mathematically be re-written as $bd0(x, M) = M * p111((x - M)/M)$ where we look into providing numerically stable formula for $p111(t)$ as its mathematical formula $p111(t) = (t + 1) \log(1 + t) - t$ suffers from cancellation for small $|t|$, even when `log1p(t)` is used instead of $\log(1+t)$.

Using a hybrid implementation, `p111()` uses a direct formula, now the stable one in `p111p()`, for $|t| > c$ and a series approximation for $|t| \leq c$ for some c .

NB: The re-expression `log1pmx()` is almost perfect; it fixes the cancellation problem entirely (and exposes the fact that `log1pmx()`'s internal cutoff seems sub optimal.

Usage

```
p111p (t, ...)
p111. (t)
p111 (t, F = t^2/2)
p111ser(t, k, F = t^2/2)
.p111ser(t, k, F = t^2/2)
```

Arguments

t	numeric a-like vector ("mpfr" included), larger (or equal) to -1.
...	optional (tuning) arguments, passed to <code>log1pmx()</code> .
k	small positive integer, the number of terms to use in the Taylor series approximation <code>p111ser(t, k)</code> of <code>p111(t)</code> .
F	numeric vector of multiplication factor; <i>must</i> be $t^2/2$ for the <code>p111()</code> function, but can be modified, e.g. in more direct <code>bd0()</code> computations.

Details

for now see in `bd0()`.

Value

numeric vector "as" t.

Author(s)

Martin Maechler

See Also

`bd0`; our package vignette *log1pmx, bd0, stirlerr - Probability Computations in R*. `dbinom` the latter for the C.Loader(2000) reference.

Examples

```
t <- seq(-1, 4, by=1/64)
plot(t, p111ser(t, 1), type="l")
lines(t, p111.(t), lwd=5, col=adjustcolor(1, 1/2)) # direct formula
for(k in 2:6) lines(t, p111ser(t, k), col=k)

## zoom in
t <- 2^seq(-59,-1, by=1/4)
t <- c(-rev(t), 0, t)
stopifnot(!is.unsorted(t))
k.s <- 1:12; names(k.s) <- paste0("k=", 1:12)

## True function values: use Rmpfr with 256 bits precision: ---
### eventually move this to ../tests/ & ../vignettes/log1pmx-etc.Rnw
#### FIXME: eventually replace with if(requireNamespace("Rmpfr")){ .....}
#### =====
if((needRmpfr <- is.na(match("Rmpfr", (srch0 <- search())))))
  require("Rmpfr")
p111.T <- p111.(mpfr(t, 256)) # "true" values
p111.n <- asNumeric(p111.T)
all.equal(sapply(k.s, function(k) p111ser(t,k)) -> m.p111,
          sapply(k.s, function(k) .p111ser(t,k)) -> m.p11., tolerance = 0)
p1tab <-
  cbind(b1 = bd0(t+1, 1),
```

```

        b.10 = bd0(10*t+10,10)/10,
        direct = p111.(t),
        p111p = p111p(t),
        p111 = p111 (t),
        sapply(k.s, function(k) p111ser(t,k)))
matplot(t, p1tab, type="l", ylab = "p111*(t)")
## (absolute) error:
##' legend for matplot()
mpLeg <- function(leg = colnames(p1tab), xy = "top", col=1:6, lty=1:5, lwd=1,
                  pch = c(1L:9L, 0L, letters, LETTERS)[seq_along(leg)], ...)
  legend(xy, legend=leg, col=col, lty=lty, lwd=lwd, pch=pch, ncol=3, ...)

titAbs <- "Absolute errors of p111(t) approximations"
matplot(t, asNumeric(p1tab - p111.T), type="o", main=titAbs); mpLeg()
i <- abs(t) <= 1/10 ## zoom in a bit
matplot(t[i], abs(asNumeric((p1tab - p111.T)[i,])), type="o", log="y",
        main=titAbs, ylim = c(1e-18, 0.003)); mpLeg()
## Relative Error
titR <- "|Relative error| of p111(t) approximations"
matplot(t[i], abs(asNumeric((p1tab/p111.T - 1)[i,])), type="o", log="y",
        ylim = c(1e-18, 2^-10), main=titR)
mpLeg(xy="topright", bg= adjustcolor("gray80", 4/5))
i <- abs(t) <= 2^-10 # zoom in more
matplot(t[i], abs(asNumeric((p1tab/p111.T - 1)[i,])), type="o", log="y",
        ylim = c(1e-18, 1e-9))
mpLeg(xy="topright", bg= adjustcolor("gray80", 4/5))

## Correct number of digits
corDig <- asNumeric(-log10(abs(p1tab/p111.T - 1)))
cbind(t, round(corDig, 1))# correct number of digits

matplot(t, corDig, type="o", ylim = c(1,17))
(cN <- colnames(corDig))
legend(-.5, 14, cN, col=1:6, lty=1:5, pch = c(1L:9L, 0L, letters), ncol=2)

## plot() function >>>> using global (t, corDig) <<<<<<<<<<
p.relEr <- function(i, ylim = c(11,17), type = "o",
                   leg.pos = "left", inset=1/128,
                   main = sprintf(
                     "Correct #{Digits} in p111() approx., notably Taylor(k=1 .. %d)",
                     max(k.s)))
{
  if((neg <- all(t[i] < 0)))
    t <- -t
  stopifnot(all(t[i] > 0), length(ylim) == 2) # as we use log="x"
  matplot(t[i], corDig[i,], type=type, ylim=ylim, log="x", xlab = quote(t), xaxt="n",
          main=main)
  legend(leg.pos, cN, col=1:6, lty=1:5, pch = c(1L:9L, 0L, letters), ncol=2,
        bg=adjustcolor("gray90", 7/8), inset=inset)
  t.epsC <- -log10(c(1,2,4)* .Machine$double.eps)
  axis(2, at=t.epsC, labels = expression(epsilon[C], 2*epsilon[C], 4*epsilon[C]),
       las=2, col=2, line=1)
}

```

```

tenRs <- function(t) floor(log10(min(t))) : ceiling(log10(max(t)))
tenE <- tenRs(t[i])
tE <- 10^tenE
abline (h = t.epsC,
        v = tE, lty=3, col=adjustcolor("gray",.8), lwd=2)
AX <- if(requireNamespace("sfsmisc")) sfsmisc::eaxis else axis
AX(1, at= tE, labels = as.expression(
    lapply(tenE,
           if(neg)
             function(e) substitute(-10^{E}, list(E = e+0))
           else
             function(e) substitute( 10^{E}, list(E = e+0))))))
}

p.relEr(t > 0, ylim = c(1,17))
p.relEr(t > 0) # full positive range
p.relEr(t < 0) # full negative range
if(FALSE) {## (actually less informative):
  p.relEr(i = 0 < t & t < .01) ## positive small t
  p.relEr(i = -.1 < t & t < 0) ## negative small t
}

## Find approximate formulas for accuracy of k=k* approximation
d.corrD <- cbind(t=t, as.data.frame(corDig))
names(d.corrD) <- sub("k=", "nC_", names(d.corrD))

fmod <- function(k, data, cut.y.at = -log10(2 * .Machine$double.eps),
                good.y = -log10(.Machine$double.eps), # ~ 15.654
                verbose=FALSE) {
  varNm <- paste0("nC_",k)
  stopifnot(is.numeric(y <- get(varNm, data, inherits=FALSE)),
            is.numeric(t <- data$t))# '$' works for data.frame, list, environment
  i <- 3 <= y & y <= cut.y.at
  i.pos <- i & t > 0
  i.neg <- i & t < 0
  if(verbose) cat(sprintf("k=%d >> y <= %g ==> #{pos. t} = %d ; #{neg. t} = %d\n",
                        k, cut.y.at, sum(i.pos), sum(i.neg)))
  nCoefLm <- function(x,y) `names<-`(.lm.fit(x=x, y=y)$coeff, c("int", "slp"))
  nC.t <- function(x,y) { cf <- nCoefLm(x,y); c(cf, t.0 = exp((good.y - cf[[1]])/cf[[2]])) }
  cbind(pos = nC.t(cbind(1, log( t[i.pos])), y[i.pos]),
         neg = nC.t(cbind(1, log(-t[i.neg])), y[i.neg]))
}

rr <- sapply(k.s, fmod, data=d.corrD, verbose=TRUE, simplify="array")
stopifnot(rr["slp",,] < 0) # all slopes are negative (important!)
matplot(k.s, t(rr["slp",,]), type="o", xlab = quote(k), ylab = quote(slope[k]))
## fantastically close to linear in k
## The numbers, nicely arranged
ftable(aperm(rr, c(3,2,1)))
signif(t(rr["t.0",,]),3) # ==> Should be boundaries for the hybrid p111()
##      pos      neg
## k=1  6.60e-16 6.69e-16
## k=2  3.65e-08 3.65e-08
## k=3  1.30e-05 1.32e-05

```

```

## k=4 2.39e-04 2.42e-04
## k=5 1.35e-03 1.38e-03
## k=6 4.27e-03 4.34e-03
## k=7 9.60e-03 9.78e-03
## k=8 1.78e-02 1.80e-02
## k=9 2.85e-02 2.85e-02
## k=10 4.13e-02 4.14e-02
## k=11 5.62e-02 5.64e-02
## k=12 7.24e-02 7.18e-02

###----- Well, p11p() is really basically good enough ... with a small exception:
rErr1k <- curve(asNumeric(p11p(x) / p11.(mpfr(x, 4096)) - 1), -.999, .999,
               n = 4000, col=2, lwd=2)
abline(h = c(-8,-4,-2:2,4,8)* 2^-52, lty=2, col=adjustcolor("gray20", 1/4))
## well, have a "spike" at around -0.8 -- why?

plot(abs(y) ~ x, data = rErr1k, ylim = c(4e-17, max(abs(y))),
     ylab = expression(abs(hat(p)/p - 1)),
     main = "p11p(x) -- Relative Error wrt mpfr(*. 4096) [log]",
     col=2, lwd=1.5, type = "b", cex=1/2, log="y", yaxt="n")
sfsmisc::eaxis(2)
eps124 <- c(1, 2,4,8)* 2^-52
abline(h = eps124, lwd=c(3,1,1,1), lty=c(1,2,2,2), col=adjustcolor("gray20", 1/4))
axLab <- expression(epsilon[c], 2*epsilon[c], 4*epsilon[c], 8*epsilon[c])
axis(4, at = eps124, labels = axLab, col="gray20", las=1)
abline(v = -.791, lty=3, lwd=2, col="blue4") # -.789 from visual ..
##--> The "error" is in log1pmx() which has cutoff minLog1Value = -0.79149064
##--> which is clearly not optimal, at least not for computing p11p()

d <- 1/2048; x <- seq(-1+d, 1, by=d)
p11Xct <- p11.(mpfr(x, 4096))
rEx.5 <- asNumeric(p11p(x, minL1 = -0.5) / p11Xct - 1)
lines(x, abs(rEx.5), lwd=2.5, col=adjustcolor(4, 1/2)); abline(v=-.5, lty=2,col=4)
rEx.25 <- asNumeric(p11p(x, minL1 = -0.25) / p11Xct - 1)
lines(x, abs(rEx.25), lwd=3.5, col=adjustcolor(6, 1/2)); abline(v=-.25, lty=2,col=6)
lines(lowess(x, abs(rEx.5), f=1/20), col=adjustcolor(4,offset=rep(1,4)/3), lwd=3)

lines(lowess(x, abs(rEx.25), f=1/20), col=adjustcolor(6,offset=rep(1,4)/3), lwd=
3)

rEx.4 <- asNumeric(p11p(x, tol_logcf=1e-15, minL1 = -0.4) / p11Xct - 1)
lines(x, abs(rEx.4), lwd=5.5, col=adjustcolor("brown", 1/2)); abline(v=-.25, lty=2,col="brown")

if(needRmpfr && isNamespaceLoaded("Rmpfr"))
  detach("package:Rmpfr")

```

Description

pbetaRv1() is an implementation of the original (“version 1” `pbeta()` function in R (versions \leq 2.2.x), before we started using TOMS 708 `bratio()` instead, see the current `pbeta` help page also for references.

pbetaRv1() is basically a manual translation from C to R of the underlying `pbeta_raw()` C function, see in R’s source tree at <https://svn.r-project.org/R/branches/R-2-2-patches/src/nmath/pbeta.c>

For consistency within R, we are using R’s argument names (`q`, `shape1`, `shape2`) instead of C code’s (`x`, `pin`, `qin`).

It is only for the *central* beta distribution.

Usage

```
pbetaRv1(q, shape1, shape2, lower.tail = TRUE,
         eps = 0.5 * .Machine$double.eps,
         sm1 = .Machine$double.xmin,
         verbose = 0)
```

Arguments

<code>q</code> , <code>shape1</code> , <code>shape2</code>	non-negative numbers, <code>q</code> in $[0, 1]$, see <code>pbeta</code> .
<code>lower.tail</code>	indicating if $F(q; *)$ should be returned or the upper tail probability $1 - F(q)$.
<code>eps</code>	the tolerance used to determine congerence. <code>eps</code> has been hard coded in C code to $0.5 * .Machine$double.eps$ which is equal to 2^{-53} or $1.110223e-16$.
<code>sm1</code>	the smallest positive number on the typical platform. The default <code>.Machine\$double.xmin</code> is hard coded in the C code (as <code>DBL_MIN</code>), and this is equal to 2^{-1022} or $2.225074e-308$ on all current platforms.
<code>verbose</code>	integer indicating the amount of verbosity of diagnostic output, 0 means no output, 1 more, etc.

Value

a number.

Note

The C code contains
This routine is a translation into C of a Fortran subroutine by W. Fullerton of Los Alamos Scientific Laboratory.

Author(s)

Martin Maechler

References

(From the C code:)

Nancy E. Bosten and E.L. Battiste (1974). Remark on Algorithm 179 (S14): Incomplete Beta Ratio. *Communications of the ACM*, **17**(3), 156–7.

See Also

[pbeta](#).

Examples

```
all.equal(pbetaRv1(1/4, 2, 3),
          pbeta (1/4, 2, 3))
set.seed(101)

N <- 1000
x <- sample.int(7, N, replace=TRUE) / 8
a <- rlnorm(N)
b <- 5*rlnorm(N)
pbt <- pbeta(x, a, b)
for(i in 1:N) {
  stopifnot(all.equal(pbetaRv1(x[i], a[i], b[i]), pbt[i]))
  cat(".", if(i %% 20 == 0) paste0(i, "\n"))
}
```

phyperAllBin

Compute Hypergeometric Probabilities via Binomial Approximations

Description

Simple utilities for ease of comparison of the different [phyper](#) approximation in package **DPQ**:

- `phyperAllBinM()` computes all four Molenaar binomial approximations to the hypergeometric cumulative distribution function `phyper()`.
- `phyperAllBin()` computes Molenaar's four and additionally the other four `phyperBin.1()`, `*.2`, `*.3`, and `*.4`.
- `.suppHyper()`, *support* of the Hyperbolic, is a simple 1-liner, providing all sensible integer values for the first argument `q` (or also `x`) of the hyperbolic probability functions (`dhyper()` and `phyper()`), and their approximations (here in **DPQ**).

Usage

```
phyperAllBin(m, n, k, q = .suppHyper(m, n, k), lower.tail = TRUE, log.p = FALSE)
phyperAllBinM(m, n, k, q = .suppHyper(m, n, k), lower.tail = TRUE, log.p = FALSE)
.suppHyper(m, n, k)
```

Arguments

m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.
q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls. The default, <code>.suppHyper(m, n, k)</code> provides the full (finite) support.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
log.p	logical; if TRUE, probabilities p are given as $\log(p)$.

Value

the `phyperAllBin*`(`)` functions return a numeric *matrix*, with each column a different approximation to `phyper(m, n, k, q, lower.tail, log.p)`.

Note that the columns of `phyperAllBinM()` are a *subset* of those from `phyperAllBin()`.

Author(s)

Martin Maechler

References

See those in [phyperBinMolenaar](#).

See Also

[phyperBin.1](#) etc, and [phyperBinMolenaar](#).
[phyper](#)

Examples

```
.suppHyper # very simple:
stopifnot(identical(.suppHyper, ignore.environment = TRUE,
  function (m, n, k) max(0, k-n):min(k, m)))

phBall <- phyperAllBin (5,15, 7)
phBallM <- phyperAllBinM(5,15, 7)
stopifnot(identical( ## indeed, ph...AllBinM() gives a *subset* of ph...AllBin():
  phBall[, colnames(phBallM)] ,
  phBallM
  , .suppHyper(5, 15, 7) == 0:5
)

round(phBall, 4)
cbind(q = 0:5, round(-log10(abs(1 - phBall / phyper(0:5, 5,15,7))), digits=2))

require(sfsmisc)## --> relErrV() {and eaxis()}:
qq <- .suppHyper(20, 47, 31)
```

```
phA <- phyperAllBin(20, 47, 31)
rE <- relErrV(target = phyper(qq, 20,47,31), phA)
signif(cbind(qq, rE), 4)
## Relative approximation error [ log scaled ] :
matplot(qq, abs(rE), type="b", log="y", yaxt="n")
eaxis(2)
## ---> approximations useful only "on the right", aka the right tail
```

phyperApprAS152 *Normal Approximation to cumulative Hyperbolic Distribution – AS 152*

Description

Compute the normal approximation (via `pnorm(.)`) from AS 152 to the cumulative hyperbolic distribution function `phyper()`.

Usage

```
phyperApprAS152(q, m, n, k)
```

Arguments

q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.

Value

a `numeric` vector of the same length (etc) as q.

Note

I have Fortran (and C code translated from Fortran) which says

```
ALGORITHM AS R77 APPL. STATIST. (1989), VOL.38, NO.1
Replaces AS 59 and AS 152
Incorporates AS R86 from vol.40(2)
```

Author(s)

Martin Maechler, 19 Apr 1999

References

- Lund, Richard E. (1980) Algorithm AS 152: Cumulative Hypergeometric Probabilities. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, **29**(2), 221–223. doi:10.2307/2986315
- Shea, B. (1989) Remark AS R77: A Remark on Algorithm AS 152: Cumulative Hypergeometric Probabilities. *JRSS C (Applied Statistics)*, **38**(1), 199–204. doi:10.2307/2347696
- Berger, R. (1991) Algorithm AS R86: A Remark on Algorithm AS 152: Cumulative Hypergeometric Probabilities. *JRSS C (Applied Statistics)*, **40**(2), 374–375. doi:10.2307/2347606

See Also

[phyper](#)

Examples

```
##---- Should be DIRECTLY executable !! ----
##-- ==> Define data, use random,
##--or do help(data=index) for the standard data sets.

## The function is currently defined as
function (q, m, n, k)
{
  kk <- n
  nn <- m
  mm <- m + n
  ll <- q
  mean <- kk * nn/mm
  sig <- sqrt(mean * (mm - nn)/mm * (mm - kk)/(mm - 1))
  pnorm(ll + 1/2, mean = mean, sd = sig)
}
```

phyperBin

HyperGeometric Distribution via Approximate Binomial Distribution

Description

Compute hypergeometric cumulative probabilities via (good) binomial distribution approximations. The arguments of these functions are *exactly* those of R's own [phyper\(\)](#).

Usage

```
phyperBin.1(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
phyperBin.2(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
phyperBin.3(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
phyperBin.4(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
```

Arguments

q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
log.p	logical; if TRUE, probabilities p are given as $\log(p)$.

Details

TODO

Value

a `numeric` vector, with the length the maximum of the lengths of q, m, n, k.

Author(s)

Martin Maechler

See Also

[phyper](#), [pbinom](#)

Examples

```
## The 1st function is
function (q, m, n, k, lower.tail = TRUE, log.p = FALSE)
  pbinom(q, size = k, prob = m/(m + n), lower.tail = lower.tail,
        log.p = log.p)
```

phyperBinMolenaar	<i>HyperGeometric Distribution via Molenaar's Binomial Approximation</i>
-------------------	--

Description

Compute hypergeometric cumulative probabilities via Molenaar's binomial approximations. The arguments of these functions are *exactly* those of R's own [phyper\(\)](#).

Usage

```
phyperBinMolenaar.1(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
phyperBinMolenaar.2(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
phyperBinMolenaar.3(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
phyperBinMolenaar.4(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
```

```
phyperBinMolenaar (q, m, n, k, lower.tail = TRUE, log.p = FALSE) # Deprecated !
```

Arguments

q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
log.p	logical; if TRUE, probabilities p are given as $\log(p)$.

Details

Molenaar(1970), as cited in Johnson et al (1992), proposed `phyperBinMolenaar.1()`; the other three are just using the mathematical symmetries of the hyperbolic distribution, swapping k and m , and using `lower.tail = TRUE` or `FALSE`.

Value

a `numeric` vector, with the length the maximum of the lengths of `q`, `m`, `n`, `k`.

Author(s)

Martin Maechler

References

- Johnson, N.L., Kotz, S. and Kemp, A.W. (1992) *Univariate Discrete Distributions*, 2nd ed.; Wiley, doi:10.1002/bimj.4710360207.
Chapter 6, mostly Section 5 *Approximations and Bounds*, p.256 ff
- Johnson, N.L., Kotz, S. and Kemp, A.W. (2005) *Univariate Discrete Distributions*, 3rd ed.; Wiley; doi:10.1002/0471715816.
Chapter 6, Section 6.5 *Approximations and Bounds*, p.268 ff

See Also

`phyper`, the hypergeometric distribution, and R's own "exact" computation. `pbinom`, the binomial distribution functions.

Our utility `phyperAllBin()`.

Examples

```
## The first function is simply
function(q, m, n, k, lower.tail = TRUE, log.p = FALSE)
  pbinom(q, size = k, prob = hyper2binomP(q, m, n, k), lower.tail = lower.tail,
        log.p = log.p)
```

phyperIbeta	<i>Pearson's incomplete Beta Approximation to the Hyperbolic Distribution</i>
-------------	---

Description

Pearson's incomplete Beta function approximation to the cumulative hyperbolic distribution function [phyper\(.\)](#).

Note that in R, [pbeta\(\)](#) provides a version of the incomplete Beta function.

Usage

```
phyperIbeta(q, m, n, k)
```

Arguments

q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.

Value

a numeric vector "like" q with values approximately equal to [phyper\(q, m, n, k\)](#).

Author(s)

Martin Maechler

References

Johnson, Kotz & Kemp (1992): (6.90), p.260 → Bol'shev (1964)

See Also

[phyper](#).

Examples

```
## The function is currently defined as
function (q, m, n, k)
{
  Np <- m
  N <- n + m
  n <- k
  x <- q
  p <- Np/N
}
```

```

np <- n * p
xi <- (n + Np - 1 - 2 * np)/(N - 2)
d.c <- (N - n) * (1 - p) + np - 1
cc <- n * (n - 1) * p * (Np - 1)/((N - 1) * d.c)
lam <- (N - 2)^2 * np * (N - n) * (1 - p)/((N - 1) * d.c *
      (n + Np - 1 - 2 * np))
pbeta(1 - xi, lam - x + cc, x - cc + 1)
}

```

phyperMolenaar

Molenaar's Normal Approximations to the Hypergeometric Distribution

Description

Compute Molenaar's two normal approximations to the (cumulative hypergeometric distribution [phyper\(\)](#)).

Usage

```

phyper1molenaar(q, m, n, k)
phyper2molenaar(q, m, n, k)

```

Arguments

q	(vector of) the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence in $0, 1, \dots, m + n$.

Details

Both approximations are from page 261 of Johnson, Kotz & Kemp (1992). `phyper1molenaar` is formula (6.91), and `phyper2molenaar` is formula (6.92).

Value

a `numeric` vector, with the length the maximum of the lengths of `q`, `m`, `n`, `k`.

Author(s)

Martin Maechler

References

Johnson, Kotz & Kemp (1992): p.261

See Also

[phyper](#), [pnorm](#).

Examples

```
## TODO -- maybe see ../tests/hyper-dist-ex.R
```

phyperPeizer

Peizer's Normal Approximation to the Cumulative Hyperbolic

Description

Compute Peizer's extremely good normal approximation to the cumulative hyperbolic distribution. This implementation corrects a typo in the reference.

Usage

```
phyperPeizer(q, m, n, k)
```

Arguments

q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.

Value

a [numeric](#) vector, with the length the maximum of the lengths of q, m, n, k.

Author(s)

Martin Maechler

References

Johnson, Kotz & Kemp (1992): (6.93) & (6.94), p.261 *CORRECTED* by M.M.

See Also

[phyper](#).

Examples

```
## The function is defined as

phyperPeizer <- function(q, m, n, k)
{
  ## Purpose: Peizer's extremely good Normal Approx. to cumulative Hyperbolic
  ## Johnson, Kotz & Kemp (1992): (6.93) & (6.94), p.261 __CORRECTED__
  ## -----
  Np <- m; N <- n + m; n <- k; x <- q
  ## (6.94) -- in proper order!
  nn <- Np ; n. <- Np + 1/6
  mm <- N - Np ; m. <- N - Np + 1/6
  r <- n ; r. <- n + 1/6
  s <- N - n ; s. <- N - n + 1/6
  N. <- N - 1/6
  A <- x + 1/2 ; A. <- x + 2/3
  B <- Np - x - 1/2 ; B. <- Np - x - 1/3
  C <- n - x - 1/2 ; C. <- n - x - 1/3
  D <- N - Np - n + x + 1/2 ; D. <- N - Np - n + x + 2/3

  n <- nn
  m <- mm
  ## After (6.93):
  L <-
  A * log((A*N)/(n*r)) +
  B * log((B*N)/(n*s)) +
  C * log((C*N)/(m*r)) +
  D * log((D*N)/(m*s))
  ## (6.93) :
  pnorm((A.*D. - B.*C.) / abs(A*D - B*C) *
        sqrt(2*L* (m* n* r* s* N.) /
              (m.*n.*r.*s.*N )))
  # The book wrongly has an extra "2*" before `m* ' (after "2*L* (" ) above
}
```

phyperR

R-only version of R's original phyper() algorithm

Description

An R version of the first phyper() algorithm in R, which was used up to svn rev 30227 on 2004-07-09.

Usage

```
phyperR(q, m, n, k, lower.tail=TRUE, log.p=FALSE)
```

Arguments

q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
log.p	logical; if TRUE, probabilities p are given as $\log(p)$.

Value

a numeric vector similar to `phyper(q, m, n, k)`.

Note

The original argument list in C was (x, NR, NB, n) where there were *red* and *black* balls in the urn. Note that we have *vectorized* a translation to R of the original C code.

Author(s)

Martin Maechler

See Also

[phyper](#) and our [phyperR2\(\)](#) for the pure R version of the newer (Welinder) `phyper()` algorithm

Examples

```
m <- 9:12; n <- 7:10; k <- 10
x <- 0:(k+1) # length 12
## confirmation that recycling + lower.tail, log.p now work:
for(lg in c(FALSE,TRUE))
  for(lt in c(FALSE, TRUE)) {
    cat("(lower.tail = ", lt, " -- log = ", lg, "):\n", sep="")
    withAutoprint({
      (rr <-
        cbind(x, m, n, k, # recycling (to 12 rows)
              ph = phyper(x, m, n, k, lower.tail=lt, log.p=lg),
              phR = phyperR(x, m, n, k, lower.tail=lt, log.p=lg)))
      all.equal(rr[,"ph"], rr[,"phR"], tol = 0)
      ## saw 4.706e-15 1.742e-15 7.002e-12 1.086e-15 [x86_64 Lnx]
      stopifnot(all.equal(rr[,"ph"], rr[,"phR"],
                          tol = if(lg && !lt) 2e-11 else 2e-14))
    })
  }
}
```

 phyperR2

Pure R version of R's C level phyper()

Description

Use pure R functions to compute (less efficiently and usually even less accurately) hypergeometric (point) probabilities with the same "Welinder"-algorithm as R's C level code has been doing since 2004.

Apart from boundary cases, each phyperR2() call uses one corresponding pdhyper() call.

Usage

```
phyperR2(q, m, n, k, lower.tail = TRUE, log.p = FALSE, ...)
pdhyper (q, m, n, k,                log.p = FALSE,
        epsC = .Machine$double.eps, verbose = getOption("verbose"))
```

Arguments

q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls.
m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
log.p	logical; if TRUE, probabilities p are given as $\log(p)$.
...	further arguments, passed to pdhyper().
epsC	a non-negative number, the computer epsilon to be used; effectively a relative convergence tolerance for the while() loop in pdhyper().
verbose	logical indicating if the pdhyper() calls, typically one per phyperR2() call, should show how many terms have been computed and summed up.

Value

a number (as q).

pdhyper(q, m, n, k) computes the ratio $\text{phyper}(q, m, n, k) / \text{dhyper}(q, m, n, k)$ but without computing numerator or denominator explicitly.

phyperR2() (in the non-boundary cases) then just computes the product $\text{dhyper}(\dots) * \text{pdhyper}(\dots)$, of course "modulo" lower.tail and log.p transformations.

Consequently, it typically returns values very close to the corresponding R phyper(q, m, n, k, ...) call.

Note

For now, all arguments of these functions must be of length **one**.

Author(s)

Martin Maechler, based on R's C code originally provided by Morton Welinder from the Gnumeric project, who thanks Ian Smith for ideas.

References

Morten Welinder (2004) phyper accuracy and efficiency; R bug report [PR#6772](https://bugs.r-project.org/show_bug.cgi?id=6772); https://bugs.r-project.org/show_bug.cgi?id=6772

See Also

[phyper](#)

Examples

```
## same example as phyper()
m <- 10; n <- 7; k <- 8
vapply(0:9, phyperR2, 0.1, m=m, n=n, k=k) == phyper(0:9, m,n,k)
## *all* TRUE (for 64b FC30)

## 'verbose=TRUE' to see the number of terms used:
vapply(0:9, phyperR2, 0.1, m=m, n=n, k=k, verbose=TRUE)

## Larger arguments:
k <- 100 ; x <- .suppHyper(k,k,k)
ph <- phyper (x, k,k,k)
ph1 <- phyperR(x, k,k,k) # ~ old R version
ph2 <- vapply(x, phyperR2, 0.1, m=k, n=k, k=k)
cbind(x, ph, ph1, ph2, rE1 = 1-ph1/ph, rE = 1-ph2/ph)
stopifnot(abs(1 -ph2/ph) < 8e-16) # 64bit FC30: see -2.22e-16 <= rE <= 3.33e-16

## Morten Welinder's example:
(p1R <- phyperR (59, 150, 150, 60, lower.tail=FALSE))
## gave 6.372680161e-14 in "old R";, here -1.04361e-14 (worse!!)
(p1x <- dhyper ( 0, 150, 150, 60))# is 5.111204798e-22.
(p1N <- phyperR2(59, 150, 150, 60, lower.tail=FALSE)) # .. "perfect"
(p1. <- phyper (59, 150, 150, 60, lower.tail=FALSE))# R's own
all.equal(p1x, p1N, tol=0) # on Lnx even perfectly
all.equal(p1x, p1., tol=0) # on Lnx even perfectly
```

phypers

The Four (4) Symmetric 'phyper()' Calls

Description

Compute the four (4) symmetric [phyper\(\)](#) calls which mathematically would be identical but in practice typically slightly differ numerically.

Usage

```
phypers(m, n, k, q = .suppHyper(m, n, k), tol = sqrt(.Machine$double.eps))
```

Arguments

m	the number of white balls in the urn.
n	the number of black balls in the urn.
k	the number of balls drawn from the urn, hence must be in $0, 1, \dots, m + n$.
q	vector of quantiles representing the number of white balls drawn without replacement from an urn which contains both black and white balls. By default all “non-trivial” abscissa values i.e., for which the mathematical value is strictly inside $(0, 1)$.
tol	a non-negative number, the tolerance for the <code>all.equal()</code> checks.

Value

a `list` with components

q	Description of ‘comp1’
phyp	a numeric <code>matrix</code> of 4 columns with the 4 different calls to <code>phyper()</code> which are theoretically equivalent because of mathematical symmetry.

Author(s)

Martin Maechler

References

Johnson et al

See Also

R’s `phyper`. In package `DPQmpfr`, `phyperQ()` uses (package `gmp` based) exact rational arithmetic, summing up `dhyperQ()`, terms computed by `chooseZ()`, exact (long integer) arithmetic binomial coefficients.

Examples

```
## The function is defined as
function(m,n,k, q = .suppHyper(m,n,k), tol = sqrt(.Machine$double.eps)) {
  N <- m+n
  pm <- cbind(ph = phyper(q,      m,  n , k), # 1 = orig.
             p2 = phyper(q,      k, N-k, m), # swap m <-> k (keep N = m+n)
             ## "lower.tail = FALSE" <==> 1 - p..(..)
             Ip2= phyper(m-1-q, N-k, k, m, lower.tail=FALSE),
             Ip1= phyper(k-1-q, n,   m, k, lower.tail=FALSE))

  ## check that all are (approximately) the same :
  stopifnot(all.equal(pm[,1], pm[,2], tolerance=tol),
```

```

        all.equal(pm[,2], pm[,3], tolerance=tol),
        all.equal(pm[,3], pm[,4], tolerance=tol))
    list(q = q, phyp = pm)
}

str(phs <- phypers(20, 47, 31))
with(phs, cbind(q, phyp))
with(phs,
      matplot(q, phyp, type = "b"), main = "phypers(20, 47, 31)")

## differences:
with(phs, phyp[,-1] - phyp[,1])
## *relative*
relE <- with(phs, { phM <- rowMeans(phyp); 1 - phyp/phM })
print.table(cbind(q = phs$q, relE / .Machine$double.eps), zero.print = ".")

```

pl2curves

Plot 2 Noncentral Distribution Curves for Visual Comparison

Description

Plot two noncentral (chi-squared or t or ..) distribution curves for visual comparison.

Usage

```

pl2curves(fun1, fun2, df, ncp, log = FALSE,
          from = 0, to = 2 * ncp, p.log = "", n = 2001,
          leg = TRUE, col2 = 2, lwd2 = 2, lty2 = 3, ...)

```

Arguments

fun1, fun2	function (curve), both to be used via curve (curve), and called with the same 4 arguments, (curve , df, ncp, log) (the name of the first argument is not specified).
df, ncp, log	parameters to be passed and used in both functions, which hence typically are non-central chi-squared or t density, probability or quantile functions.
from, to	numbers determining the x-range, passed to curve (curve).
p.log	string, passed as curve (curve , log = log.p).
n	the number of evaluation points, passed to curve (curve).
leg	logical specifying if a legend (curve) should be drawn.
col2, lwd2, lty2	color, line width and line type for the second curve. (The first curve uses defaults for these graphical properties.)
...	further arguments passed to <i>first</i> curve (curve) call.

Value

TODO: invisible return both [curve](#)([curve](#)) results, i.e., (x,y1, y2), possibly as data frame

Author(s)

Martin Maechler

See Also[curve](#), ..**Examples**

```
p.dnchiBessel <- function(df, ncp, log=FALSE, from=0, to = 2*ncp, p.log="", ...)
{
  pl2curves(dnchisqBessel, dchisq, df=df, ncp=ncp, log=log,
            from=from, to=to, p.log=p.log, ...)
}

## TODO the p.dnchiB() examples >>>>> ../tests/chisq-nonc-ex.R <<<
```

pnbeta

*Noncentral Beta Probabilities***Description**

pnbetaAppr2() and its initial version pnbetaAppr2v1() provide the “approximation 2” of Chattamvelli and Shanmugam(1997) to the noncentral Beta probability distribution.

pnbetaAS310() is an R level interface to a C translation (and “Rification”) of the AS 310 Fortran implementation.

Usage

```
pnbetaAppr2(x, a, b, ncp = 0, lower.tail = TRUE, log.p = FALSE)
```

```
pnbetaAS310(x, a, b, ncp = 0, lower.tail = TRUE, log.p = FALSE,
            useAS226 = (ncp < 54.),
            errmax = 1e-6, itrmax = 100)
```

Arguments

x	numeric vector (of quantiles), typically from inside [0, 1].
a, b	the shape parameters of Beta, aka as shape1 and shape2.
ncp	non-centrality parameter.
log.p	logical; if TRUE, probabilities p are given as log(p).
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
useAS226	logical specifying if AS 226 (with R84 and R95 amendments) should be used which is said to be sufficient for small ncp. The default ncp < 54 had been hardwired in AS 310.
errmax	non-negative number determining convergence for AS 310.
itrmax	positive integer number, only if (useAS226) is passed to AS 226.

Value

a numeric vector of (log) probabilities of the same length as x.

Note

The authors in the reference compare AS 310 with Lam(1995), Frick(1990) and Lenth(1987) and state to be better than them. R's current (2019) noncentral beta implementation builds on these, too, with some amendments though; still, pnbetaAS310() may potentially be better, at least in certain corners of the 4-dimensional input space.

Author(s)

Martin Maechler; pnbetaAppr2() in Oct 2007.

References

– not yet implemented –

Gil, A., Segura, J., and Temme, N. M. (2019) On the computation and inversion of the cumulative noncentral beta distribution function. *Applied Mathematics and Computation* **361**, 74–86; doi:10.1016/j.amc.2019.05.014 . Chattamvelli, R., and Shanmugam, R. (1997) Algorithm AS 310: Computing the Non-Central Beta Distribution Function. *Journal of the Royal Statistical Society. Series C (Applied Statistics)* **46**(1), 146–156, for “approximation 2” notably p.154; doi:10.1111/14679876.00055 .

Lenth, R. V. (1987) Algorithm AS 226, . . . , Frick, H. (1990)'s AS R84, . . . , and Lam, M.L. (1995)'s AS R95 : See ‘References’ in R's [pbeta](#) page.

See Also

R's own [pbeta](#).

Examples

```
## Same arguments as for Table 1 (p.151) of the reference
a <- 5*rep(1:3, each=3)
aargs <- cbind(a = a, b = a,
              ncp = rep(c(54, 140, 170), 3),
              x = 1e-4*c(8640, 9000, 9560, 8686, 9000, 9000, 8787, 9000, 9220))
aargs
pnbA2 <- apply(aargs, 1, function(aa) do.call(pnbetaAppr2, as.list(aa)))
pnA310 <- apply(aargs, 1, function(aa) do.call(pnbetaAS310, as.list(aa)))
aar2 <- aargs; dimnames(aar2)[[2]] <- c(paste0("shape", 1:2), "ncp", "q")
pnbR <- apply(aar2, 1, function(aa) do.call(pbeta, as.list(aa)))
range(reID2 <- 1 - pnbA2 / pnbR)
range(reID310 <- 1 - pnA310 / pnbR)
cbind(aargs, pnbA2, pnA310, pnbR,
      reID2 = signif(reID2, 3), reID310 = signif(reID310, 3)) # <-----> Table 1
stopifnot(abs(reID2) < 0.009) # max is 0.006286
stopifnot(abs(reID310) < 1e-5) # max is 6.3732e-6

## Arguments as for Table 2 (p.152) of the reference :
```

```

aarg2 <- cbind(a = c( 10, 10, 15, 20, 20, 20, 30, 30),
              b = c( 20, 10,  5, 10, 30, 50, 20, 40),
              ncp=c(150,120, 80,110, 65,130, 80,130),
              x = c(868,900,880,850,660,720,720,800)/1000)
pnbA2 <- apply(aarg2, 1, function(aa) do.call(pnbetaAppr2, as.list(aa)))
pnA310<- apply(aarg2, 1, function(aa) do.call(pnbetaAS310, as.list(aa)))
aar2 <- aarg2; dimnames(aar2)[[2]] <- c(paste0("shape", 1:2), "ncp", "q")
pnbR  <- apply(aar2, 1, function(aa) do.call(pbeta, as.list(aa)))
range(relD2  <- 1 - pnbA2 /pnbR)
range(relD310 <- 1 - pnA310/pnbR)
cbind(aarg2, pnbA2, pnA310, pnbR,
      relD2 = signif(relD2, 3), relD310 = signif(relD310, 3)) # <-----> Table 2
stopifnot(abs(relD2  ) < 0.006) # max is 0.00412
stopifnot(abs(relD310) < 1e-5 ) # max is 5.5953e-6

## Arguments as for Table 3 (p.152) of the reference :
aarg3 <- cbind(a = c( 10, 10, 10, 15, 10, 12, 30, 35),
              b = c(  5, 10, 30, 20,  5, 17, 30, 30),
              ncp=c( 20, 54, 80,120, 55, 64,140, 20),
              x = c(644,700,780,760,795,560,800,670)/1000)
pnbA3 <- apply(aarg3, 1, function(aa) do.call(pnbetaAppr2, as.list(aa)))
pnA310<- apply(aarg3, 1, function(aa) do.call(pnbetaAS310, as.list(aa)))
aar3 <- aarg3; dimnames(aar3)[[2]] <- c(paste0("shape", 1:2), "ncp", "q")
pnbR  <- apply(aar3, 1, function(aa) do.call(pbeta, as.list(aa)))
range(relD2  <- 1 - pnbA3 /pnbR)
range(relD310 <- 1 - pnA310/pnbR)
cbind(aarg3, pnbA3, pnA310, pnbR,
      relD2 = signif(relD2, 3), relD310 = signif(relD310, 3)) # <-----> Table 3
stopifnot(abs(relD2  ) < 0.09) # max is 0.06337
stopifnot(abs(relD310) < 1e-4) # max is 3.898e-5

```

pnchi1sq

(Probabilities of Non-Central Chi-squared Distribution for Special Cases)

Description

Computes probabilities for the non-central chi-squared distribution, in special cases, currently for $df = 1$ and $df = 3$, using 'exact' formulas only involving the standard normal (Gaussian) cdf $\Phi()$ and its derivative $\phi()$, i.e., R's `pnorm()` and `dnorm()`.

Usage

```

pnchi1sq(q, ncp = 0, lower.tail = TRUE, log.p = FALSE, epsS = .01)
pnchi3sq(q, ncp = 0, lower.tail = TRUE, log.p = FALSE, epsS = .04)

```

Arguments

q	number (‘quantile’, i.e., abscissa value.)
ncp	non-centrality parameter δ ;
lower.tail, log.p	logical, see, e.g., pchisq() .
epsS	small number, determining where to switch from the “small case” to the regular case, namely by defining <code>small <- sqrt(q/ncp) <= epsS</code> .

Details

In the “small case” (epsS above), the direct formulas suffer from cancellation, and we use Taylor series expansions in $s := \sqrt{q}$, which in turn use “probabilists” Hermite polynomials $He_n(x)$.

The default values epsS have currently been determined by experiments as those in the ‘Examples’ below.

Value

a numeric vector “like” q+ncp, i.e., recycled to common length.

Author(s)

Martin Maechler, notably the Taylor approximations in the “small” cases.

References

Johnson et al.(1995), see ‘References’ in [pnchisqPearson](#).

https://en.wikipedia.org/wiki/Hermite_polynomials for the notation.

See Also

[pchisq](#), the (simple and R-like) approximations, such as [pnchisqPearson](#) and the wienergerm approximations, [pchisqW\(\)](#) etc.

Examples

```
qq <- seq(9500, 10500, length=1000)
m1 <- cbind(pch = pchisq (qq, df=1, ncp = 10000),
            p1 = pnchi1sq(qq, ncp = 10000))
matplot(qq, m1, type = "l"); abline(h=0:1, v=10000+1, lty=3)
all.equal(m1[, "p1"], m1[, "pch"], tol=0) # for now, 2.37e-12

m3 <- cbind(pch = pchisq (qq, df=3, ncp = 10000),
            p3 = pnchi3sq(qq, ncp = 10000))
matplot(qq, m3, type = "l"); abline(h=0:1, v=10000+3, lty=3)
all.equal(m3[, "p3"], m3[, "pch"], tol=0) # for now, 1.88e-12

stopifnot(exprs = {
  all.equal(m1[, "p1"], m1[, "pch"], tol=1e-10)
  all.equal(m3[, "p3"], m3[, "pch"], tol=1e-10)
})
```

```

)})

### Very small 'x' i.e., 'q' would lead to cancellation: -----

## df = 1 -----

qS <- c(0, 2^seq(-40,4, by=1/16))
m1s <- cbind(pch = pchisq(qS, df=1, ncp = 1)
             , p1.0= pnchilsq(qS, ncp = 1, epsS = 0)
             , p1.4= pnchilsq(qS, ncp = 1, epsS = 1e-4)
             , p1.3= pnchilsq(qS, ncp = 1, epsS = 1e-3)
             , p1.2= pnchilsq(qS, ncp = 1, epsS = 1e-2)
             )
cols <- adjustcolor(1:5, 1/2); lws <- seq(4,2, by = -1/2)
abl.leg <- function(x.leg = "topright", epsS = 10^-(4:2), legend = NULL)
{
  abline(h = .Machine$double.eps, v = epsS^2,
         lty = c(2,3,3,3), col= adjustcolor(1, 1/2))
  if(is.null(legend))
    legend <- c(quote(epsS == 0), as.expression(lapply(epsS,
                                                       function(K) substitute(epsS == KK,
                                                       list(KK = formatC(K, w=1))))))
  legend(x.leg, legend, lty=1:4, col=cols, lwd=lws, bty="n")
}
matplot(qS, m1s, type = "l", log="y", col=cols, lwd=lws)
matplot(qS, m1s, type = "l", log="xy", col=cols, lwd=lws) ; abl.leg("right")
## ==== "Errors" =====
## Absolute: -----
matplot(qS, m1s[,1] - m1s[,-1], type = "l", log="x", col=cols, lwd=lws)
matplot(qS, abs(m1s[,1] - m1s[,-1]), type = "l", log="xy", col=cols, lwd=lws)
abl.leg("bottomright")
rbind(all = range(aE1e2 <- abs(m1s[, "pch"] - m1s[, "p1.2"])),
      less.75 = range(aE1e2[qS <= 3/4]))
## Lnx(F34;i7) M1mac(BDR)
## all 0 7.772e-16 1.110e-15
## less.75 0 1.665e-16 2.220e-16
stopifnot(aE1e2[qS <= 3/4] <= 4e-16, aE1e2 <= 2e-15) # check
## Relative: -----
matplot(qS, 1 - m1s[,-1]/m1s[,1], type = "l", log="x", col=cols, lwd=lws)
abl.leg()
matplot(qS, abs(1 - m1s[,-1]/m1s[,1]), type = "l", log="xy", col=cols, lwd=lws)
abl.leg()
## number of correct digits ('Inf' |--> 17) :
corrDigs <- pmin(round(-log10(abs(1 - m1s[,-1]/m1s[,1])[-1,]), 1), 17)
table(corrDigs > 9.8) # all
range(corrDigs[qS[-1] > 1e-8, 1], corrDigs[, 2:4]) # [11.8, 17]
(min(corrDigs[qS[-1] > 1e-6, 1:2], corrDigs[, 3:4]) -> mi6) # 13
(min(corrDigs[qS[-1] > 1e-4, 1:3], corrDigs[, 4]) -> mi4) # 13.9
stopifnot(exprs = {
  corrDigs >= 9.8
  c(corrDigs[qS[-1] > 1e-8, 1], corrDigs[, 2]) >= 11.5
  mi6 >= 12.7
  mi4 >= 13.6
})

```

```

})

## df = 3 ----- NOTE: epsS=0 for small qS is "non-sense" -----

qS <- c(0, 2^seq(-40,4, by=1/16))
ee <- c(1e-3, 1e-2, .04)
m3s <- cbind(pch = pchisq (qS, df=3, ncp = 1)
             , p1.0= pnchi3sq(qS,      ncp = 1, epsS = 0)
             , p1.3= pnchi3sq(qS,      ncp = 1, epsS = ee[1])
             , p1.2= pnchi3sq(qS,      ncp = 1, epsS = ee[2])
             , p1.1= pnchi3sq(qS,      ncp = 1, epsS = ee[3])
             )
matplot(qS, m3s, type = "l", log="y" , col=cols, lwd=lws)
matplot(qS, m3s, type = "l", log="xy", col=cols, lwd=lws); abl.legend("right", ee)
## ===== "Errors" =====
## Absolute: -----
matplot(qS,      m3s[,1] - m3s[,-1] , type = "l", log="x" , col=cols, lwd=lws)
matplot(qS, abs(m3s[,1] - m3s[,-1]), type = "l", log="xy", col=cols, lwd=lws)
abl.legend("right", ee)
## Relative: -----
matplot(qS,      1 - m3s[,-1]/m3s[,1] , type = "l", log="x", col=cols, lwd=lws)
abl.legend(, ee)
matplot(qS, abs(1 - m3s[,-1]/m3s[,1]), type = "l", log="xy", col=cols, lwd=lws)
abl.legend(, ee)

```

pnchisqAppr

(Approximate) Probabilities of Non-Central Chi-squared Distribution

Description

Compute (approximate) probabilities for the non-central chi-squared distribution.

The non-central chi-squared distribution with $df = n$ degrees of freedom and non-centrality parameter $ncp = \lambda$ has density

$$f(x) = f_{n,\lambda}(x) = e^{-\lambda/2} \sum_{r=0}^{\infty} \frac{(\lambda/2)^r}{r!} f_{n+2r}(x)$$

for $x \geq 0$; for more, see R's help page for [pchisq](#).

- R's own historical and current versions, but with more tuning parameters;

Historical relatively simple approximations listed in Johnson, Kotz, and Balakrishnan (1995):

- Patnaik(1949)'s approximation to the non-central via central chi-squared. Is also the formula 26.4.27 in Abramowitz & Stegun, p.942. Johnson et al mention that the approximation error is $O(1/\sqrt{\lambda})$ for $\lambda \rightarrow \infty$.
- Pearson(1959) is using 3 moments instead of 2 as Patnaik (to approximate via a central chi-squared), and therefore better than Patnaik for the right tail; further (in Johnson et al.), the approximation error is $O(1/\lambda)$ for $\lambda \rightarrow \infty$.

- Abdel-Aty(1954)'s "first approximation" based on Wilson-Hilferty via Gaussian (`pnorm`) probabilities, is partly *wrongly* cited in Johnson et al., p.463, eq.(29.61a).
- Bol'shev and Kuznetsov (1963) concentrate on the case of **small** $n_{cp} \lambda$ and provide an "approximation" via *central* chi-squared with the same degrees of freedom df , but a modified q ('x'); the approximation has error $O(\lambda^3)$ for $\lambda \rightarrow 0$ and is from Johnson et al., p.465, eq.(29.62) and (29.63).
- Sankaran(1959, 1963) proposes several further approximations base on Gaussian probabilities, according to Johnson et al., p.463. `pnchisqSankaran_d()` implements its formula (29.61d).

`pnchisq()`: an R implementation of R's own C `pnchisq_raw()`, but almost only up to Feb.27, 2004, long before the `log.p=TRUE` addition there, including *logspace arithmetic* in April 2014, its finish on 2015-09-01. Currently for historical reference only.

`pnchisqV()`: a `Vectorize()`d `pnchisq`.

`pnchisqRC()`: R's C implementation as of Aug.2019; but with many more options. Currently extreme cases tend to hang on Winbuilder (?)

`pnchisqIT`:

`pnchisqTerms`:

`pnchisqT93`: pure R implementations of approximations when both q and n_{cp} are large, by Temme(1993), from Johnson et al., p.467, formulas (29.71a), and (29.71b), using auxiliary functions `pnchisqT93a()` and `pnchisqT93b()` respectively, with adapted formulas for the `log.p=TRUE` cases.

`pnchisq_ss()`:

`ss`:

`ss2`:

`ss2.:`

Usage

```
pnchisq      (q, df, ncp = 0, lower.tail = TRUE,
             cutOffncp = 80, itSimple = 110, errmax = 1e-12, reltol = 1e-11,
             maxit = 10* 10000, verbose = 0, xLrg.sigma = 5)
```

```
pnchisqV(x, ..., verbose = 0)
```

```
pnchisqRC    (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE,
             no2nd.call = FALSE,
             cutOffncp = 80, small.ncp.logspace = small.ncp.logspaceR2015,
             itSimple = 110, errmax = 1e-12,
             reltol = 8 * .Machine$double.eps, epsS = reltol/2, maxit = 1e6,
             verbose = FALSE)
```

```
pnchisqAbdelAty (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
```

```
pnchisqBolKuz   (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
```

```
pnchisqPatnaik (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
```

```
pnchisqPearson (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
```

```
pnchisqSankaran_d(q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
```

```
pnchisq_ss     (x, df, ncp = 0, lower.tail = TRUE, log.p = FALSE, i.max = 10000)
```

```
pnchisqTerms   (x, df, ncp, lower.tail = TRUE, i.max = 1000)
```

```
pnchisqT93 (q, df, ncp, lower.tail = TRUE, log.p = FALSE, use.a = q > ncp)
pnchisqT93.a(q, df, ncp, lower.tail = TRUE, log.p = FALSE)
pnchisqT93.b(q, df, ncp, lower.tail = TRUE, log.p = FALSE)

ss (x, df, ncp, i.max = 10000, useLv = !(expMin < -lambda && 1/lambda < expMax))
ss2 (x, df, ncp, i.max = 10000, eps = .Machine$double.eps)
ss2. (q, df, ncp = 0, errmax = 1e-12, reltol = 2 * .Machine$double.eps,
      maxit = 1e+05, eps = reltol, verbose = FALSE)
```

Arguments

x	numeric vector (of ‘quantiles’, i.e., abscissa values).
q	number (‘quantile’, i.e., abscissa value.)
df	degrees of freedom > 0, maybe non-integer.
ncp	non-centrality parameter δ ;
lower.tail, log.p	logical, see, e.g., pchisq() .
i.max	number of terms in evaluation ...
use.a	logical vector for Temme pnchisqT93* (pnchisqT93*) formulas, indicating to use formula ‘a’ over ‘b’. The default is as recommended in the references, but they did not take into account <code>log.p = TRUE</code> situations.
cutOffncp	a positive number, the cutoff value for ncp...
itSimple	...
errmax	absolute error tolerance.
reltol	convergence tolerance for <i>relative</i> error.
maxit	maximal number of iterations.
xLrg.sigma	positive number ...
no2nd.call	logical indicating if a 2nd call is made to the internal function
small.ncp.logspace	logical vector or function , indicating if the logspace computations for “small” ncp (defined to fulfill <code>ncp < cutOffncp</code> !).
epsS	small positive number, the convergence tolerance of the ‘simple’ iterations...
verbose	logical or integer specifying if or how much the algorithm progress should be monitored.
...	further arguments passed from pnchisqV() to pnchisq() .
useLv	logical indicating if logarithmic scale should be used for λ computations.
eps	convergence tolerance, a positive number.

Details

`pnchisq_ss()` uses `si <- ss(x, df, ...)` to get the series terms, and returns `2*dchisq(x, df = df + 2) * sum(si$s)`.

`ss()` computes the terms needed for the expansion used in `pnchisq_ss()`.

`ss2()` computes some simple “statistics” about `ss(...)`.

Value

ss() returns a list with 3 components

s	the series
i1	location (in s[]) of the first change from 0 to positive.
max	(first) location of the maximal value in the series (i.e., <code>which.max(s)</code>).

Author(s)

Martin Maechler, from May 1999; starting from a post to the S-news mailing list by Ranjan Maitra (@ math.umbc.edu) who showed a version of our `pnchisqAppr.0()` thanking Jim Stapleton for providing it.

References

Johnson, N.L., Kotz, S. and Balakrishnan, N. (1995) Continuous Univariate Distributions Vol 2, 2nd ed.; Wiley; chapter 29 *Noncentral χ^2 -Distributions*; notably Section 8 *Approximations*, p.461 ff.

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover.
https://en.wikipedia.org/wiki/Abramowitz_and_Stegun

See Also

`pnchisq` and the wienergerm approximations for it: `pnchisqW()` etc.

`r_pois()` and its plot function, for an aspect of the series approximations we use in `pnchisq_ss()`.

Examples

```
## set of quantiles to use :
qq <- c(.001, .005, .01, .05, (1:9)/10, 2^seq(0, 10, by= 0.5))
## Take "all interesting" pnchisq-approximation from our pkg :
pkg <- "package:DPQ"
pnchNms <- c(paste0("pnchisq", c("V", "W", "W.", "W.R")),
            ls(pkg, pattern = "^pnchisq"))
pnchNms <- pnchNms[!grepl("Terms$", pnchNms)]
pnchF <- sapply(pnchNms, get, envir = as.environment(pkg))
str(pnchF)
ncps <- c(0, 1/8, 1/2)
pnchR <- as.list(setNames(ncps, paste("ncp",ncps, sep="=")))
for(i.n in seq_along(ncps)) {
  ncp <- ncps[i.n]
  pnF <- if(ncp == 0) pnchF[!grepl("chisqT93", pnchNms)] else pnchF
  pnchR[[i.n]] <- sapply(pnF, function(F)
    Vectorize(F, names(formals(F)))[[1]])(qq, df = 3, ncp=ncp)
}
str(pnchR, max=2)
```

```
## A case where the non-central P[] should be improved :
## First, the central P[] which is close to exact -- choosing df=2 allows
```

```

## truly exact values: chi^2 = Exp(1) !
opal <- palette()
palette(c("black", "red", "green3", "blue", "cyan", "magenta", "gold3", "gray44"))
cR <- curve(pchisq(x, df=2, lower.tail=FALSE, log.p=TRUE), 0, 4000, n=2001)
cRC <- curve(pnchisqRC(x, df=2, ncp=0, lower.tail=FALSE, log.p=TRUE),
            add=TRUE, col=adjustcolor(2,1/2), lwd=3, lty=2, n=2001)
cR0 <- curve(pchisq(x, df=2, ncp=0, lower.tail=FALSE, log.p=TRUE),
            add=TRUE, col=adjustcolor(3,1/2), lwd=4, n=2001)
## smart "named list" constructor :
list_ <- function(...)
  `names<-`(list(...), vapply(sys.call()[-1L], as.character, ""))
JKBfn <- list_(pnchisqPatnaik,
              pnchisqPearson,
              pnchisqAbdelAty,
              pnchisqBolKuz,
              pnchisqSankaran_d)
cl. <- setNames(adjustcolor(3+seq_along(JKBfn), 1/2), names(JKBfn))
lw. <- setNames(2+seq_along(JKBfn), names(JKBfn))
cR.JKB <- sapply(names(JKBfn), function(nmf) {
  curve(JKBfn[[nmf]](x, df=2, ncp=0, lower.tail=FALSE, log.p=TRUE),
        add=TRUE, col=cl. [[nmf]], lwd=lw. [[nmf]], lty=lw. [[nmf]], n=2001)
})
legend("bottomleft", c("pchisq", "pchisq.ncp=0", "pnchisqRC", names(JKBfn)),
      col=c(palette()[1], adjustcolor(2:3,1/2), cl.),
      lwd=c(1,3,4, lw.), lty=c(1,2,1, lw.))
palette(opal)# revert

all.equal(cRC, cR0, tol = 1e-15) # TRUE [for now]
## the problematic "jump" :
as.data.frame(cRC)[744:750,]
if(.Platform$OS.type == "unix")
  ## verbose=TRUE may reveal which branches of the algorithm are taken:
  pnchisqRC(1500, df=2, ncp=0, lower.tail=FALSE, log.p=TRUE, verbose=TRUE) #
  ## |--> -Inf currently

## The *two* principal cases (both lower.tail = {TRUE,FALSE} !), where
## "2nd call" happens *and* is currently beneficial :
dfs <- c(1:2, 5, 10, 20)
pL. <- pnchisqRC(.00001, df=dfs, ncp=0, log.p=TRUE, lower.tail=FALSE, verbose = TRUE)
pR. <- pnchisqRC( 100, df=dfs, ncp=0, log.p=TRUE, verbose = TRUE)
## R's own non-central version (specifying 'ncp'):
pL0 <- pchisq (.00001, df=dfs, ncp=0, log.p=TRUE, lower.tail=FALSE)
pR0 <- pchisq ( 100, df=dfs, ncp=0, log.p=TRUE)
## R's *central* version, i.e., *not* specifying 'ncp' :
pL <- pchisq (.00001, df=dfs, log.p=TRUE, lower.tail=FALSE)
pR <- pchisq ( 100, df=dfs, log.p=TRUE)
cbind(pL., pL, relEc = signif(1-pL./pL, 3), relE0 = signif(1-pL./pL0, 3))
cbind(pR., pR, relEc = signif(1-pR./pR, 3), relE0 = signif(1-pR./pR0, 3))

```

Description

Functions implementing the two Wiener germ approximations to `pchisq()`, the (non-central) chi-squared distribution, and to `qchisq()` its inverse, the quantile function.

These have been proposed by Penev and Raykov (2000) who also listed a Fortran implementation.

In order to use them in numeric boundary cases, Martin Maechler has improved the original formulas.

Auxiliary functions:

`sW()`: The $s()$ as in the Wienergerm approximation, but using Taylor expansion when needed, i.e., $(x \cdot ncp / df^2) \ll 1$.

`qs()`: ...

`z0()`: ...

`z.f()`: ...

`z.s()`: ...

.....

Usage

```
pchisqW. (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE,
         Fortran = TRUE, variant = c("s", "f"))
```

```
pchisqV (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE,
         Fortran = TRUE, variant = c("s", "f"))
```

```
pchisqW (q, df, ncp = 0, lower.tail = TRUE, log.p = FALSE, variant = c("s", "f"))
```

```
pchisqW.R(x, df, ncp = 0, lower.tail = TRUE, log.p = FALSE, variant = c("s", "f"),
          verbose = getOption("verbose"))
```

```
sW(x, df, ncp)
```

```
qs(x, df, ncp, f.s = sW(x, df, ncp), eps1 = 1/2, sMax = 1e+100)
```

```
z0(x, df, ncp)
```

```
z.f(x, df, ncp)
```

```
z.s(x, df, ncp, verbose = getOption("verbose"))
```

Arguments

- | | |
|--------------------------------|---|
| <code>q, x</code> | vector of quantiles (main argument, see <code>pchisq</code>). |
| <code>df</code> | degrees of freedom (non-negative, but can be non-integer). |
| <code>ncp</code> | non-centrality parameter (non-negative). |
| <code>lower.tail, log.p</code> | logical, see <code>pchisq</code> . |
| <code>variant</code> | a character string, currently either "f" for the first or "s" for the second Wienergerm approximation in Penev and Raykov (2000). |
| <code>Fortran</code> | logical specifying if the Fortran or the C version should be used. |
| <code>verbose</code> | logical (or integer) indicating if or how much diagnostic output should be printed to the console during the computations. |

f . s a number must be a “version” of $s(x, df, ncp)$.
 eps1 for `qs()`: use direct approximation instead of $h(1 - 1/s)$ for $s < \text{eps1}$.
 sMax for `qs()`: cutoff to switch the $h(.)$ formula for $s > \text{sMax}$.

Details

....TODO... or write vignette

Value

all these functions return `numeric` vectors according to their arguments.

Note

The exact auxiliary function names etc, are still considered *provisional*; currently they are exported for easier documentation and use, but may well all disappear from the exported functions or even completely.

Author(s)

Martin Maechler, mostly end of Jan 2004

References

Penev, Spiridon and Raykov, Tenko (2000) A Wiener Germ approximation of the noncentral chi square distribution and of its quantiles. *Computational Statistics* **15**, 219–228. doi:10.1007/s001800000029
 Dinges, H. (1989) Special cases of second order Wiener germ approximations. *Probability Theory and Related Fields*, **83**, 5–57.

See Also

`pchisq`, and other approximations for it: `pnchisq()` etc.

Examples

```
## see example(pnchisqAppr) which looks at all of the pchisq() approximating functions
```

pnormAsymp *Asymptotic Approximation of (Extreme Tail) 'pnorm()'*

Description

Provide the first few terms of the asymptotic series approximation to `pnorm()`'s (extreme) tail, from Abramowitz and Stegun's 26.2.13 (p.932).

Usage

```
pnormAsymp(x, k, lower.tail = FALSE, log.p = FALSE)
```

Arguments

`x` positive (at least non-negative) numeric vector.
`lower.tail, log.p` logical, see, e.g., `pnorm()`.
`k` integer ≥ 0 indicating how many terms the approximation should use; currently $k \leq 5$.

Value

a numeric vector “as” `x`; see the examples, on how to use it with arbitrary precise `mpfr`-numbers from package **Rmpfr**.

Author(s)

Martin Maechler

References

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover. https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

See Also

`pnormU_S53` for (also asymptotic) upper and lower bounds.

Examples

```
x <- c((2:10)*2, 25, (3:9)*10, (1:9)*100, (1:8)*1000, (2:4)*5000)
Px <- pnorm(x, lower.tail = FALSE, log.p=TRUE)
PxA <- sapply(setNames(0:5, paste("k =",0:5)),
              pnormAsymp, x=x, lower.tail = FALSE, log.p=TRUE)
## rel.errors :
signif(head( cbind(x, 1 - PxA/Px) , 20))

## Look more closely with high precision computations
if(requireNamespace("Rmpfr")) {
  ## ensure our function uses Rmpfr's dnorm(), etc:
  environment(pnormAsymp) <- asNamespace("Rmpfr")
  environment(pnormU_S53) <- asNamespace("Rmpfr")
  x. <- Rmpfr::mpfr(x, precBits=256)
  Px. <- Rmpfr::pnorm(x., lower.tail = FALSE, log.p=TRUE)
  ## manual, better sapplyMpfr():
  PxA. <- sapply(setNames(0:5, paste("k =",0:5)),
                pnormAsymp, x=x., lower.tail = FALSE, log.p=TRUE)
  PxA. <- new("mpfrMatrix", unlist(PxA.), Dim=dim(PxA.), Dimnames=dimnames(PxA.))
  PxA2 <- Rmpfr::cbind(pn_dbl = Px, PxA.,
                      pnormU_S53 = pnormU_S53(x=x., lower.tail = FALSE, log.p=TRUE))
  ## rel.errors : note that pnormU_S53() is very slightly better than "k=2":
  print( Rmpfr::roundMpfr(Rmpfr::cbind(x., 1 - PxA2/Px.), precBits = 13), width = 111)
```

```

pch <- c("R", 0:5, "U")
matplot(x, abs(1 -PxA2/Px.), type="o", log="xy", pch=pch,
        main="pnorm(<tail>) approximations' relative errors - pnormAsymp(*, k=k)")
legend("bottomleft", colnames(PxA2), col=1:6, pch=pch, lty=1:5, bty="n", inset=.01)
at1 <- axTicks(1, axp = c(par("xaxp")[1:2], 3))
axis(1, at=at1)
abline(h = 1:2* 2^-53, v = at1, lty=3, col=adjustcolor("gray20", 1/2))
axis(4, las=2, at= 2^-53, label = quote(epsilon[C]), col="gray20")
}

```

pnormLU

*Bounds for $1 - \Phi(\cdot)$ – Mill's Ratio related Bounds for pnorm()***Description**

Bounds for $1 - \Phi(x)$, i.e., `pnorm(x, *, lower.tail=FALSE)`, typically related to Mill's Ratio.

Usage

```

pnormL_LD10(x, lower.tail = FALSE, log.p = FALSE)
pnormU_S53(x, lower.tail = FALSE, log.p = FALSE)

```

Arguments

`x` positive (at least non-negative) numeric vector.
`lower.tail, log.p` logical, see, e.g., `pnorm()`.

Value

a numeric vector like `x`

Author(s)

Martin Maechler

References

Lutz Duembgen (2010) *Bounding Standard Gaussian Tail Probabilities*; arXiv preprint 1012.2063, <https://arxiv.org/abs/1012.2063>

See Also

`pnorm`.

Examples

```

x <- seq(1/64, 10, by=1/64)
px <- cbind(
  lQ = pnorm      (x, lower.tail=FALSE, log.p=TRUE)
  , Lo = pnormL_LD10(x, lower.tail=FALSE, log.p=TRUE)
  , Up = pnormU_S53 (x, lower.tail=FALSE, log.p=TRUE))
matplot(x, px, type="l") # all on top of each other

matplot(x, (D <- px[,2:3] - px[,1]), type="l") # the differences
abline(h=0, lty=3, col=adjustcolor(1, 1/2))

## check they are lower and upper bounds indeed :
stopifnot(D[, "Lo"] < 0, D[, "Up"] > 0)

matplot(x[x>4], D[x>4,], type="l") # the differences
abline(h=0, lty=3, col=adjustcolor(1, 1/2))

### zoom out to larger x : [1, 1000]
x <- seq(1, 1000, by=1/4)
px <- cbind(
  lQ = pnorm      (x, lower.tail=FALSE, log.p=TRUE)
  , Lo = pnormL_LD10(x, lower.tail=FALSE, log.p=TRUE)
  , Up = pnormU_S53 (x, lower.tail=FALSE, log.p=TRUE))
matplot(x, px, type="l") # all on top of each other
matplot(x, (D <- px[,2:3] - px[,1]), type="l", log="x") # the differences
abline(h=0, lty=3, col=adjustcolor(1, 1/2))

## check they are lower and upper bounds indeed :
table(D[, "Lo"] < 0) # no longer always true
table(D[, "Up"] > 0)
## not even when equality (where it's much better though):
table(D[, "Lo"] <= 0)
table(D[, "Up"] >= 0)

## *relative* differences:
matplot(x, (rD <- 1 - px[,2:3] / px[,1]), type="l", log = "x")
abline(h=0, lty=3, col=adjustcolor(1, 1/2))
## abs()
matplot(x, abs(rD), type="l", log = "xy", axes=FALSE, # NB: curves *cross*
  main = "relative differences 1 - pnormUL(x, *) / pnorm(x,*)")
legend("top", c("Low.Bnd(D10)", "Upp.Bnd(S53)"), bty="n", col=1:2, lty=1:2)
sfsmisc::eaxis(1, sub10 = 2)
sfsmisc::eaxis(2)
abline(h=(1:4)*2^-53, col=adjustcolor(1, 1/4))

### zoom out to LARGE x : -----
x <- 2^seq(0, 30, by = 1/64)
if(FALSE)## or even HUGE:
  x <- 2^seq(4, 513, by = 1/16)
px <- cbind(
  lQ = pnorm      (x, lower.tail=FALSE, log.p=TRUE)

```

```

, a0 = dnorm(x, log=TRUE)
, a1 = dnorm(x, log=TRUE) - log(x)
, Lo = pnormL_LD10(x, lower.tail=FALSE, log.p=TRUE)
, Up = pnormU_S53 (x, lower.tail=FALSE, log.p=TRUE))
col4 <- adjustcolor(1:4, 1/2)
doLegTit <- function() {
  title(main = "relative differences 1 - pnormUL(x, *)/pnorm(x,*)")
  legend("top", c("phi(x)", "phi(x)/x", "Low.Bnd(D10)", "Upp.Bnd(S53)"),
        bty="n", col=col4, lty=1:4)
}
## *relative* differences are relevant:
matplot(x, (rD <- 1 - px[,-1] / px[,1]), type="l", log = "x",
        ylim = c(-1,1)/2^8, col=col4) ; doLegTit()
abline(h=0, lty=3, col=adjustcolor(1, 1/2))

## abs(rel.Diff) ---> can use log-log:
matplot(x, abs(rD), type="l", log = "xy", xaxt="n", yaxt="n"); doLegTit()
sfsmisc::eaxis(1, sub10=2)
sfsmisc::eaxis(2, nintLog=12)
abline(h=(1:4)*2^-53, col=adjustcolor(1, 1/4))

## lower.tail=TRUE (w/ log.p=TRUE) works "the same" for x < 0:
x <- - 2^seq(0, 30, by = 1/64)
## ==
px <- cbind(
  lQ = pnorm (x, lower.tail=TRUE, log.p=TRUE)
, a0 = log1mexp(- dnorm(-x, log=TRUE))
, a1 = log1mexp(-(dnorm(-x, log=TRUE) - log(-x)))
, Lo = log1mexp(-pnormL_LD10(-x, lower.tail=TRUE, log.p=TRUE))
, Up = log1mexp(-pnormU_S53 (-x, lower.tail=TRUE, log.p=TRUE)) )
matplot(-x, (rD <- 1 - px[,-1] / px[,1]), type="l", log = "x",
        ylim = c(-1,1)/2^8, col=col4) ; doLegTit()
abline(h=0, lty=3, col=adjustcolor(1, 1/2))

```

pnt

Non-central t Probability Distribution - Algorithms and Approximations

Description

Compute different approximations for the non-central t-Distribution cumulative probability distribution function.

Usage

```

pntR      (t, df, ncp, lower.tail = TRUE, log.p = FALSE,
          use.pnorm = (df > 4e5 ||
            ncp^2 > 2*log(2)*1021), # .Machine$double.min.exp = -1022
          itrmax = 1000, errmax = 1e-12, verbose = TRUE)

```

```

pntR1      (t, df, ncp, lower.tail = TRUE, log.p = FALSE,
            use.pnorm = (df > 4e5 ||
                        ncp^2 > 2*log(2)*1021),
            itrmax = 1000, errmax = 1e-12, verbose = TRUE)

pntP94     (t, df, ncp, lower.tail = TRUE, log.p = FALSE,
            itrmax = 1000, errmax = 1e-12, verbose = TRUE)
pntP94.1   (t, df, ncp, lower.tail = TRUE, log.p = FALSE,
            itrmax = 1000, errmax = 1e-12, verbose = TRUE)

pnt3150    (t, df, ncp, lower.tail = TRUE, log.p = FALSE, M = 1000, verbose = TRUE)
pnt3150.1  (t, df, ncp, lower.tail = TRUE, log.p = FALSE, M = 1000, verbose = TRUE)

pntLrg     (t, df, ncp, lower.tail = TRUE, log.p = FALSE)

pntJW39    (t, df, ncp, lower.tail = TRUE, log.p = FALSE)
pntJW39.0  (t, df, ncp, lower.tail = TRUE, log.p = FALSE)

pntVW13    (t, df, ncp, lower.tail = TRUE, log.p = FALSE,
            keepS = FALSE, verbose = FALSE)

pntGST23_T6 (t, df, ncp, lower.tail = TRUE, log.p = FALSE,
            y1.tol = 1e-8, Mterms = 20, alt = FALSE, verbose = TRUE)
pntGST23_T6.1(t, df, ncp, lower.tail = TRUE, log.p = FALSE,
            y1.tol = 1e-8, Mterms = 20, alt = FALSE, verbose = TRUE)

## *Non*-asymptotic, (at least partly much) better version of R's Lenth(1998) algorithm
pntGST23_1(t, df, ncp, lower.tail = TRUE, log.p = FALSE,
            j0max = 1e4, # for now
            IxpqFUN = Ixpq,
            alt = FALSE, verbose = TRUE, ...)

```

Arguments

<code>t</code>	vector of quantiles (called <code>q</code> in <code>pt(...)</code>).
<code>df</code>	degrees of freedom (> 0 , maybe non-integer). <code>df = Inf</code> is allowed.
<code>ncp</code>	non-centrality parameter $\delta \geq 0$; If omitted, use the central <code>t</code> distribution.
<code>log, log.p</code>	logical; if <code>TRUE</code> , probabilities <code>p</code> are given as <code>log(p)</code> .
<code>lower.tail</code>	logical; if <code>TRUE</code> (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
<code>use.pnorm</code>	logical indicating if the <code>pnorm()</code> approximation of Abramowitz and Stegun (26.7.10) should be used, which is available as <code>pntLrg()</code> . The default corresponds to R <code>pt()</code> 's own behaviour (which is suboptimal).
<code>itrmax</code>	number of iterations / terms.
<code>errmax</code>	convergence bound for the iterations.
<code>verbose</code>	logical or integer determining the amount of diagnostic print out to the console.

M	positive integer specifying the number of terms to use in the series.
keepS	logical indicating if the function should return a list with component <code>cdf</code> and other informational elements, or just the CDF values directly (by default).
y1.tol	positive tolerance for warning if $y := t^2/(t^2 + df)$ is too close to 1 (as the formulas use $1/(1 - y)$).
Mterms	number of summation terms for <code>pntGST23_T6()</code> .
j0max	<i>experimental</i> : large integer limiting the summation terms in <code>pntGST23_1()</code> .
IxpqFUN	the (scaled) incomplete beta function $I_x(p, q)$ to be used; currently, it defaults to the <code>Ixpq</code> function derived from Nico Temme's Maple code for "Table 1" in Gil et al. (2023).
alt	logical specifying if and how log-scale should be used. Experimental and not-yet-tested.
...	further arguments passed to <code>IxpqFUN()</code> .

Details

`pntR1()`: a pure R version of the (C level) code of R's own `pt()`, additionally giving more flexibility (via arguments `use.pnorm`, `itrmax`, `errmax` whose defaults here have been hard-coded in R's C code called by `pt()`).

This implements an improved version of the AS 243 algorithm from Lenth(1989);

R's help on non-central `pt()` says: *This computes the lower tail only, so the upper tail suffers from cancellation and a warning will be given when this is likely to be significant.*

and (in 'Note:') *The code for non-zero ncp is principally intended to be used for moderate values of ncp: it will not be highly accurate, especially in the tails, for large values.*

`pntR()`: the `Vectorize()`d version of `pntR1()`.

`pntP94()`, `pntP94.1()`: New versions of `pntR1()`, `pntR()`; using the Posten (1994) algorithm. `pntP94()` is the `Vectorize()`d version of `pntP94.1()`.

`pnt3150()`, `pnt3150.1()`: Simple inefficient but hopefully correct version of `pntP94..()` This is really a direct implementation of formula (31.50), p.532 of Johnson, Kotz and Balakrishnan (1995)

`pntLrg()`: provides the `pnorm()` approximation (to the non-central t) from Abramowitz and Stegun (26.7.10), p.949; which should be employed only for *large* `df` and/or `ncp`.

`pntJW39.0()`: use the Jennett & Welch (1939) approximation see Johnson et al. (1995), p. 520, after (31.26a). This is still *fast* for huge `ncp` but has *wrong* asymptotic tail for $|t| \rightarrow \infty$. Crucially needs `b = b_chi(df)`.

`pntJW39()`: is an improved version of `pntJW39.0()`, using $1 - b = b_chi(df, one.minus=TRUE)$ to avoid cancellation when computing $1 - b^2$.

`pntGST23_T6()`: (and `pntGST23_T6.1()` for informational purposes only) use the Gil et al.(2023)'s approximation of their Theorem 6.

`pntGST23_1()`: implements Gil et al.(2023)'s direct `pbeta()` based formula (1), which is very close to Lenth's algorithm.

`pntVW13()`: use MM's R translation of Viktor Witkowský (2013)'s matlab implementation.

Value

a number for `pntJKBf1()` and `.pntJKBch1()`.

a numeric vector of the same length as the maximum of the lengths of `x`, `df`, `ncp` for `pntJKBf()` and `.pntJKBch()`.

Author(s)

Martin Maechler

References

Johnson, N.L., Kotz, S. and Balakrishnan, N. (1995) *Continuous Univariate Distributions Vol-2*, 2nd ed.; Wiley; chapter 31, Section 5 *Distribution Function*, p.514 ff

Lenth, R. V. (1989). *Algorithm AS 243* — Cumulative distribution function of the non-central *t* distribution, *JRSS C (Applied Statistics)* **38**, 185–189.

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover; formula (26.7.10), p.949

Posten, Harry O. (1994) A new algorithm for the noncentral *t* distribution function, *Journal of Statistical Computation and Simulation* **51**, 79–87; doi:10.1080/00949659408811623.

– not yet implemented –

Chattamvelli, R. and Shanmugam, R. (1994) An enhanced algorithm for noncentral *t*-distribution, *Journal of Statistical Computation and Simulation* **49**, 77–83. doi:10.1080/00949659408811561

– not yet implemented –

Akahira, Masafumi. (1995). A higher order approximation to a percentage point of the noncentral *t* distribution, *Communications in Statistics - Simulation and Computation* **24**:3, 595–605; doi:10.1080/03610919508813261

Michael Perakis and Evdokia Xekalaki (2003) On a Comparison of the Efficacy of Various Approximations of the Critical Values for Tests on the Process Capability Indices CPL, CPU, and Cpk, *Communications in Statistics - Simulation and Computation* **32**, 1249–1264; doi:10.1081/SAC120023888

Witkovský, Viktor (2013) A Note on Computing Extreme Tail Probabilities of the Noncentral *T* Distribution with Large Noncentrality Parameter, *Acta Universitatis Palackianae Olomucensis, Facultas Rerum Naturalium, Mathematica* **52**(2), 131–143.

Gil A., Segura J., and Temme N.M. (2023) New asymptotic representations of the noncentral *t*-distribution, *Stud Appl Math.* **151**, 857–882; doi:10.1111/sapm.12609 ; acronym “GST23”.

See Also

`pt`, for R’s version of non-central *t* probabilities.

Examples

```
tt <- seq(0, 10, len = 21)
ncp <- seq(0, 6, len = 31)
pt3R <- outer(tt, ncp, pt, , df = 3)
pt3JKB <- outer(tt, ncp, pntR, df = 3)# currently verbose
```

```

stopifnot(all.equal(pt3R, pt3JKB, tolerance = 4e-15))# 64-bit Lnx: 2.78e-16

## Gil et al.(2023) -- Table 1 p.869
str(GST23_tab1 <- read.table(header=TRUE, text = "
  x      pnt_x_delta      Rel.accuracy  l_y  j_max
  5      0.7890745035061528e-20  0.20e-13  0.29178  254
  8      0.1902963697413609e-07  0.40e-12  0.13863  294
  11     0.4649258368179092e-03  0.12e-09  0.07845  310
  14     0.2912746016055676e-01  0.11e-07  0.04993  317
  17     0.1858422833307925e-00  0.41e-06  0.03441  321
  20     0.4434882973203470e-00  0.82e-05  0.02510  323"))

x1 <- c(5,8,11,14,17,20)
(p1 <- pt (x1, df=10.3, ncp=20))
(p1R <- pntR(x1, df=10.3, ncp=20)) # verbose=TRUE is default
all.equal(p1, p1R, tolerance=0) # 4.355452e-15 {on x86_64} as have *no* LDOUBLE on R level
stopifnot(all.equal(p1, p1R))
## NB: According to Gil et al., the first value (x=5) is really wrong
## p1.23 <- .. Gil et al., Table 1:
p1.23.11 <- pntGST23_T6(x1, df=10.3, ncp=20, Mterms = 11)
p1.23.20 <- pntGST23_T6(x1, df=10.3, ncp=20, Mterms = 20, verbose=TRUE)
# ==> Mterms = 11 is good only for x=5
p1.23.50 <- pntGST23_T6(x1, df=10.3, ncp=20, Mterms = 50, verbose=TRUE)

x <- 4:40 ; df <- 10.3
ncp <- 20
p1 <- pt (x, df=df, ncp=ncp)
pG1 <- pntGST23_1(x, df=df, ncp=ncp)
pG1.bR <- pntGST23_1(x, df=df, ncp=ncp,
  IxpqFUN = \ (x, l_x=.5-x+.5, p, q) Ixpq(x,l_x, p,q))
pG1.BR <- pntGST23_1(x, df=df, ncp=ncp,
  IxpqFUN = \ (x, l_x, p, q) pbeta(x, p,q))
cbind(x, p1, pG1, pG1.bR, pG1.BR)
all.equal(pG1, p1, tolerance=0) # 1.034 e-12
all.equal(pG1, pG1.bR, tolerance=0) # 2.497031 e-13
all.equal(pG1, pG1.BR, tolerance=0) # 2.924698 e-13
all.equal(pG1.BR,pG1.bR,tolerance=0)# 1.68644 e-13
stopifnot(exprs = {
  all.equal(pG1, p1, tolerance = 4e-12)
  all.equal(pG1, pG1.bR, tolerance = 1e-12)
  all.equal(pG1, pG1.BR, tolerance = 1e-12)
})

ncp <- 40 ## is > 37.62 = "critical" for Lenth' algorithm

### ----- pntVW13() -----
## length 1 arguments:
str(rr <- pntVW13(t = 1, df = 2, ncp = 3, verbose=TRUE, keepS=TRUE))
all.equal(rr$cdf, pt(1,2,3), tol = 0)# "Mean relative difference: 4.956769e-12"
stopifnot( all.equal(rr$cdf, pt(1,2,3)) )

str(rr <- pntVW13(t = 1:19, df = 2, ncp = 3, verbose=TRUE, keepS=TRUE))

```

```

str(r2 <- pntVW13(t = 1, df = 2:20, ncp = 3, verbose=TRUE, keepS=TRUE))
str(r3 <- pntVW13(t = 1, df = 2:20, ncp = 3:21, verbose=TRUE, keepS=TRUE))

pt1.10.5_T <- 4.34725285650591657e-5 # Ex. 7 of Witkovsky(2013)
pt1.10.5 <- pntVW13(1, 10, 5)
all.equal(pt1.10.5_T, pt1.10.5, tol = 0)# TRUE! (Lnx Fedora 40; 2024-07-04);
# 3.117e-16 (Macbuilder R 4.4.0, macOS Ventura 13.3.1)
stopifnot(exprs = {
  identical(rr$cdf, r1 <- pntVW13(t = 1:19, df = 2, ncp = 3))
  identical(r1[1], pntVW13(1, 2, 3))
  identical(r1[7], pntVW13(7, 2, 3))
  all.equal(pt1.10.5_T, pt1.10.5, tol = 9e-16)# NB even tol=0 (64 Lnx)
})
## However, R' pt() is only equal for the very first
cbind(t = 1:19, pntVW = r1, pt = pt(1:19, 2,3))

```

pow

*X to Power of Y – R C API R_pow()***Description**

`pow(x, y)` calls R C API ‘Rmathlib’`s` `R_pow(x, y)` function to compute x^y or when `try.int.y` is true (as by default), and `y` is integer valued and fits into integer range, `R_pow_di(x, y)`.

`pow_di(x, y)` with integer `y` calls R mathlib’s `R_pow_di(x, y)`.

Usage

```

pow (x, y, try.int.y = TRUE)
pow_di(x, y)
.pow (x, y)

```

Arguments

<code>x</code>	a numeric vector.
<code>y</code>	a numeric or in the case of <code>pow_di()</code> integer vector.
<code>try.int.y</code>	logical indicating if <code>pow()</code> should check if <code>y</code> is integer valued and fits into integer range, and in that case call <code>pow_di()</code> automatically.

Details

In January 2024, I found (e.g., in ‘tests/pow-tst.R’) that the accuracy of `pow_di()`, i.e., also the C function `R_pow_di()` in R’s API is of much lower precision than R’s x^y or (equivalently) `R_pow(x, y)` in R’s API, notably on Linux and macOS, using glib etc, sometimes as soon as $y \geq 6$ or so.

`.pow(x, y)` is identical to `pow(x, y, try.int.y = FALSE)`

Value

a numeric vector like `x` or `y` which are recycled to common length, of course.

Author(s)

Martin Maechler

See Also

Base R's `^` “operator”.

Examples

```
set.seed(27)
x <- rnorm(100)
y <- 0:9
stopifnot(exprs = {
  all.equal(x^y, pow(x,y))
  all.equal(x^y, pow(x,y, FALSE))
  all.equal(x^y, pow_di(x,y))
})
```

pow1p

Accurate $(1 + x)^y$, notably for small $|x|$

Description

Compute $(1 + x)^y$ accurately, notably also for small $|x|$, where the naive formula suffers from cancellation, returning 1, often.

Usage

```
pow1p(x, y,
      pow = ((x + 1) - 1) == x || abs(x) > 0.5 || is.na(x))
```

Arguments

`x, y` numeric or number-like; in the latter case, arithmetic incl. `^`, comparison, `exp`, `log1p`, `abs`, and `is.na` methods must work.

`pow` **logical** indicating if the “naive” / direct computation $(1 + x)^y$ should be used (unless `y` is in `0:4`, where the binomial is used, see ‘Details’). The current default is the one used in R’s C-level function (but beware of compiler optimization there!).

Details

A pure R-implementation of R 4.4.0's new C-level `pow1p()` function which was introduced for more accurate `dbinom_raw()` computations.

Currently, we use the “exact” (nested) polynomial formula for $y \in \{0, 1, 2, 3, 4\}$.

MM is conjecturing that the default `pow=FALSE` for (most) $x \leq \frac{1}{2}$ is sub-optimal.

Value

numeric or number-like, as $x + y$.

Author(s)

Originally proposed by Morten Welinder, see [PR#18642](#); tweaked, notably for small integer y , by Martin Maechler.

See Also

[^](#), [log1p](#), [dbinom_raw](#).

Examples

```
x <- 2^-(1:50)
y <- 99
f1 <- (1+x)^99
f2 <- exp(y * log1p(x))
fp <- pow1p(x, 99)
matplot(x, cbind(f1, f2, fp), type = "l", col = 2:4)
legend("top", legend = expression((1+x)^99, exp(99 * log1p(x)), pow1p(x, 99)),
      bty="n", col=2:4, lwd=2)
cbind(x, f1, f2, sfsmisc::relErrV(f2, f1))
```

ppoisson

Direct Computation of 'ppois()' Poisson Distribution Probabilities

Description

Direct computation and errors of [ppois](#) Poisson distribution probabilities.

Usage

```
ppoisD(q, lambda, all.from.0 = TRUE, verbose = 0L)
ppoisErr(lambda, ppFUN = ppoisD, iP = 1e-15,
          xM = qpois(iP, lambda=lambda, lower.tail=FALSE),
          verbose = FALSE)
```

Arguments

q	numeric vector of non-negative integer values, “quantiles” at which to evaluate <code>ppois(q, la)</code> and <code>ppFUN(q, la)</code> .
lambda	positive parameter of the Poisson distribution, $\text{lambda} = \lambda = E[X] = \text{Var}[X]$ where $X \sim \text{Pois}(\lambda)$.
all.from.0	logical indicating if q is positive integer, and the probabilities should computed for all quantile values of 0:q.
ppFUN	alternative <code>ppois</code> evaluation, by default the direct summation of <code>dpois(k, lambda)</code> .
iP	small number, $iP \ll 1$, used to construct the abscissa values x at which to evaluate and compare <code>ppois()</code> and <code>ppFUN()</code> , see xM:
xM	(specified instead of iP:) the maximal x-value to be used, i.e., the values used will be $x \leftarrow 0:iM$. The default, <code>ppois(1-iP, lambda = lambda)</code> is the upper tail iP-quantile of <code>Poi(lambda)</code> .
verbose	integer (≥ 0) or logical indicating if extra information should be printed.

Value

`ppoisD()` contains the poisson probabilities along q, i.e., is a numeric vector of length `length(q)`.
`re <- ppoisErr()` returns the relative “error” of `ppois(x0, lambda)` where `ppFUN(x0, lambda)` is assumed to be the truth and `x0` the “worst case”, i.e., the value (among x) with the largest such difference.

Additionally, `attr(re, "x0")` contains that value `x0`.

Author(s)

Martin Maechler, March 2004; 2019 ff

See Also

[ppois](#)

Examples

```
(lams <- outer(c(1,2,5), 10^(0:3)))# 10^4 is already slow!
system.time(e1 <- sapply(lams, ppoisErr))
e1 / .Machine$double.eps

## Try another 'ppFUN' :-----
## this relies on the fact that it's *only* used on an 'x' of the form 0:M :
ppD0 <- function(x, lambda, all.from.0=TRUE)
  cumsum(dpois(if(all.from.0) 0:x else x, lambda=lambda))
## and test it:
p0 <- ppD0 ( 1000, lambda=10)
p1 <- ppois(0:1000, lambda=10)
stopifnot(all.equal(p0,p1, tol=8*.Machine$double.eps))

system.time(p0.slow <- ppoisD(0:1000, lambda=10, all.from.0=FALSE))# not very slow, here
```

```

p0.1 <- ppoisD(1000, lambda=10)
if(requireNamespace("Rmpfr")) {
  ppoisMpfr <- function(x, lambda) cumsum(Rmpfr::dpois(x, lambda=lambda))
  p0.best <- ppoisMpfr(0:1000, lambda = Rmpfr::mpfr(10, precBits = 256))
  AllEq. <- Rmpfr::all.equal
  AllEq <- function(target, current, ...)
    AllEq.(target, current, ...,
            formatFUN = function(x, ...) Rmpfr::format(x, digits = 9))
  print(AllEq(p0.best, p0, tol = 0)) # 2.06e-18
  print(AllEq(p0.best, p0.slow, tol = 0)) # the "worst" (4.44e-17)
  print(AllEq(p0.best, p0.1, tol = 0)) # 1.08e-18
}

## Now (with 'all.from.0 = TRUE', it is fast too):
p15 <- ppoisErr(2^13)
p15.0. <- ppoisErr(2^13, ppFUN = ppD0)
c(p15, p15.0.) / .Machine$double.eps # on Lnx 64b, see (-10 2.5), then (-2 -2)

## lapply(), so you see "x0" values :
str(e0. <- lapply(lams, ppoisErr, ppFUN = ppD0))

## The first version [called 'err.lambd0()' for years] used simple cumsum(dpois(..))
## NOTE: It is *stil* much faster, as it relies on special x == 0:M relation
## Author: Martin Maechler, Date: 1 Mar 2004, 17:40
##
e0 <- sapply(lams, function(lamb) ppoisErr(lamb, ppFUN = ppD0))
all.equal(e1, e0) # typically TRUE, though small "random" differences:
cbind(e1, e0) * 2^53 # on Lnx 64b, seeing integer values in {-24, .., 33}

```

pt_Witkovsky_Tab1

Viktor Witosky's Table_1 pt() Examples

Description

A data frame with 17 `pt()` examples from Witosky (2013)'s 'Table 1'. We provide the results for the FOSS Softwares, additionally including octave's, running the original 2013 matlab code, and the corrected one from 2022.

Usage

```
data(pt_Witkovsky_Tab1)
```

Format

A data frame with 17 observations on the following `numeric` variables.

`x` the abscissa, called `q` in `pt()`.

`nu` the *positive* degrees of freedom, called `df` in `pt()`.

`delta` the noncentrality parameter, called `ncp` in `pt()`.

true_pnt “true” values (computed via higher precision, see Witkovsky(2013)).

NCTCDFVW the pt() values computed with Witkovsky’s matlab implementation. Confirmed by using octave (on Fedora 40 Linux). These correspond to our R (package **DPQ**) pntVW13() values.

Boost computed via the Boost C++ library; reported by Witkovsky.

R_3.3.0 computed by R version 3.3.0; confirmed to be identical using R 4.4.1

NCT2013_octave_7.3.0 values computed using Witkovsky’s original matlab code, by octave 7.3.0

NCT2022_octave_8.4.0 values computed using Witkovsky’s 2022 corrected matlab code, by octave 8.4.0

Source

The table was extracted (by MM) from the result of pdf to text --layout <*>.pdf from the publication. The NCT2013_octave_7.3.0 column was computed from the 2013 code, using GPL octave 7.3.0 on Linux Fedora 38, whereas NCT2013_octave_8.4.0 from the 2022 code, using GPL octave 8.4.0 on Linux Fedora 40.

Note that the ‘arXiv’ pre-publication has very slightly differing numbers in its R column, e.g., first entry ending in 00200 instead of 00111.

References

Witkovský, Viktor (2013) A Note on Computing Extreme Tail Probabilities of the Noncentral T Distribution with Large Noncentrality Parameter, *Acta Universitatis Palackianae Olomucensis, Facultas Rerum Naturalium, Mathematica* **52**(2), 131–143.

Examples

```
data(pt_Witkovsky_Tab1)
stopifnot(is.data.frame(d.W <- pt_Witkovsky_Tab1), # shorter
          nrow(d.W) >= 17)
mW <- as.matrix(d.W); row.names(mW) <- NULL # more efficient
colnames(mW)[1:3] # "x" "nu" "delta"
## use 'R pt()' - compatible' names:
(n3 <- names(formals(pt)[1:3]))# "q" "df" "ncp"
colnames(mW)[1:3] <- n3
ptR <- apply(mW[, 1:3], 1, \(a3) unname(do.call(pt, as.list(a3))))
cNm <- paste0("R_", with(R.version, paste(major, minor, sep=".")))
mW <- cbind(mW, `colnames<-`(cbind(ptR), cNm),
            relErr = sfsmisc::relErrV(mW[, "true_pnt"], ptR))

mW
## is current R better than R 3.3.0? -- or even "the same"?
all.equal(ptR, mW[, "R_3.3.0"]) # still true in R 4.4.1
all.equal(ptR, mW[, "R_3.3.0"], tolerance = 1e-14) # (ditto)
table(ptR == mW[, "R_3.3.0"]) # {see only 4 (out of 17) *exactly* equal ??}

## How close to published NCTCDFVW is octave's run of the 2022 code?
with(d.W, all.equal(NCTCDFVW, NCT2022_octave_8.4.0, tolerance = 0)) # 3.977e-16
```

```
pVW <- apply(unnamed(mW[, 1:3]), 1, \(a3) unname(do.call(pntVW13, as.list(a3))))
all.equal(pVW, d.W$NCT2013_oct, tolerance = 0)# 2013-based pntVW13() --> 5.6443e-16
all.equal(pVW, d.W$NCT2022_oct, tolerance = 0)
```

qbetaAppr

Compute (Approximate) Quantiles of the Beta Distribution

Description

Compute quantiles (inverse distribution values) of the beta distribution, using diverse approximations.

Usage

```
qbetaAppr.1(a, p, q, lower.tail=TRUE, log.p=FALSE,
            y = qnormUappr(a, lower.tail=lower.tail, log.p=log.p))

qbetaAppr.2(a, p, q, lower.tail=TRUE, log.p=FALSE, logbeta = lbeta(p,q))
qbetaAppr.3(a, p, q, lower.tail=TRUE, log.p=FALSE, logbeta = lbeta(p,q))
qbetaAppr.4(a, p, q, lower.tail=TRUE, log.p=FALSE,
            y = qnormUappr(a, lower.tail=lower.tail, log.p=log.p),
            verbose = getOption("verbose"))

qbetaAppr (a, p, q, lower.tail=TRUE, log.p=FALSE,
            y = qnormUappr(a, lower.tail=lower.tail, log.p=log.p),
            logbeta = lbeta(p,q),
            verbose = getOption("verbose") && length(a) == 1)

qbeta.R (alpha, p, q,
         lower.tail = TRUE, log.p = FALSE,
         logbeta = lbeta(p,q),
         low.bnd = 3e-308, up.bnd = 1-2.22e-16,
         method = c("AS109", "Newton-log"),
         tol.outer = 1e-15,
         f.acu = function(a,p,q) max(1e-300, 10^(-13- 2.5/pp^2 - .5/a^2)),
         fpu = .Machine$ double.xmin,
         qnormU.fun = function(u, lu) qnormUappr(p=u, lp=lu)
         , R.pre.2014 = FALSE
         , verbose = getOption("verbose")
         , non.finite.report = verbose
         )
```

Arguments

a, alpha vector of probabilities (otherwise, e.g., in `qbeta()`, called p).
p, q the two shape parameters of the beta distribution; otherwise, e.g., in `qbeta()`, called shape1 and shape2.

y	an approximation to $\Phi^{-1}(1 - \alpha)$ (aka $z_{1-\alpha}$) where $\Phi(x)$ is the standard normal cumulative probability function and $\Phi^{-1}(x)$ its inverse, i.e., R's <code>qnorm(x)</code> .
lower.tail, log.p	logical, see, e.g., <code>qchisq()</code> ; must have length 1.
logbeta	must be <code>lbeta(p, q)</code> ; mainly an option to pass a value already computed.
verbose	logical or integer indicating if and how much “monitoring” information should be produced by the algorithm.
low.bnd, up.bnd	lower and upper bounds for ...TODO...
method	a string specifying the approximation method to be used.
tol.outer	the “outer loop” convergence tolerance; the default 1e-15 has been hardwired in R's <code>qbeta()</code> .
f.acu	a <code>function</code> with arguments (a, p, q) ...TODO...
fpu	a very small positive number.
qnormU.fun	a <code>function</code> with arguments (u, lu) to compute “the same” as <code>qnormUappr()</code> , the upper standard normal quantile.
R.pre.2014	a <code>logical</code> ... TODO ...
non.finite.report	<code>logical</code> indicating if during the “outer loop” refining iterations, if y becomes non finite and the iterations have to stop, it should be reported (before the current best value is returned).

Value

...

Author(s)

The R Core Team for the C version of `qbeta` in R's sources; Martin Maechler for the R port, and the approximations.

See Also

`qbeta`.

Examples

```
qbeta.R(0.6, 2, 3) # 0.4445
qbeta.R(0.6, 2, 3) - qbeta(0.6, 2,3) # almost 0

qbetaRV <- Vectorize(qbeta.R, "alpha") # now can use
curve(qbetaRV(x, 1.5, 2.5))
curve(qbeta(x, 1.5, 2.5), add=TRUE, lwd = 3, col = adjustcolor("red", 1/2))

## an example of disagreement (and doubt, as borderline, close to underflow):
qbeta.R(0.5078, .01, 5) # -> 2.77558e-15 # but
qbeta(0.5078, .01, 5) # now gives 4.651188e-31 -- correctly!
qbeta(0.5078, .01, 5, ncp=0)# ditto
```

```
## which is because qbeta() now works in log-x scale here:
curve(pbeta(x, .01, 5), 1e-40, 1, n=10001, log="x", xaxt="n")
sfsmisc::eaxis(1); abline(h=.5078, lty=3); abline(v=4.651188e-31,col=2)
```

qbinomR

*Pure R Implementation of R's qbinom() with Tuning Parameters***Description**

A pure R implementation, including many tuning parameter arguments, of R's own Rmathlib C code algorithm, but with more flexibility.

It is using `Vectorize(qbinomR1, *)` where the hidden `qbinomR1` works for numbers (aka 'scalar', length one) arguments only, the same as the C code.

Usage

```
qbinomR(p, size, prob, lower.tail = TRUE, log.p = FALSE,
        yLarge = 4096, # was hard wired to 1e5
        incF = 1/64, # was hard wired to .001
        iShrink = 8, # was hard wired to 100
        relTol = 1e-15, # was hard wired to 1e-15
        pfEps.n = 8, # was hard wired to 64: "fuzz to ensure left continuity"
        pfEps.L = 2, # was hard wired to 64: " " ..
        fpf = 4, # *MUST* be >= 1 (did not exist previously)
        trace = 0)
```

Arguments

<code>p, size, prob, lower.tail, log.p</code>	<code>qbinom()</code> standard argument, see its help page.
<code>yLarge</code>	when $y \geq y_L$, $y_L = yLarge$, the binary root finding search is made "cleverer", taking larger increments, determined by <code>incF</code> and <code>iShrink</code> :
<code>incF</code>	a positive "increment factor" (originally hardwired to 0.001), used only when $y \geq yLarge$; defines the initial increment in the search algorithm as <code>incr <- floor(incF * y)</code> .
<code>iShrink</code>	a positive increment shrinking factor, used only when $y \geq yLarge$ to define the new increment from the old one as <code>incr <- max(1, floor(incr/iShrink))</code> where the LHS was hardired original to <code>(incr/100)</code> .
<code>relTol</code>	relative tolerance, > 0 ; the search terminates when the (integer!) increment is less than <code>relTol * y</code> or the previous increment was not larger than 1.
<code>pfEps.n</code>	fuzz factor to ensure left continuity in the normal case <code>log.p=FALSE</code> ; used to be hardwired to 64 (in R up to 2021-05-08).
<code>pfEps.L</code>	fuzz factor to ensure left continuity in case <code>log.p=TRUE</code> ; used to be hardwired to 64 (in R up to 2021-05-08).

fpf	factor $f \geq 1$ for the normal upper tail case (<code>log.p=FALSE</code> , <code>lower.tail=FALSE</code>): <code>p</code> is only “fuzz-corrected”, i.e., multiplied by $1 + \epsilon$ when $1 - p > \text{fpf} * \epsilon$ for $\epsilon < \text{pfEps.n} * c_e$ and $c_e = 2^{-52}$, the <code>.Machine\$double_epsilon</code> .
trace	logical (or integer) specifying if (and how much) output should be produced from the algorithm.

Details

as mentioned on [qbinom](#) help page, `qbinom` uses the Cornish–Fisher Expansion to include a skewness correction to a normal approximation, thus defining $y := \text{Fn}(p, \text{size}, \text{prob}, \dots)$.

The following (root finding) binary search is tweaked by the `yLarge`, `...`, `fpf` arguments.

Value

a numeric vector like `p` recycled to the common lengths of `p`, `size`, and `prob`.

Author(s)

Martin Maechler

See Also

[qbinom](#), [qpois](#).

Examples

```
set.seed(12)
pr <- (0:16)/16 # supposedly recycled
x10 <- rbinom(500, prob=pr, size = 10); p10 <- pbinom(x10, prob=pr, size= 10)
x1c <- rbinom(500, prob=pr, size = 100); p1c <- pbinom(x1c, prob=pr, size=100)
## stopifnot(exprs = {
table( x10 == (qp10 <- qbinom (p10, prob=pr, size= 10) ))
table( qp10 == (qp10R <- qbinomR(p10, prob=pr, size= 10) )); summary(warnings()) # 30 x NaN
table( x1c == (qp1c <- qbinom (p1c, prob=pr, size=100) ))
table( qp1c == (qp1cR <- qbinomR(p1c, prob=pr, size=100) )); summary(warnings()) # 30 x NaN
## })
```

Description

Compute quantiles (inverse distribution values) for the chi-squared distribution. using Johnson,Kotz,...
TODO.....

Usage

```

qchisqKG (p, df, lower.tail = TRUE, log.p = FALSE)
qchisqWH (p, df, lower.tail = TRUE, log.p = FALSE)
qchisqAppr (p, df, lower.tail = TRUE, log.p = FALSE, tol = 5e-7)
qchisqAppr.R(p, df, lower.tail = TRUE, log.p = FALSE, tol = 5e-07,
             maxit = 1000, verbose = getOption("verbose"), kind = NULL)

```

Arguments

p vector of probabilities.

df degrees of freedom > 0, maybe non-integer; must have length 1.

lower.tail, log.p logical, see, e.g., [qchisq\(\)](#); must have length 1.

tol non-negative number, the convergence tolerance

maxit the maximal number of iterations

verbose logical indicating if the algorithm should produce “monitoring” information.

kind the *kind* of approximation; if NULL, the default, the approximation chosen depends on the arguments; notably it is chosen separately for each p. Otherwise, it must be a [character](#) string. The main approximations are Wilson-Hilferty versions, when the string contains “WH”. More specifically, it must be one of the strings

- "**chi.small**" particularly useful for small chi-squared values p;... ..
- "**WH**"
- "**p1WH**"
- "**WHchk**"
- "**df.small**" particularly useful for small degrees of freedom df... ..

Value

...

Author(s)

Martin Maechler

See Also

[qchisq](#). Further, our approximations to the *non-central* chi-squared quantiles, [qnchisqAppr](#)

Examples

```
## TODO
```

qgammaAppr

Compute (Approximate) Quantiles of the Gamma Distribution

Description

Compute approximations to the quantile (i.e., inverse cumulative) function of the Gamma distribution.

Usage

```
qgammaAppr(p, shape, lower.tail = TRUE, log.p = FALSE,
           tol = 5e-07)
qgamma.R (p, alpha, scale = 1, lower.tail = TRUE, log.p = FALSE,
          EPS1 = 0.01, EPS2 = 5e-07, epsN = 1e-15, maxit = 1000,
          pMin = 1e-100, pMax = (1 - 1e-14),
          verbose = getOption("verbose"))

qgammaApprKG(p, shape, lower.tail = TRUE, log.p = FALSE)

qgammaApprSmallP(p, shape, lower.tail = TRUE, log.p = FALSE)
```

Arguments

p	numeric vector (possibly log transformed) probabilities.
shape, alpha	shape parameter, non-negative.
scale	scale parameter, non-negative, see qgamma .
lower.tail, log.p	logical, see, e.g., qgamma() ; must have length 1.
tol	tolerance of maximal approximation error.
EPS1	small positive number. ...
EPS2	small positive number. ...
epsN	small positive number. ...
maxit	maximal number of iterations. ...
pMin, pMax	boundaries for p. ...
verbose	logical indicating if the algorithm should produce “monitoring” information.

Details

qgammaApprSmallP(p, a) should be a good approximation in the following situation when both p and shape = $\alpha =: a$ are small :

If we look at Abramowitz&Stegun $gamma * (a, x) = x^{-a} * P(a, x)$ and its series $g * (a, x) = 1/gamma(a) * (1/a - 1/(a + 1) * x + \dots)$,

then the first order approximation $P(a, x) = x^a * g * (a, x) = x^a / gamma(a + 1)$ and hence its inverse $x = qgamma(p, a) = (p * gamma(a + 1))^{1/a}$ should be good as soon as $1/a \gg 1/(a + 1) * x$

$$\iff x \ll (a+1)/a = (1 + 1/a)$$

$$\iff x < \text{eps} * (a+1)/a$$

$$\iff \log(x) < \log(\text{eps}) + \log((a+1)/a) = \log(\text{eps}) + \log((a+1)/a) \sim -36 - \log(a) \text{ where } \log(x) \sim \log(p * gamma(a+1)) / a = (\log(p) + lgamma1p(a))/a$$

such that the above

$$\iff (\log(p) + lgamma1p(a))/a < \log(\text{eps}) + \log((a+1)/a)$$

$$\iff \log(p) + lgamma1p(a) < a * (-\log(a) + \log(\text{eps}) + \log1p(a))$$

$$\iff \log(p) < a * (-\log(a) + \log(\text{eps}) + \log1p(a)) - lgamma1p(a) =: \text{bnd}(a)$$

Note that qgammaApprSmallP() indeed also builds on `lgamma1p()`.

.qgammaApprBnd(a) provides this bound $\text{bnd}(a)$; it is simply $a * (\log\text{Eps} + \log1p(a) - \log(a)) - lgamma1p(a)$, where $\log\text{Eps}$ is $\log(\epsilon) = \log(\text{eps})$ where $\text{eps} <- .Machine\$double.\text{eps}$, i.e. typically (always?) $\log\text{Eps} = \log \epsilon = -52 * \log(2) = -36.04365$.

Value

numeric

Author(s)

Martin Maechler

References

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover. https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

See Also

`qgamma` for R's Gamma distribution functions.

Examples

```
## TODO : Move some of the curve()s from ../tests/qgamma-ex.R !!
```

qnbinomR

*Pure R Implementation of R's qnbinom() with Tuning Parameters***Description**

A pure R implementation, including many tuning parameter arguments, of R's own Rmathlib C code algorithm, but with more flexibility.

It is using `Vectorize(qnbinomR1, *)` where the hidden `qnbinomR1` works for numbers (aka 'scalar', length one) arguments only, the same as the C code.

Usage

```
qnbinomR(p, size, prob, mu, lower.tail = TRUE, log.p = FALSE,
         yLarge = 4096, # was hard wired to 1e5
         incF = 1/64, # was hard wired to .001
         iShrink = 8, # was hard wired to 100
         relTol = 1e-15, # was hard wired to 1e-15
         pfEps.n = 8, # was hard wired to 64: "fuzz to ensure left continuity"
         pfEps.L = 2, # was hard wired to 64: " " ..
         fpf = 4, # *MUST* be >= 1 (did not exist previously)
         trace = 0)
```

Arguments

`p`, `size`, `prob`, `mu`, `lower.tail`, `log.p`
 [qnbinom\(\)](#) standard argument, see its help page.

`yLarge`, `incF`, `iShrink`, `relTol`, `pfEps.n`, `pfEps.L`, `fpf`
 numeric arguments tweaking the "root finding" search after the initial Cornish-Fisher approximation, see [qbinomR](#), for details. The defaults should be more reliable (but also a bit more "expensive") than R's (original) [qnbinom\(\)](#) hard wired values.

`trace`
 logical (or integer) specifying if (and how much) output should be produced from the algorithm.

Value

a numeric vector like `p` recycled to the common lengths of `p`, `size`, and either `prob` or `mu`.

Author(s)

Martin Maechler

See Also

[qnbinom](#), [qpois](#).

Examples

```

set.seed(12)
x10 <- rnbinom(500, mu = 4, size = 10) ; p10 <- pnbinom(x10, mu=4, size=10)
x1c <- rnbinom(500, prob = 31/32, size = 100); p1c <- pnbinom(x1c, prob=31/32, size=100)
stopifnot(exprs = {
  x10 == qnbinom (p10, mu=4, size=10)
  x10 == qnbinomR(p10, mu=4, size=10)
  x1c == qnbinom (p1c, prob=31/32, size=100)
  x1c == qnbinomR(p1c, prob=31/32, size=100)
})

```

qnchisqAppr

Compute Approximate Quantiles of Noncentral Chi-Squared Distribution

Description

Compute quantiles (inverse distribution values) for the *non-central* chi-squared distribution.
 using Johnson,Kotz, and other approximations

Usage

```

qnchisqAppr.0 (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqAppr.1 (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqAppr.2 (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqAppr.3 (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqApprCF1(p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqApprCF2(p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)

qnchisqCappr.2 (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqN      (p, df, ncp = 0, qIni = qchisqAppr.0, ...)

qnchisqAbdelAty (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqBolKuz   (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqPatnaik  (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqPearson  (p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)
qnchisqSankaran_d(p, df, ncp = 0, lower.tail = TRUE, log.p = FALSE)

```

Arguments

p vector of probabilities.
df degrees of freedom > 0, maybe non-integer.
ncp non-centrality parameter δ ;
lower.tail, log.p logical, see, e.g., [qchisq\(\)](#).
qIni a [function](#) that computes an approximate noncentral chi-squared quantile as starting value x_0 for the Newton algorithm [newton\(\)](#).
... further arguments to [newton\(\)](#), notably `eps` or `maxiter`.

Details

Compute (approximate) quantiles, using approximations analogous to those for the probabilities, see [pnchisqPearson](#).

qchisqAppr.0(): ...TODO...

qchisqAppr.1(): ...TODO...

qchisqAppr.2(): ...TODO...

qchisqAppr.3(): ...TODO...

qchisqApprCF1(): ...TODO...

qchisqApprCF2(): ...TODO...

qchisqCappr.2(): ...TODO...

qchisqN(): Uses Newton iterations with [pchisq\(\)](#) and [dchisq\(\)](#) to determine [qchisq\(.\)](#) values.

qnchisqAbdelAty(): ...TODO...

qnchisqBolKuz(): ...TODO...

qnchisqPatnaik(): ...TODO...

qnchisqPearson(): ...TODO...

qnchisqSankaran_d(): ...TODO...

Value

[numeric](#) vectors of (noncentral) chi-squared quantiles, corresponding to probabilities p .

Author(s)

Martin Maechler, from May 1999; starting from a post to the S-news mailing list by Ranjan Maitra (@ math.umbc.edu) who showed a version of our `qchisqAppr.0()` thanking Jim Stapleton for providing it.

References

Johnson, N.L., Kotz, S. and Balakrishnan, N. (1995) Continuous Univariate Distributions Vol 2, 2nd ed.; Wiley; chapter 29 *Noncentral χ^2 -Distributions*; notably Section 8 *Approximations*, p.461 ff.

See Also

[qchisq](#).

Examples

```
pp <- c(.001, .005, .01, .05, (1:9)/10, .95, .99, .995, .999)
pkg <- "package:DPQ"
qnchNms <- c(paste0("qchisqAppr.",0:3), paste0("qchisqApprCF",1:2),
            "qchisqN", "qchisqCappr.2", ls(pkg, pattern = "^qnchisq"))
qnchF <- sapply(qnchNms, get, envir = as.environment(pkg))
for(ncp in c(0, 1/8, 1/2)) {
```

```

cat("\n~~~~~\nncp: ", ncp, "\n=====\n")
print(sapply(qnchF, function(F) Vectorize(F, "p")(pp, df = 3, ncp=ncp)))
}

## Bug: qchisqSankaran_d() has numeric overflow problems for large df:
qchisqSankaran_d(pp, df=1e200, ncp = 100)

## One current (2019-08) R bug: Noncentral chi-squared quantiles on *LOG SCALE*

## a) left/lower tail : -----
qs <- 2^seq(0,11, by=1/16)
pqL <- pchisq(qs, df=5, ncp=1, log.p=TRUE)
plot(qs, -pqL, type="l", log="xy") # + expected warning on log(0) -- all fine
qpqL <- qchisq(pqL, df=5, ncp=1, log.p=TRUE) # severe overflow :
qm <- cbind(qs, pqL, qchisq=qpqL
, qchA.0 = qchisqAppr.0 (pqL, df=5, ncp=1, log.p=TRUE)
, qchA.1 = qchisqAppr.1 (pqL, df=5, ncp=1, log.p=TRUE)
, qchA.2 = qchisqAppr.2 (pqL, df=5, ncp=1, log.p=TRUE)
, qchA.3 = qchisqAppr.3 (pqL, df=5, ncp=1, log.p=TRUE)
, qchACF1= qchisqApprCF1(pqL, df=5, ncp=1, log.p=TRUE)
, qchACF2= qchisqApprCF2(pqL, df=5, ncp=1, log.p=TRUE)
, qchCa.2= qchisqCappr.2(pqL, df=5, ncp=1, log.p=TRUE)
, qnPatnaik = qchisqPatnaik (pqL, df=5, ncp=1, log.p=TRUE)
, qnAbdelAty = qchisqAbdelAty (pqL, df=5, ncp=1, log.p=TRUE)
, qnBolKuz = qchisqBolKuz (pqL, df=5, ncp=1, log.p=TRUE)
, qnPearson = qchisqPearson (pqL, df=5, ncp=1, log.p=TRUE)
, qnSankaran_d= qchisqSankaran_d(pqL, df=5, ncp=1, log.p=TRUE)
)

round(qm[ qs %in% 2^(0:11) , -2])
#=> Approximations don't overflow but are not good enough

## b) right/upper tail , larger ncp -----
qS <- 2^seq(-3, 3, by=1/8)
pqLu <- pchisq(qS, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
## using "the alternative" (here is currently identical):
identical(pqLu, (pqLu.<- log1p(-pchisq(qS, df=5, ncp=100)))) # here TRUE
plot (qS, -pqLu, type="l", log="xy") # fine
qpqLu <- qchisq(pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
cbind(qS, pqLu, qpqLu)# # severe underflow
qchMat <- cbind(qchisq = qpqLu
, qchA.0 = qchisqAppr.0 (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qchA.1 = qchisqAppr.1 (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qchA.2 = qchisqAppr.2 (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qchA.3 = qchisqAppr.3 (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qchACF1= qchisqApprCF1(pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qchACF2= qchisqApprCF2(pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qchCa.2= qchisqCappr.2(pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qnPatnaik = qchisqPatnaik (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qnAbdelAty = qchisqAbdelAty (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qnBolKuz = qchisqBolKuz (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qnPearson = qchisqPearson (pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)
, qnSankaran_d= qchisqSankaran_d(pqLu, df=5, ncp=100, log.p=TRUE, lower.tail=FALSE)

```

```

)
cbind(L2err <- sort(sqrt(colSums((qchMat - qS)^2))))
##--> "Sankaran_d", "CF1" and "CF2" are good here

plot (qS, qpqLu, type = "b", log="x", lwd=2)
lines(qS, qS, col="gray", lty=2, lwd=3)
top3 <- names(L2err)[1:3]
use <- c("qchisq", top3)
matlines(qS, qchMat[, use]) # 3 of the approximations are "somewhat ok"
legend("topleft", c(use,"True"), bty="n", col=c(palette()[1:4], "gray"),
      lty = c(1:4,2), lwd = c(2, 1,1,1, 3))

```

qnormAppr

Approximations to 'qnorm()', i.e., z_α

Description

Approximations to the standard normal (aka “Gaussian”) quantiles, i.e., the inverse of the normal cumulative probability function.

The `qnormUappr*`(`)` are relatively simple approximations from Abramowitz and Stegun, computed by Hastings(1955): `qnormUappr()` is the 4-coefficient approximation to (the upper tail) standard normal quantiles, `qnorm()`, used in some `qbeta()` computations.

`qnormUappr6()` is the “traditional” 6-coefficient approximation to `qnorm()`, see in ‘Details’.

Usage

```

qnormUappr(p, lp = .DT_Clog(p, lower.tail=lower.tail, log.p=log.p),
           lower.tail = FALSE, log.p = missing(p),
           tLarge = 1e10)
qnormUappr6(p,
            lp = .DT_Clog(p, lower.tail=lower.tail, log.p=log.p),
            # ~= log(1-p) -- independent of lower.tail, log.p
            lower.tail = FALSE, log.p = missing(p),
            tLarge = 1e10)

```

```

qnormCappr(p, k = 1) ## *implicit* lower.tail=TRUE, log.p=FALSE >>> TODO: add! <<

```

```

qnormAppr(p) # << deprecated; use qnormUappr(..) instead!

```

Arguments

<code>p</code>	numeric vector of probabilities, possibly transformed, depending on <code>log.p</code> . Does not need to be specified, if <code>lp</code> is instead.
<code>lp</code>	<code>log(1 - p*)</code> , assuming <code>p*</code> is the <code>lower.tail=TRUE, log.p=FALSE</code> version of <code>p</code> . If passed as argument, it can be much more accurate than when computed from <code>p</code> by default.

lower.tail	logical; if TRUE (<i>not</i> the default here!), probabilities are $P[X \leq x]$, otherwise (by default) upper tail probabilities, $P[X > x]$.
log.p	logical; if TRUE, probabilities p are given as $\log(p)$ in argument p . Note that it is <i>not used</i> , when <code>missing(p)</code> and <code>lp</code> is specified.
tLarge	a large number $t0$; if $t \geq t0$, where $t := \sqrt{-2 * lp}$, the result will be $= t$.
k	positive integer, specifying the iterative plugin ‘order’.

Details

This is now *deprecated*; use `qnormUappr()` instead! `qnormAppr(p)` uses the simple 4 coefficient rational approximation to `qnorm(p)`, provided by Abramowitz and Stegun (26.2.22), p.933, to be used *only* for $p > 1/2$ and typically `qbeta()` computations, e.g., `qbeta.R`.

The relative error of this approximation is quite *asymmetric*: It is mainly < 0 .

`qnormUappr(p)` uses the same rational approximation directly for the Upper tail where it is relatively good, and for the lower tail via “swapping the tails”, so it is good there as well.

`qnormUappr6(p, *)` uses the 6 coefficient rational approximation to `qnorm(p, *)`, from Abramowitz and Stegun (26.2.23), again mostly useful in the outer tails.

`qnormCappr(p, k)` inverts formula (26.2.24) of Abramowitz and Stegun, and for $k \geq 2$ improves it, by iterative recursive plug-in, using A.&S. (26.2.25).

Value

numeric vector of (approximate) normal quantiles corresponding to probabilities p

Author(s)

Martin Maechler

References

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover. https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

Hastings jr., Cecil (1955) *Approximations for Digital Computers*. Princeton Univ. Press.

See Also

`qnorm` (in base R package `stats`), and importantly, `qnormR` and `qnormAsymp()` in this package (DPQ).

Examples

```
pp <- c(.001, .005, .01, .05, (1:9)/10, .95, .99, .995, .999)
z_p <- qnorm(pp)
assertDeprecation <- function(expr, verbose=TRUE)
  tools::assertCondition(expr, verbose=verbose, "deprecatedWarning")
assertDeprecation(qA <- qnormAppr(pp))
(R <- cbind(pp, z_p, qA,
```

```

        qUA = qnormUappr(pp, lower.tail= TRUE),
        qA6 = qnormUappr6(pp, lower.tail=TRUE))
## Errors, absolute and relative:
relEr <- function(targ, curr) { ## simplistic "smart" rel.error
  E <- curr - targ
  r <- E/targ # simple, but fix 0/0:
  r[targ == 0 & E == 0] <- 0
  r
}
mER <- cbind(pp,
             errA = z_p - R[, "qA" ],
             errUA = z_p - R[, "qUA"],
             rE.A = relEr(z_p, R[, "qA" ]),
             rE.UA = relEr(z_p, R[, "qUA"]),
             rE.A6 = relEr(z_p, R[, "qA6"]))
signif(mER)

lp <- -c(1000, 500, 200, 100, 50, 20:10, seq(9.75, 0, by = -1/8))
signif(digits=5, cbind(lp # 'p' need not be specified if 'lp' is !
, p. = -expm1(lp)
, qnU = qnormUappr (lp=lp)
, qnU6= qnormUappr6(lp=lp)
, qnA1= qnormAsymp(lp=lp, lower.tail=FALSE, order=1)
, qnA5= qnormAsymp(lp=lp, lower.tail=FALSE, order=5)
, qn = qnorm(lp, log.p=TRUE)
)) ## oops! shows *BUG* for last values where qnorm() > 0 !

curve(qnorm(x, lower.tail=FALSE), n=1001)
curve(qnormUappr(x), add=TRUE, n=1001, col = adjustcolor("red", 1/2))

## Error curve:
curve(qnormUappr(x) - qnorm(x, lower.tail=FALSE), n=1001,
      main = "Absolute Error of qnormUappr(x)")
abline(h=0, v=1/2, lty=2, col="gray")

curve(qnormUappr(x) / qnorm(x, lower.tail=FALSE) - 1, n=1001,
      main = "Relative Error of qnormUappr(x)")
abline(h=0, v=1/2, lty=2, col="gray")

curve(qnormUappr(lp=x) / qnorm(x, log.p=TRUE) - 1, -200, -1, n=1001,
      main = "Relative Error of qnormUappr(lp=x)"); mtext("& qnormUappr6() [log.p scale]", col=2)
curve(qnormUappr6(lp=x) / qnorm(x, log.p=TRUE) - 1, add=TRUE, col=2, n=1001)
abline(h=0, lty=2, col="gray")

curve(qnormUappr(lp=x) / qnorm(x, log.p=TRUE) - 1,
      -2000, -.1, ylim = c(-2e-4, 1e-4), n=1001,
      main = "Relative Error of qnormUappr(lp=x)"); mtext("& qnormUappr6() [log.p scale]", col=2)
curve(qnormUappr6(lp=x) / qnorm(x, log.p=TRUE) - 1, add=TRUE, col=2, n=1001)
abline(h=0, lty=2, col="gray")

## zoom out much more - switch x-axis {use '-x'} and log-scale:
curve(qnormUappr6(lp=-x) / qnorm(-x, log.p=TRUE) - 1,
      .1, 1.1e10, log = "x", ylim = 2.2e-4*c(-2,1), n=2048,

```

```

    main = "Relative Error of  qnormUappr6(lp = -x)  [log.p scale]" -> xy.q
  abline(h=0, lty=2, col="gray")

  ## 2023-02: qnormUappr6() can be complemented with
  ## an approximation around center p=1/2: qnormCappr()
  p <- seq(0,1, by=2^-10)
  M <- cbind(p, qn=(qn <- qnorm(p)),
            reC1 = relEr(qn, qnormCappr(p)),
            reC2 = relEr(qn, qnormCappr(p, k=2)),
            reC3 = relEr(qn, qnormCappr(p, k=3)),
            reU6 = relEr(qn, qnormUappr6(p,lower.tail=TRUE)))
  matplot(M[, "p"], M[, -(1:2)], type="l", col=2:7, lty=1, lwd=2,
          ylim = c(-.004, +1e-4), xlab=quote(p), ylab = "relErr")
  abline(h=0, col="gray", lty=2)
  oo <- options(width=99)
  summary(  M[, -(1:2)])
  summary(abs(M[, -(1:2)]))
  options(oo)

```

qnormAsymp

Asymptotic Approximation to Outer Tail of qnorm()

Description

Implementing new asymptotic tail approximations of normal quantiles, i.e., the R function `qnorm()`, mostly useful when `log.p=TRUE` and log-scale p is relatively large negative, i.e., $p \ll -1$.

Usage

```

qnormAsymp(p,
           lp = .DT_Clog(p, lower.tail = lower.tail, log.p = log.p),
           order, lower.tail = TRUE, log.p = missing(p))

```

Arguments

<code>p</code>	numeric vector of probabilities, possibly transformed, depending on <code>log.p</code> . Does not need to be specified, if <code>lp</code> is used instead.
<code>lp</code>	numeric (vector) of $\log(1-p)$ values; if not specified, computed from <code>p</code> , depending on <code>lower.tail</code> and <code>log.p</code> .
<code>order</code>	an integer in $\{0, 1, \dots, 5\}$, specifying the approximation order.
<code>lower.tail</code>	logical; if true, probabilities are $P[X \leq x]$, otherwise upper tail probabilities, $P[X > x]$.
<code>log.p</code>	logical; if TRUE (as typical here!), probabilities p are given as $\log(p)$ in argument <code>p</code> .

Details

These *asymptotic* approximations have been derived by Maechler (2022) via iterative plug-in to the well known asymptotic approximations of $Q(x) = 1 - \Phi(x)$ from Abramowitz and Stegun (26.2.13), p.932, which are provided in our package **DPQ** as `pnormAsymp()`. They will be used in $R \geq 4.3.0$'s `qnorm()` to provide very accurate quantiles in the extreme tails.

Value

a numeric vector like `p` or `lp` if that was specified instead.

The simplest (for extreme tails) is `order = 0`, where the asymptotic approximation is simply $\sqrt{-2s}$ and `s` is `-lp`.

Author(s)

Martin Maechler

References

Martin Maechler (2022). Asymptotic Tail Formulas For Gaussian Quantiles; **DPQ** vignette, see <https://CRAN.R-project.org/package=DPQ/vignettes/qnorm-asymp.pdf>.

See Also

The upper tail approximations in Abramowitz & Stegun, in **DPQ** available as `qnormUappr()` and `qnormUappr6()`, are less accurate than our `order >= 1` formulas in the tails.

Examples

```
lp <- -c(head(c(outer(c(5,2,1), 10^(18:1))), -2), 20:10, seq(9.75, 2, by = -1/8))
qnU6 <- qnormUappr6(lp=lp) # 'p' need not be specified if 'lp' is
qnAsy <- sapply(0:5, function(ord) qnormAsymp(lp=lp, lower.tail=FALSE, order=ord))
matplot(-lp, cbind(qnU6, qnAsy), type = "b", log = "x", pch=1:7) # all "the same"
legend("center", c("qnormUappr6()",
  paste0("qnormAsymp(*, order=", 0:5, ")")),
  bty="n", col=1:6, lty=1:5, pch=1:7) # as in matplot()

p.ver <- function() mtext(R.version.string, cex=3/4, adj=1)
matplot(-lp, cbind(qnU6, qnAsy) - qnorm(lp, lower.tail=TRUE, log.p=TRUE),
  pch=1:7, cex = .5, xaxt = "n", # and use eaxis() instead
  main = "absolute Error of qnorm() approximations", type = "b", log = "x")
sfsmisc::eaxis(1, sub10=2); p.ver()
legend("bottom", c("qnormUappr6()",
  paste0("qnormAsymp(*, order=", 0:5, ")")),
  bty="n", col=1:6, lty=1:5, pch=1:7, pt.cex=.5)

## If you look at the numbers, in versions of R <= 4.2.x,
## qnorm() is *worse* for large -lp than the higher order approximations
## ---> using qnormR() here:
absP <- function(re) pmax(abs(re), 2e-17) # not zero, so log-scale "shows" it
qnT <- qnormR(lp, lower.tail=TRUE, log.p=TRUE, version="2022") # ~ TRUE qnorm()
matplot(-lp, absP(cbind(qnU6, qnAsy)) / qnT - 1),
```

```

        ylim = c(2e-17, .01), xaxt = "n", yaxt = "n", col=1:7, lty=1:7,
        main = "relative |Error| of qnorm() approximations", type = "l", log = "xy")
abline(h = .Machine$double.eps * c(1/2, 1, 2), col=adjustcolor("bisque",3/4),
       lty=c(5,2,5), lwd=c(1,3,1))
sfsmisc::eaxis(1, sub10 = 2, nintLog=20)
sfsmisc::eaxis(2, sub10 = c(-3, 2), nintLog=16)
mtext("qnT <- qnormR(*, version=\"2022\")", cex=0.9, adj=1)# ; p.ver()
legend("topright", c("qnormUappr6()",
                    paste0("qnormAsymp(*, order=",0:5,")")),
      bty="n", col=1:7, lty=1:7, cex = 0.8)

####=== Optimal cut points / regions for different approximation orders k =====

## Zoom into each each cut-point region :
p.qnormAsy2 <- function(r0, k, # use k-1 and k in region around r0
                      n = 2048, verbose=TRUE, ylim = c(-1,1) * 2.5e-16,
                      rr = seq(r0 * 0.5, r0 * 1.25, length = n), ...)
{
  stopifnot(is.numeric(rr), !is.unsorted(rr), # the initial 'r'
            length(k) == 1L, is.numeric(k), k == as.integer(k), k >= 1)
  k.s <- (k-1L):k; nks <- paste0("k=", k.s)
  if(missing(r0)) r0 <- quantile(rr, 2/3)# allow specifying rr instead of r0
  if(verbose) cat("Around r0 = ", r0,"; k = ", deparse(k.s), "\n")
  lp <- (-rr^2) # = -r^2 = -s <==> rr = sqrt(- lp)
  q <- qnormR(lp, lower.tail=FALSE, log.p=TRUE, version="2022-08")# *not* depending on R ver!
  pq <- pnorm(q., lower.tail=FALSE, log.p=TRUE) # ~ = lp
  ## the arg of pnorm() is the true qnorm(pq, ..) == q. by construction
  ## cbind(rr, lp, q., pq)
  r <- sqrt(- pq)
  stopifnot(all.equal(rr, r, tol=1e-15))
  qnAsy <- sapply(setNames(k.s, nks), function(ord)
                 qnormAsymp(pq, lower.tail=FALSE, log.p=TRUE, order=ord))
  relE <- qnAsy / q. - 1
  m <- cbind(r, pq, relE)
  if(verbose) {
    print(head(m, 9)); for(j in 1:2) cat(" ..... \n")
    print(tail(m, 4))
  }
  ## matplot(r, relE, type = "b", main = paste("around r0 = ", r0))
  matplot(r, relE, type = "l", ylim = ylim,
          main = paste("Relative error of qnormAsymp(*, k) around r0 = ", r0,
                      "for k = ", deparse(k.s)),
          xlab = quote(r == sqrt(-log(p))), ...)
  legend("topleft", nks, col=1:2, lty=1:2, bty="n", lwd=2)
  for(j in seq_along(k.s))
    lines(smooth.spline(r, relE[,j]), col=adjustcolor(j, 2/3), lwd=4, lty=2)
  cc <- "blue2"; lab <- substitute(r[0] == R, list(R = r0))
  abline(v = r0, lty=2, lwd=2, col=cc)
  axis(3, at= r0, labels=lab, col=cc, col.axis=cc, line=-1)
  abline(h = (-1:1)*.Machine$double.eps, lty=c(3,1,3),
        col=c("green3", "gray", "tan2"))
  invisible(cbind(r = r, qn = q., relE))
}

```

```

}

r0 <- c(27, 55, 109, 840, 36000, 6.4e8) # <--> in ../R/norm_f.R {and R's qnorm.c eventually}
## use k = 5 4 3 2 1 0 e.g. k = 0 good for r >= 6.4e8
for(ir in 2:length(r0)) {
  p.qnormAsy2(r0[ir], k = 5 +2-ir) # k = 5, 4, ..
  if(interactive() && ir < length(r0)) {
    cat("[Enter] to continue: "); cat(readLines(stdin(), n=1), "\n") }
}

```

qnormR	<i>Pure R version of R's qnorm() with Diagnostics and Tuning Parameters</i>
--------	---

Description

Computes R level implementations of R's `qnorm()` as implemented in C code (in R's 'Rmathlib'), historically and present.

Usage

```

qnormR1(p, mu = 0, sd = 1, lower.tail = TRUE, log.p = FALSE, trace = 0, version = )
qnormR (p, mu = 0, sd = 1, lower.tail = TRUE, log.p = FALSE, trace = 0,
        version = c("4.0.x", "1.0.x", "1.0_noN", "2020-10-17", "2022-08-04"))

```

Arguments

p	probability p , $1-p$, or $\log(p)$, $\log(1-p)$, depending on <code>lower.tail</code> and <code>log.p</code> .
mu	mean of the normal distribution.
sd	standard deviation of the normal distribution.
lower.tail, log.p	logical, see, e.g., <code>qnorm()</code> .
trace	logical or integer; if positive or TRUE, diagnostic output is printed to the console during the computations.
version	a character string specifying which version or variant is used. The <i>current</i> default, "4.0.x" is the one used in R versions up to 4.0.x. The two "1.0*" versions are as used up to R 1.0.1, based on Algorithm AS 111, improved by a branch for extreme tails by Wichura, <i>and</i> a final Newton step which is only sensible when <code>log.p=FALSE</code> . That final stepped is skipped for <code>version = "1.0_noN"</code> , "noN" := "no Newton". "2020-10-17" is the one committed to the R development sources on 2020-10-17, which prevents the worst for very large $ p $ when <code>log.p=TRUE</code> . "2022-08-04" uses very accurate asymptotic formulas found on that date and provides full double precision accuracy also for extreme tails.

Details

For `qnormR1(p, ...)`, `p` must be of length one, whereas `qnormR(p, m, s, ...)` works vectorized in `p`, `mu`, and `sd`. In the **DPQ** package source, `qnormR` is simply the result of `Vectorize(qnormR1, ...)`.

Value

a numeric vector like the input `q`.

Author(s)

Martin Maechler

References

For versions "1.0.x" and "1.0_noN":

Beasley, J.D. and Springer, S.G. (1977) Algorithm AS 111: The Percentage Points of the Normal Distribution. *JRSS C (Applied Statistics)* **26**, 118–121; doi:10.2307/2346889.

For the asymptotic approximations used in versions newer than "4.0.x", i.e., "2020-10-17" and later, see the reference(s) on `qnormAsymp`'s help page.

See Also

`qnorm`, `qnormAsymp`.

Examples

```
qR <- curve(qnormR, n = 2^11)
abline(h=0, v=0:1, lty=3, col=adjustcolor(1, 1/2))
with(qR, all.equal(y, qnorm(x), tol=0)) # currently shows TRUE
with(qR, all.equal(pnorm(y), x, tol=0)) # currently: mean rel. diff.: 2e-16
stopifnot(with(qR, all.equal(pnorm(y), x, tol = 1e-14)))

(ver.qn <- eval(formals(qnormR)$version)) # the possible versions
(doExtras <- DPQ::doExtras()) # TRUE e.g. if interactive()
lp <- - 4^(1:30) # effect of 'trace = *' :
qpAll <- sapply(ver.qn, function (V)
  qnormR(lp, log.p=TRUE, trace=doExtras, version = V))
head(qpAll) # the "1.0" versions underflow quickly ..

cAdj <- adjustcolor(palette(), 1/2)
matplot(-lp, -qpAll, log="xy", type="l", lwd=3, col=cAdj, axes=FALSE,
  main = "- qnormR(lp, log.p=TRUE, version = * )")
sfsmisc::eaxis(1, nintLog=15, sub=2); sfsmisc::eaxis(2)
lines(-lp, sqrt(-2*lp), col=cAdj[ncol(qpAll)+1])
leg <- as.expression(c(paste("version=", ver.qn), quote(sqrt(-2 %.% lp))))
matlines(-lp, -qpAll[,2:3], lwd=6, col=cAdj[2:3])
legend("top", leg, bty='n', col=cAdj, lty=1:3, lwd=2)

## Showing why/where R's qnorm() was poor up to 2020: log.p=TRUE extreme tail
### MM: more TODO? --> ~/R/MM/NUMERICS/dpq-functions/qnorm-extreme-bad.R
```

```

qs <- 2^seq(0, 155, by=1/8)
lp <- pnorm(qs, lower.tail=FALSE, log.p=TRUE)
## The inverse of pnorm() fails BADLY for extreme tails:
## this is identical to qnorm(.) in R <= 4.0.x:
qp <- qnormR(lp, lower.tail=FALSE, log.p=TRUE, version="4.0.x")
## asymptotically correct approximation :
qpA <- sqrt(- 2* lp)
##^
col2 <- c("black", adjustcolor(2, 0.6))
col3 <- c(col2, adjustcolor(4, 0.6))
## instead of going toward infinity, it converges at 9.834030e+07 :
matplot(-lp, cbind(qs, qp, qpA), type="l", log="xy", lwd = c(1,1,3), col=col3,
        main = "Poorness of qnorm(lp, lower.tail=FALSE, log.p=TRUE)",
        ylab = "qnorm(lp, .)", axes=FALSE)
sfsmisc::eaxis(1); sfsmisc::eaxis(2)
legend("top", c("truth", "qnorm(.) = qnormR(., \"4.0.x\")", "asympt. approx"),
      lwd=c(1,1,3), lty=1:3, col=col3, bty="n")

rM <- cbind(lp, qs, 1 - cbind(relE.qnorm=qp, relE.approx=qpA)/qs)
rM[ which(1:nrow(rM) %% 20 == 1) ,]

```

qntR

Pure R Implementation of R's qt() / qnt()

Description

A pure R implementation of R's C API ('Mathlib' specifically) `qnt()` function which computes (non-central) t quantiles.

The simple inversion (of `pnt()`) scheme has seen to be deficient, even in cases where `pnt()`, i.e., R's `pt(..., ncp=*)` does not loose accuracy.

Usage

```

qntR1(p, df, ncp, lower.tail = TRUE, log.p = FALSE,
      pnt = stats::pt, accu = 1e-13, eps = 1e-11)
qntR (p, df, ncp, lower.tail = TRUE, log.p = FALSE,
      pnt = stats::pt, accu = 1e-13, eps = 1e-11)

```

Arguments

`p, df, ncp` vectors of probabilities, degrees of freedom, and non-centrality parameter; see [qt](#).

`lower.tail, log.p` logical; see [qt](#).

`pnt` a [function](#) for computing the CDF of the (non-central) t-distribution.

`accu` a non-negative number, the "accu"racy desired in the "root finding" loop.

`eps` a non-negative number, used for determining the start interval for the root finding.

Value

numeric vector of t quantiles, properly recycled in (p, df, ncp).

Author(s)

Martin Maechler

See Also

Our [qtU\(\)](#) and [qtAppr\(\)](#); non-central density and probability approximations in [dntJKBf](#), and e.g., [pntR](#). Further, R's [qt](#).

Examples

```
## example where qt() and qntR() "fail" {warnings; --> Inf}
lp <- seq(-30, -24, by=1/4)
summary(p <- exp(lp))
(qp <- qntR( p, df=35, ncp=-7, lower.tail=FALSE))
qp2 <- qntR(lp, df=35, ncp=-7, lower.tail = FALSE, log.p=TRUE)
all.equal(qp, qp2)## same warnings, same values
```

qpoisR

Pure R Implementation of R's qpois() with Tuning Parameters

Description

A pure R implementation, including many tuning parameter arguments, of R's own Rmathlib C code algorithm, but with more flexibility.

It is using [Vectorize](#)(qpoisR1, *) where the hidden qpoisR1 works for numbers (aka 'scalar', length one) arguments only, the same as the C code.

Usage

```
qpoisR(p, lambda, lower.tail = TRUE, log.p = FALSE,
       yLarge = 4096, # was hard wired to 1e5
       incF = 1/64,   # was hard wired to .001
       iShrink = 8,   # was hard wired to 100
       relTol = 1e-15, # was hard wired to 1e-15
       pfEps.n = 8,   # was hard wired to 64: "fuzz to ensure left continuity"
       pfEps.L = 2,   # was hard wired to 64: " " ..
       fpf = 4, # *MUST* be >= 1 (did not exist previously)
       trace = 0)
```

Arguments

p, lambda, lower.tail, log.p	<code>qpois()</code> standard argument, see its help page.
yLarge	a positive number; in R up to 2021, was internally hardwired to <code>yLarge = 1e5</code> : Uses more careful search for $y \geq y_L$, where y is the initial approximate result, derived from a Cornish-Fisher expansion.
incF	a positive “increment factor” (originally hardwired to 0.001), used only when $y \geq y_{Large}$; defines the initial increment in the search algorithm as <code>incr <- floor(incF * y)</code> .
iShrink	a positive increment shrinking factor, used only when $y \geq y_{Large}$ to define the new increment from the old one as <code>incr <- max(1, floor(incr/iShrink))</code> where the LHS was hardired original to <code>(incr/100)</code> .
relTol	originally hard wired to <code>1e-15</code> , defines the convergence tolerance for the search iterations when $y \geq y_{Large}$; the iterations stop when <code>(new) incr <= y * relTol</code> .
pfEps.n, pfEps.L	positive factors defining “fuzz to ensure left continuity”, both originally hard-wired to 64, the fuzz adjustment was <code>p <- p * (1 - 64 *.Machine\$double.eps)</code> Now, <code>pfEps.L</code> is used if <code>(log.p)</code> is true and <code>pfEps.n</code> is used otherwise (“normal case”), and the adjustments also depend on <code>lower.tail</code> , and also on <code>fpf</code> :
fpf	a number larger than 1, together with <code>pfEps.n</code> determines the fuzz-adjustment to <code>p</code> in the case <code>(lower=tail=FALSE, log.p=FALSE)</code> : with <code>e <- pfEps.n * .Machine\$double.eps</code> , the adjustment <code>p <- p * (1 + e)</code> is made <i>iff</i> <code>1 - p > fpf*e</code> .
trace	logical (or integer) specifying if (and how much) output should be produced from the algorithm.

Details

The defaults and exact meaning of the algorithmic tuning arguments from `yLarge` to `fpf` were experimentally determined are subject to change.

Value

a numeric vector like `p` recycled to the common lengths of `p` and `lambda`.

Author(s)

Martin Maechler

See Also

[qpois](#).

Examples

```
x <- 10*(15:25)
Pp <- ppois(x, lambda = 100, lower.tail = FALSE) # no cancellation
qPp <- qpois(Pp, lambda = 100, lower.tail=FALSE)
table(x == qPp) # all TRUE ?
## future: if(getRversion() >= "4.2") stopifnot(x == qPp) # R-devel
qpRp <- qpoisR(Pp, lambda = 100, lower.tail=FALSE)
all.equal(x, qpRp, tol = 0)
stopifnot(all.equal(x, qpRp, tol = 1e-15))
```

qtAppr

*Compute Approximate Quantiles of the (Non-Central) t-Distribution***Description**

Compute quantiles (inverse distribution values) for the non-central t distribution. using Johnson, Kotz, ... p.521, formula (31.26 a) (31.26 b) & (31.26 c)

Note that `qt(..., ncp=*)` did not exist yet in 1999, when MM implemented `qtAppr()`.

`qtNappr()` approximates t-quantiles for large df, i.e., when close to the Gaussian / normal distribution, using up to 4 asymptotic terms from Abramowitz & Stegun 26.7.5 (p.949).

Usage

```
qtAppr(p, df, ncp, lower.tail = TRUE, log.p = FALSE, method = c("a", "b", "c"))
qtNappr(p, df, lower.tail = TRUE, log.p=FALSE, k)
```

Arguments

p	vector of probabilities.
df	degrees of freedom > 0, maybe non-integer.
ncp	non-centrality parameter δ ;
lower.tail, log.p	logical, see, e.g., <code>qt()</code> .
method	a string specifying the approximation method to be used.
k	an integer in {0,1,2,3,4}, choosing the number of terms in <code>qtNappr()</code> .

Value

numeric vector of length `length(p) + df + ncp` with approximate t-quantiles.

References

Johnson, N.L., Kotz, S. and Balakrishnan, N. (1995) Continuous Univariate Distributions Vol~2, 2nd ed.; Wiley; chapter 31, Section 6 *Approximation*, p.519 ff

Abramowitz, M. and Stegun, I. A. (1972) *Handbook of Mathematical Functions*. New York: Dover; formula (26.7.5), p.949; https://en.wikipedia.org/wiki/Abramowitz_and_Stegun provides links to the full text which is in public domain.

Description

A pure R implementation of R's Mathlib own C-level `qt()` function. `qtR()` is simply defined as

```
qtR <- Vectorize(qtR1, c("p","df"))
```

where in `qtR1(p, df, *)` both `p` and `df` must be of length one.

Usage

```
qtR1(p, df, lower.tail = TRUE, log.p = FALSE,
      eps = 1e-12, d1_accu = 1e-13, d1_eps = 1e-11,
      itNewt = 10L, epsNewt = 1e-14, logNewton = log.p,
      verbose = FALSE)
qtR (p, df, lower.tail = TRUE, log.p = FALSE,
     eps = 1e-12, d1_accu = 1e-13, d1_eps = 1e-11,
     itNewt = 10L, epsNewt = 1e-14, logNewton = log.p,
     verbose = FALSE)
```

Arguments

<code>p, df</code>	vectors of probabilities and degrees of freedom, see qt .
<code>lower.tail, log.p</code>	logical; see qt .
<code>eps</code>	non-negative tolerance for checking if <code>df</code> is “very close” to 1 or 2, respectively (when a special branch will be chosen).
<code>d1_accu, d1_eps</code>	non-negative tolerances only for the <code>df < 1</code> cases.
<code>itNewt</code>	integer, the maximal number of final Newton(-Raphson) steps.
<code>epsNewt</code>	non-negative convergence tolerance for the final Newton steps.
<code>logNewton</code>	logical, in case of <code>log.p=TRUE</code> indicating if final Newton steps should happen in log-scale.
<code>verbose</code>	logical indicating if diagnostic console output should be produced.

Value

numeric vector of `t` quantiles, properly recycled in `(p, df)`.

Author(s)

Martin Maechler

See Also

[qtU](#) and R's [qt](#).

Examples

```
## Inspired from Bugzilla PR#16380
pxy <- curve(pt(-x, df = 1.09, log.p = TRUE), 4e152, 1e156, log="x", n=501)
qxy <- curve(-qt(x, df = 1.09, log.p = TRUE), -392, -385, n=501, log="y", col=4, lwd=2)
lines(x ~ y, data=pxy, col = adjustcolor(2, 1/2), lwd=5, lty=3)
## now our "pure R" version:

qRy <- -qtR(qxy$x, df = 1.09, log.p = TRUE)
all.equal(qRy, qxy$y) # "'is.NA' value mismatch: 14 in current 0 in target" for R <= 4.2.1
cbind(as.data.frame(qxy), qRy, D = qxy$y - qRy)
plot((y - qRy) ~ x, data = qxy, type="o", cex=1/4)

qtR1(.1, .1, verbose=TRUE)
pt(qtR(-390.5, df=1.10, log.p=TRUE, verbose=TRUE, itNewt = 100), df=1.10, log.p=TRUE)/-390.5 - 1
## qt(p=      -390.5, df=          1.1, *) -- general case
## -> P=2.55861e-170, neg=TRUE, is_neg_lower=TRUE; -> final P=5.11723e-170
## usual 'df' case: P_ok:= P_ok1 = TRUE, y=3.19063e-308, P..., !P_ok: log.p2=-390.5, y=3.19063e-308
## !P_ok && x < -36.04: q=5.87162e+153
## P_ok1: log-scale Taylor (iterated):
## it= 1, .. d{q}1=exp(1F - dt(q,df,log=T))*(1F - log(P/2)) = -5.03644e+152; n.q=5.36798e+153
## it= 2, .. d{q}1=exp(1F - dt(q,df,log=T))*(1F - log(P/2)) =  2.09548e+151; n.q=5.38893e+153
## it= 3, .. d{q}1=exp(1F - dt(q,df,log=T))*(1F - log(P/2)) =  4.09533e+148; n.q=5.38897e+153
## it= 4, .. d{q}1=exp(1F - dt(q,df,log=T))*(1F - log(P/2)) =  1.5567e+143; n.q=5.38897e+153
## [1] 0
##    == perfect!
pt(qtR(-391, df=1.10, log.p=TRUE, verbose=TRUE),
  df=1.10, log.p=TRUE)/-391 - 1 # now perfect
```

qtU

'uniroot()'-based Computing of t-Distribution Quantiles

Description

Currently, R's own `qt()` (aka `qnt()` in the non-central case) uses simple inversion of `pt` to compute quantiles in the case where `ncp` is specified.

That simple inversion (of `pnt()`) has seen to be deficient, even in cases where `pnt()`, i.e., R's `pt(..., ncp=*)` does not loose accuracy.

This `uniroot()`-based inversion does *not* suffer from these deficits in some cases.

`qtU()` is simply defined as

```
qtU <- Vectorize(qtU1, c("p", "df", "ncp"))
```

where in `qtU1(p, df, ncp, *)` each of `(p, df, ncp)` must be of length one.

Usage

```
qtU1(p, df, ncp, lower.tail = TRUE, log.p = FALSE, interval = c(-10, 10),
     tol = 1e-05, verbose = FALSE, ...)
qtU(p, df, ncp, lower.tail = TRUE, log.p = FALSE, interval = c(-10, 10),
    tol = 1e-05, verbose = FALSE, ...)
```

Arguments

p, df, ncp	vectors of probabilities, degrees of freedom, and non-centrality parameter; see qt . As there, ncp may be missing which amounts to being zero.
lower.tail, log.p	logical; see qt .
interval	the interval in which quantiles should be searched; passed to uniroot() ; the current default is arbitrary and suboptimal; when pt(q,*) is accurate enough and hence <i>montone</i> (increasing iff <code>lower.tail</code>), this interval is automatically correctly extended by uniroot() .
tol	non-negative convergence tolerance passed to uniroot() .
verbose	logical indicating if <i>every</i> call of the objective function should produce a line of console output.
...	optional further arguments passed to uniroot() .

Value

numeric vector of t quantiles, properly recycled in (p, df, ncp).

Author(s)

Martin Maechler

See Also

[uniroot](#) and [pt](#) are the simple R level building blocks. The length-1 argument version [qtU1\(\)](#) is short and simple to understand.

Examples

```
qtU1 # simple definition {with extras only for 'verbose = TRUE'}

## An example, seen to be deficient
## Stephen Berman to R-help, 13 June 2022,
## "Why does qt() return Inf with certain negative ncp values?"
q2 <- seq(-3/4, -1/4, by=1/128)
pq2 <- pt(q2, 35, ncp=-7, lower.tail=FALSE)
### ==> via qtU(), a simple uniroot() - based inversion of pt()
qpqU <- qtU(pq2, 35, ncp=-7, lower.tail=FALSE, tol=1e-10)
stopifnot(all.equal(q2, qpqU, tol=1e-9)) # perfect!

## These two currently (2022-06-14) give Inf whereas qtU() works fine
qt (9e-12, df=35, ncp=-7, lower.tail=FALSE) # warnings; --> Inf
qntR(9e-12, df=35, ncp=-7, lower.tail=FALSE) # (ditto)
## verbose = TRUE shows all calls to pt():
qtU1(9e-12, df=35, ncp=-7, lower.tail=FALSE, verbose=TRUE)
```

`rexp1`*TOMS 708 Approximation REXP(x) of exp1(x) = exp(x) - 1*

Description

Originally `REXP()`, now `rexp1()` is a numeric (double precision) approximation of $\exp(x) - 1$, notably for small $|x| \ll 1$ where direct evaluation loses accuracy through cancellation.

Fully accurate computations of $\exp(x) - 1$ are now known as `expm1(x)` and have been provided by math libraries (for C, C++, ..) and R, (and are typically more accurate than `rexp1()`).

The `rexp1()` approximation was developed by Didonato & Morris (1986) and uses a minimax rational approximation for $|x| \leq 0.15$; the authors say “*accurate to within 2 units of the 14th significant digit*” (top of p.379).

Usage

`rexp1(x)`

Arguments

`x` a numeric vector.

Value

a numeric vector (or array) as `x`,

Author(s)

Martin Maechler, for the C to R *vectorized* translation.

References

Didonato, A.R. and Morris, A.H. (1986) Computation of the Incomplete Gamma Function Ratios and their Inverse. *ACM Trans. on Math. Softw.* **12**, 377–393, doi:10.1145/22721.23109; The above is the “flesh” of ‘TOMS 654’:

Didonato, A.R. and Morris, A.H. (1987) Algorithm 654: FORTRAN subroutines for Compute the Incomplete Gamma Function Ratios and their Inverse. *ACM Transactions on Mathematical Software* **13**, 318–319, doi:10.1145/29380.214348.

See Also

`pbeta`, where the C version of `rexp1()` has been used in several places, notably in the original TOMS 708 algorithm.

Examples

```

x <- seq(-3/4, 3/4, by=1/1024)
plot(x, rexp1(x)/expm1(x) - 1, type="l", main = "Error wrt expm1()")
abline(h = (-8:8)*2^-53, lty=1:2, col=adjustcolor("gray", 1/2))
cb2 <- adjustcolor("blue", 1/2)
do.15 <- function(col = cb2) {
  abline(v = 0.15*(-1:1), lty=3, lwd=c(3,1,3), col=col)
  axis(1, at=c(-.15, .15), col=cb2, col.axis=cb2)
}
do.15()

op <- par(mar = par("mar") + c(0,0,0,2))
plot(x, abs(rexp1(x)/expm1(x) - 1), type="l", log = 'y',
      main = "*Relative* Error wrt expm1() [log scale]"), yaxt="n")
abline(h = (1:9)*2^-53, lty=2, col=adjustcolor("gray", 1/2))
axis(4, at = (1:9)*2^-53, las = 1, labels =
      expression(2^-53, 2^-52, 3 %*% 2^-53, 2^-51, 5 %*% 2^-53,
                 6 %*% 2^-53, 7 %*% 2^-53, 2^-50, 9 %*% 2^-53))
do.15()
par(op)

## "True" Accuracy comparison of rexp1() with [OS mathlib based] expm1():
if(require("Rmpfr")) withAutoprint({
  xM <- mpfr(x, 128); Xexpm1 <- expm1(xM)
  REr1 <- asNumeric(rexp1(x)/Xexpm1 - 1)
  REe1 <- asNumeric(expm1(x) /Xexpm1 - 1)
  absC <- function(E) pmax(2^-55, abs(E))

  plot(x, absC(REr1), type= "l", log="y",
        main = "|rel.Error| of exp(x)-1 computations wrt 128-bit MPFR ")
  lines(x, absC(REe1), col = (c2 <- adjustcolor(2, 3/4)))
  abline(h = (1:9)*2^-53, lty=2, col=adjustcolor("gray60", 1/2))
  do.15()
  axis(4, mgp=c(2,1/4,0), tcl=-1/8, at=2^-(53:51), labels=expression(2^-53, 2^-52, 2^-51), las=1)
  legend("topleft", c("rexp1(x)", " expm1(x)"), lwd=2, col=c("black", c2),
        bg = "gray90", box.lwd=.1)

})

```

r_pois

*Compute Relative Size of i-th term of Poisson Distribution Series***Description**

Compute

$$r_{\lambda}(i) := (\lambda^i / i!) / e_{i-1}(\lambda),$$

where $\lambda = \text{lambda}$, and

$$e_n(x) := 1 + x + x^2/2! + \dots + x^n/n!$$

is the n -th partial sum of $\exp(x) = e^x$.

Questions: As function of i

- Can this be put in a simple formula, or at least be well approximated for large λ and/or large i ?
- For which i ($:= i_m(\lambda)$) is it maximal?
- When does $r_\lambda(i)$ become smaller than $(f+2i-x)/x = a + b*i$?

NB: This is relevant in computations for non-central chi-squared (and similar non-central distribution functions) defined as weighted sum with ‘‘Poisson weights’’.

Usage

```
r_pois(i, lambda)
r_pois_expr # the R expression() for the asymptotic branch of r_pois()

plRpois(lambda, iset = 1:(2*lambda), do.main = TRUE,
         log = 'xy', type = "o", cex = 0.4, col = c("red", "blue"),
         do.eaxis = TRUE, sub10 = "10")
```

Arguments

i	integer ..
lambda	non-negative number ...
iset
do.main	logical specifying if a main title should be drawn via (main = r_pois_expr).
type	type of (line) plot, see lines .
log	string specifying if (and where) logarithmic scales should be used, see plot.default() .
cex	character expansion factor.
col	colors for the two curves.
do.eaxis	logical specifying if eaxis() (package sfsmisc) should be used.
sub10	argument for eaxis() (with a different default than the original).

Details

r_pois() is related to our series expansions and approximations for the non-central chi-squared; in particular

plRpois() simply produces a ‘‘nice’’ plot of r_pois(ii, *) vs ii.

Value

r_pois() returns a numeric vector $r_\lambda(i)$ values.

r_pois_expr() an [expression](#).

Author(s)

Martin Maechler, 20 Jan 2004

See Also

[dpois\(\)](#).

Examples

```
pLRpois(12)
pLRpois(120)
```

stirlerr

Stirling's Error Function - Auxiliary for Gamma, Beta, etc

Description

Stirling's approximation (to the factorial or Γ function) error in log scale is the difference of the left and right hand side of Stirling's approximation to $n!$, $n! \approx \left(\frac{n}{e}\right)^n \sqrt{2\pi n}$, i.e., $\text{stirlerr}(n) := \delta(n)$, where

$$\delta(n) = \log \Gamma(n + 1) - n \log(n) + n - \log(2\pi n)/2.$$

Partly, pure R transcriptions of the C code utility functions for [dgamma\(\)](#), [dbinom\(\)](#), [dpois\(\)](#), [dt\(\)](#), and similar "base" density functions by Catherine Loader.

These **DPQ** versions typically have extra arguments with defaults that correspond to R's Mathlib C code hardwired cutoffs and tolerances.

[lgammacor\(x\)](#) is "the same" as [stirlerr\(x\)](#), both computing $\delta(x)$ accurately, however is only defined for $x \geq 10$, and has been crucially used for R's own [lgamma\(\)](#) and [lbeta\(\)](#) computations.

Note that the example below suggests that R's hardwired default of `na.lgm = 5` is unnecessarily losing more than one digit accuracy, `na.lgm = 6` seems much better.

Usage

```
stirlerr(n, scheme = c("R3", "R4.4_0"),
         cutoffs = switch(scheme
                          , R3      = c(15, 35, 80, 500)
                          , R4.4_0 = c(5.25, rep(6.5, 4), 7.1, 7.6, 8.25, 8.8, 9.5, 11,
                                          14, 19, 25, 36, 81, 200, 3700, 17.4e6)
                          ),
         use.halves = missing(cutoffs),
         direct.ver = c("R3", "lgamma1p", "MM2", "n0"),
         order = NA,
         verbose = FALSE)

stirlerrC(n, version = c("R3", "R4..1", "R4.4_0"))
```

```
stirlerr_simpl(n, version = c("R3", "lgamma1p", "MM2", "n0"), minPrec = 128L)
lgammacor(x, nalgm = 5, xbig = 2^26.5)
```

Arguments

<code>x, n</code>	numeric (or number-alike such as "mpfr").
<code>verbose</code>	logical indicating if some information about the computations are to be printed.
<code>version</code>	a character string specifying the version of <code>stirlerr_simpl()</code> or <code>stirlerrC()</code> .
<code>scheme</code>	a character string specifying the cutoffs scheme for <code>stirlerr()</code> .
<code>cutoffs</code>	an increasing numeric vector, required to start with <code>cutoffs[1] <= 15</code> specifying the cutoffs to switch from 2 to 3 to ..., up to 10 term approximations for non-small n , where the direct formula loses precision. When missing (as by default), <code>scheme</code> is used, where <code>scheme = "R3"</code> chooses (15, 35, 80, 500), the cutoffs in use in R versions up to (and including) 4.3.z.
<code>use.halves</code>	logical indicating if the full-accuracy prestored values should be use when $2n \in \{0, 1, \dots, 30\}$, i.e., $n \leq 15$ and n is integer or integer + $\frac{1}{2}$. Turn this off to judge the underlying approximation accuracy by comparison with MPFR. However, keep the default TRUE for back-compatibility.
<code>direct.ver</code>	a character string specifying the version of <code>stirlerr_simpl()</code> to be used for the "direct" case in <code>stirlerr(n)</code> .
<code>order</code>	approximation order, $1 \leq \text{order} \leq 20$ or NA for <code>stirlerr()</code> . If not NA, it specifies the number of terms to be used in the Stirling series which will be used for all n , i.e., <code>scheme</code> , <code>cutoffs</code> , <code>use.halves</code> , and <code>direct.ver</code> are irrelevant.
<code>minPrec</code>	a positive integer; for <code>stirlerr_simpl</code> the minimal accuracy or precision in bits when mpfr numbers are used.
<code>nalgm</code>	number of terms to use for Chebyshev polynomial approximation in <code>lgammacor()</code> . The default, 5, is the value hard wired in R's C Mathlib.
<code>xbig</code>	a large positive number; if $x \geq \text{xbig}$, the simple asymptotic approximation $\text{lgammacor}(x) := 1/(12*x)$ is used. The default, $2^{26.5} = 94906265.6$, is the value hard wired in R's C Mathlib.

Details

`stirlerr()`: Stirling's error, $\text{stirlerr}(n) := \delta(n)$ has asymptotic ($n \rightarrow \infty$) expansion

$$\delta(n) = \frac{1}{12n} - \frac{1}{360n^3} + \frac{1}{1260n^5} \pm O(n^{-7}),$$

and this expansion is used up to remainder $O(n^{-35})$ in current (package **DPQ**) `stirlerr(n)`; different numbers of terms between different cutoffs for n , and using the direct formula for $n \leq c_1$, where c_1 is the first cutoff, `cutoff[1]`.

Note that (new in 2024-01) `stirlerr(n, order = k)` will *not* use cutoffs nor the direct formula (with its `direct.ver`), nor halves (`use.halves=TRUE`), and allows $k \leq 20$. Tests seem to indicate that for current double precision arithmetic, only $k \leq 17$ seem to make sense.

Value

a numeric vector “like” x ; in some cases may also be an (high accuracy) “mpfr”-number vector, using CRAN package **Rmpfr**.

`lgammacor(x)` originally returned NaN for all $|x| < 10$, as its Chebyshev polynomial approximation has been constructed for $x \in [10, x_{big}]$, specifically for $u \in [-1, 1]$ where $t := 10/x \in [1/x_B, 1]$ and $u := 2t^2 - 1 \in [-1 + \epsilon_B, 1]$.

Author(s)

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References

C. Loader (2000), see [dbinom](#)’s documentation.

Our package vignette *log1pmx, bd0, stirlerr - Probability Computations in R*.

See Also

[dgamma](#), [dpois](#). High precision versions `stirlerrM(n)` and `stirlerrSer(n,k)` in package **DPQmpfr** (via the **Rmpfr** and **gmp** packages).

Examples

```
n <- seq(1, 50, by=1/4)
st.n <- stirlerr(n) # now vectorized
stopifnot(identical(st.n, sapply(n, stirlerr)))
st3. <- stirlerr(n, "R3", direct.ver = "R3") # previous default
st3 <- stirlerr(n, "R3", direct.ver = "lgamma1p") # new? default
## for these n, there is *NO* difference:
stopifnot(st3 == st3.)
plot(n, st.n, type = "b", log="xy", ylab = "stirlerr(n)")
st4 <- stirlerr(n, "R4.4_0", verbose = TRUE) # verbose: give info on cases
## order = k = 1:20 terms in series approx:
k <- 1:20
stirlOrd <- sapply(k, function(k) stirlerr(n, order = k))
matlines(n, stirlOrd)
matplot(n, stirlOrd - st.n, type = "b", cex=1/2, ylim = c(-1,1)/10, log = "x",
        main = substitute(list(stirlerr(n, order=k) ~"error", k == 1:mK), list(mK = max(k))))

matplot(n, abs(stirlOrd - st.n), type = "b", cex=1/2, log = "xy",
        main = "| stirlerr(n, order=k) error |")
mtext(paste("k =", deparse(k))) ; abline(h = 2^-(53:51), lty=3, lwd=1/2)
colnames(stirlOrd) <- paste0("k=", k)

stCn <- stirlerrC(n)
all.equal(st.n, stCn, tolerance = 0) # see 6.7447e-14
stopifnot(all.equal(st.n, stCn, tolerance = 1e-12))
stC2 <- stirlerrC(n, version = "R4..1")
stC4 <- stirlerrC(n, version = "R4.4_0")
```

```

## lgamma(n) : only defined for n >= 10
lgcor <- lgamma(n)
lgcor6 <- lgamma(n, nalgm = 6) # more accurate?

all.equal(lgcor[n >= 10], st.n[n >= 10], tolerance=0)# .. rel.diff.: 4.687e-14
stopifnot(identical(is.na(lgcor), n < 10),
           all.equal(lgcor[n >= 10],
                     st.n [n >= 10], tolerance = 1e-12))

## look at *relative* errors -- need "Rmpfr" for "truth" % Rmpfr / DPQmpfr in 'Suggests'
if(requireNamespace("Rmpfr") && requireNamespace("DPQmpfr")) {
  ## stirlerr(n) uses DPQmpfr::stirlerrM() automatically when n is <mpfr>
  relErrV <- sfsmisc::relErrV; eaxis <- sfsmisc::eaxis
  mpfr <- Rmpfr::mpfr; asNumeric <- Rmpfr::asNumeric
  stM <- stirlerr(mpfr(n, 512))
  relE <- asNumeric(relErrV(stM, cbind(st3, st4, stCn, stC4,
                                     lgcor, lgcor6, stirlOrd)))

  matplot(n, pmax(abs(relE), 1e-20), type="o", cex=1/2, log="xy", ylim =c(8e-17, 0.1),
           xaxt="n", yaxt="n", main = quote(abs(relErr(stirlerr(n))))))
  ## mark "lgcor*" -- lgamma(n) particularly !
  col.lgc <- adjustcolor(c(2,4), 2/3)
  matlines(n, abs(relE[,c("lgcor", "lgcor6")]), col=col.lgc, lwd=3)
  lines(n, abs(relE[, "lgcor6"]), col=adjustcolor(4, 2/3), lwd=3)
  eaxis(1, sub10=2); eaxis(2); abline(h = 2^-(53:51), lty=3, col=adjustcolor(1, 1/2))
  axis(1, at=15, col=NA, line=-1); abline(v=c(10,15), lty=2, col=adjustcolor(1, 1/4))
  legend("topright", legend=colnames(relE), cex = 3/4,
        col=1:6, lty=1:5, pch= c(1L:9L, 0L, letters)[seq_len(ncol(relE))])
  legend("topright", legend=colnames(relE)[1:6], cex = 3/4, lty=1:5, lwd=3,
        col=c(rep(NA,4), col.lgc), bty="n")
  ## Note that lgamma(x) {default, n=5} is clearly inferior,
  ## but lgamma(x, 6) is really good {in [10, 50] at least}
}# end if( <Rmpfr> )

```

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