

How to generate new distributions in packages "`distr`", "`distrEx`"

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Version control information:

Head URL: <svn+ssh://ruckdeschel@svn.r-forge.r-project.org/svnroot/distr/pkg/distr/vignettes/newDistributions-knitr.Rnw>
Last changed date: 2022-11-12 14:50:48 +0100 (Sa, 12. Nov 2022)
Last changes revision: 1374
Version: Revision 1374
Last changed by: Peter Ruckdeschel (ruckdeschel)

May 7, 2023

Abstract

In this vignette, we give short examples how to produce new distributions in packages "`distr`" and "`distrEx`". This vignette refers to package version 2.7.

Basically there are three ways to produce new distributions in packages "`distr`" and "`distrEx`":

1. automatic generation of single distribution objects by arithmetics and the like
2. using generating functions to produce single distribution objects
3. defining new distribution classes / doing it from scratch

We will give short examples of all three of them.

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1 Automatic generation by arithmetics and the like

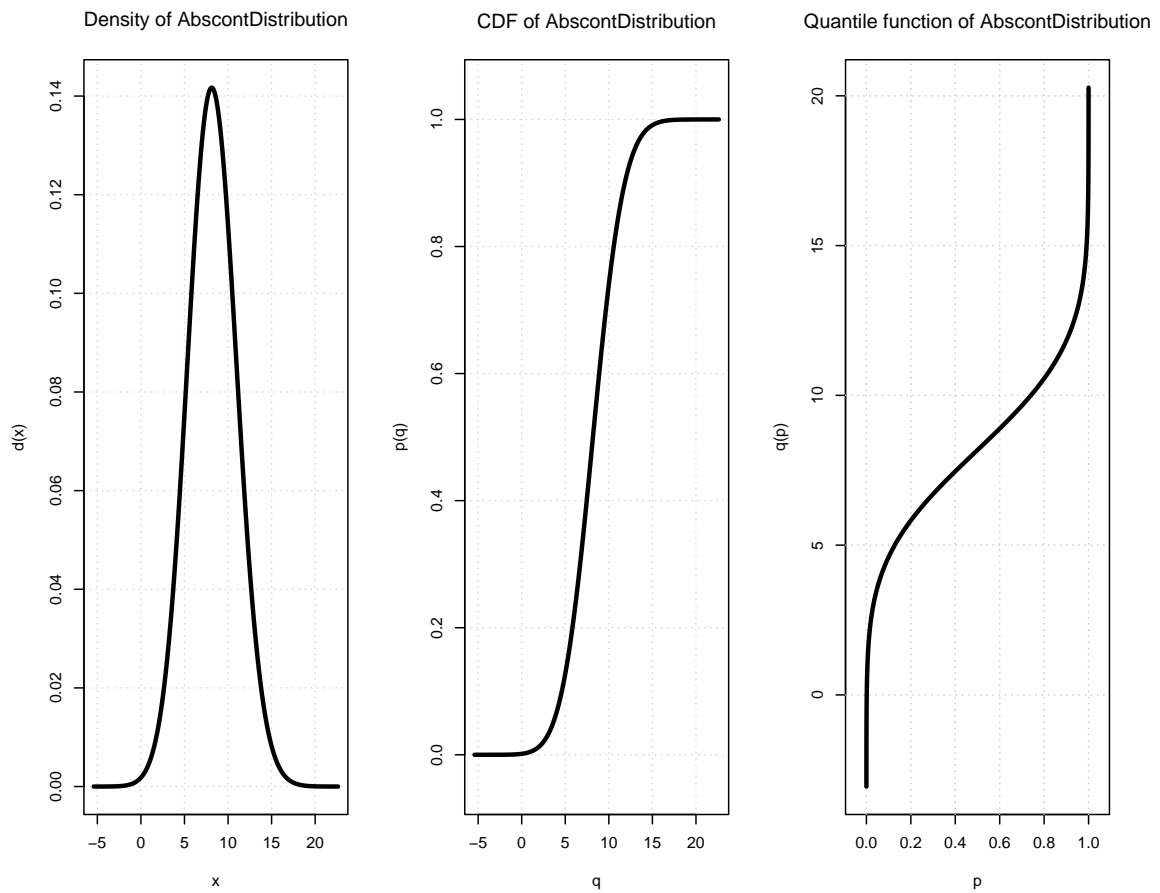
We have made available quite general arithmetical operations to our distribution objects, generating new image distribution objects automatically. As an example, try

```
require(distr)
N <- Norm(mean = 2, sd = 1.3)
P <- Pois(lambda = 1.2)
Z <- 2*N + 3 + P
Z

## Distribution Object of Class: AbscontDistribution

## Warning in methods::show(x): arithmetics on distributions are understood as operations
on r.v.'s
## see 'distrARITH()'; for switching off this warning see '?distrOptions'

plot(Z, panel.first = grid(), lwd=3)
```



```

p(Z)(0.4)
## [1] 0.002415402

q(Z)(0.3)
## [1] 6.705068

## in RStudio or Jupyter IRKernel, use q.l(.)(.) instead of q(.)(.)
Zs <- r(Z)(50)
Zs
## [1] 7.060649 12.178681 11.058350 6.558189 11.660569 4.880812
## [7] 5.562933 6.161343 10.360223 8.580670 6.323012 9.804325
## [13] 3.883793 5.611886 7.068922 7.799435 8.850062 11.562541
## [19] 1.906356 9.544556 11.877043 10.846236 3.053054 9.019586
## [25] 7.805982 7.812951 8.853489 10.003837 12.858628 9.401044

```

```
## [31]  8.777803  5.876074  7.168226  9.540465  6.202422 15.314841
## [37]  7.970773 11.403179  9.150158  7.137060  2.404407 10.224761
## [43] 11.351813  4.249681  2.080497  5.963317  2.235871 11.264014
## [49]  5.428712  5.162254
```

Comment:

Let `N` an object of class "Norm" with parameters `mean=2`, `sd=1.3` and let `P` an object of class "Pois" with parameter `lambda=1.2`. Assigning to `Z` the expression `2*N+3+P`, a new distribution object is generated —of class "AbscontDistribution" in our case— so that identifying `N`, `P`, `Z` with random variables distributed according to `N`, `P`, `Z`, $\mathcal{L}(Z) = \mathcal{L}(2 * N + 3 + P)$, and writing `p(Z)(0.4)` we get $P(Z \leq 0.4)$, `q(Z)(0.3)` the 30%-quantile of `Z`, and with `r(Z)(50)` we generate 50 pseudo random numbers distributed according to `Z`, while the `plot` command generates the above figure.

In the environments of RStudio, see <https://posit.co/> and Jupyter IRKernel, see <https://github.com/IRkernel/IRkernel>, calls to `q` are caught away from standard R evaluation and are treated in a non-standard way. This non-standard evaluation in particular throws errors at calls to our accessor methods `q` to slot `q` of the respective distribution object. To amend this, from version 2.6 on, we provide function `q.l` (for left-continuous quantile function) as alias to our accessors `q`, so that all our package functionality also becomes available in RStudio and IRKernel.

There are caveats to take care about; for details refer to the (larger) vignette `distr` in package "distrDoc".

2 Using generating functions

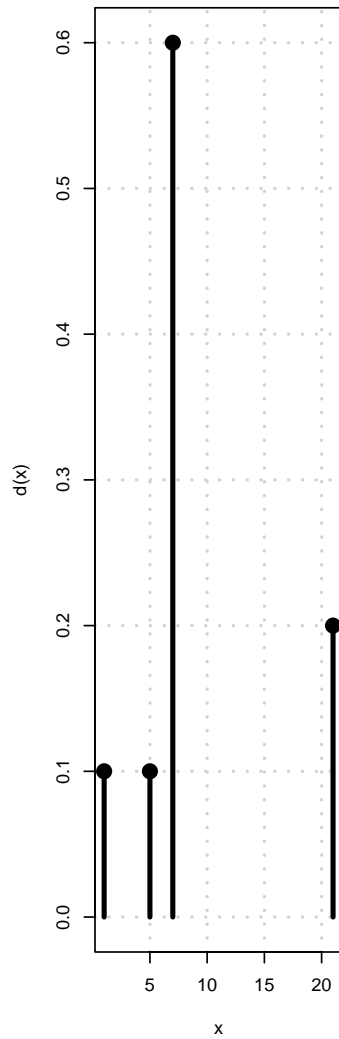
If you want to generate a single distribution object (without any particular parameter) generating functions are the method of choice:

Objects of classes `LatticeDistribution` resp. `DiscreteDistribution`, `AbscontDistribution`, may be generated using the generating functions `LatticeDistribution()` resp. `DiscreteDistribution()` resp. `AbscontDistribution()`; see also the corresponding help.

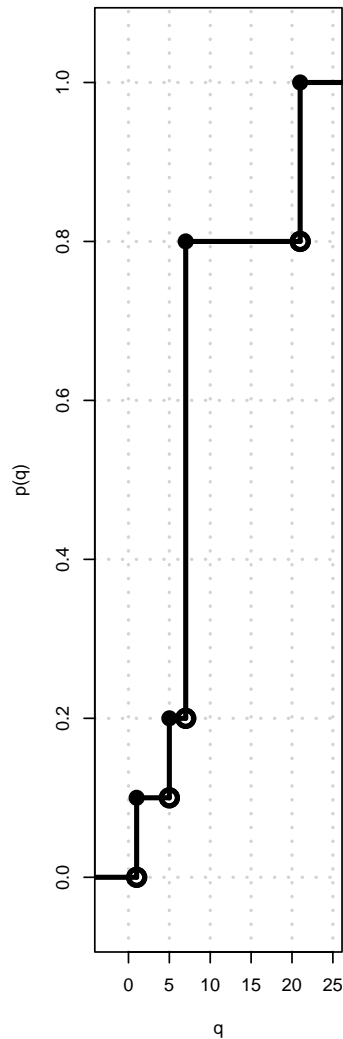
E.g., to produce a discrete distribution with support (1, 5, 7, 21) with corresponding probabilities (0.1, 0.1, 0.6, 0.2) we may write

```
D <- DiscreteDistribution(supp = c(1,5,7,21), prob = c(0.1,0.1,0.6,0.2))
D
## Distribution Object of Class: DiscreteDistribution
plot(D, panel.first = grid(lwd=2), lwd = 3)
```

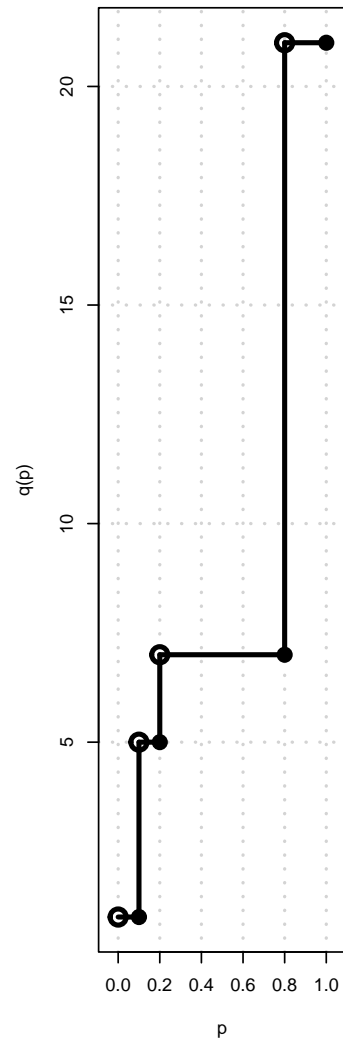
Probability function of DiscreteDistribu



CDF of DiscreteDistribution



Quantile function of DiscreteDistribut



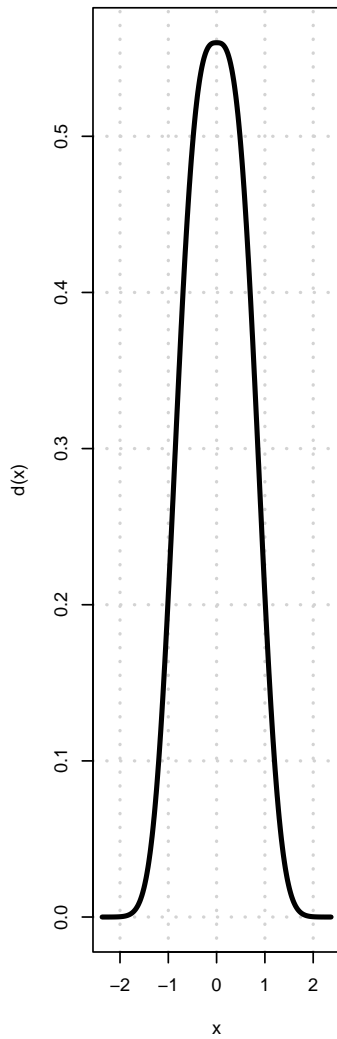
and to generate an absolutely continuous distribution with density proportional to $e^{-|x|^3}$, we write

```
AC <- AbscontDistribution(d = function(x) exp(-abs(x)^3), withStand = TRUE)
AC

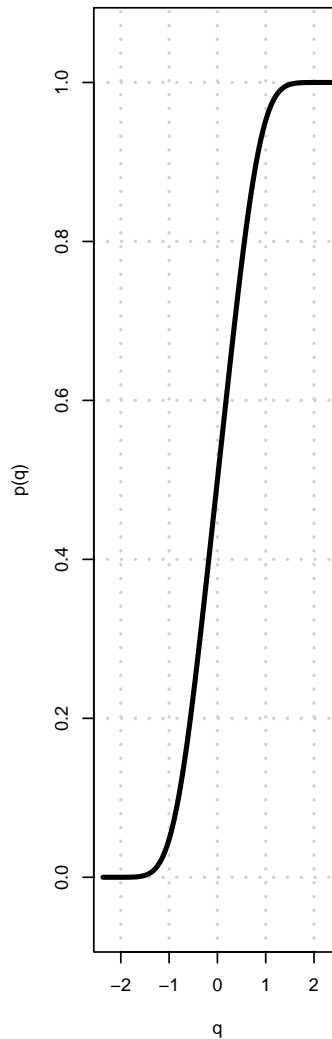
## Distribution Object of Class: AbscontDistribution

plot(AC, panel.first = grid(lwd=2), lwd = 3)
```

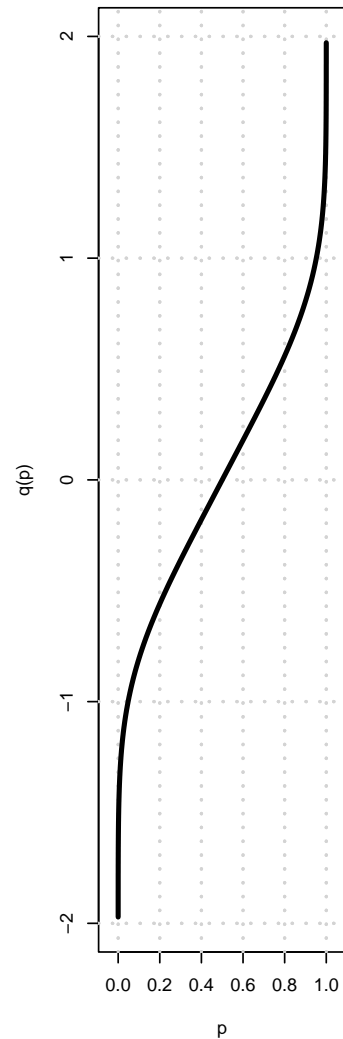
Density of AbscontDistribution



CDF of AbscontDistribution



Quantile function of AbscontDistribution



3 Doing it from scratch

If you would like to create new parametric distributions, using already implemented `r`, `d`, `p`, and `q` functions (e.g. implementing additional distributions realized in another [CRAN](#) package), you should probably envisage introducing new distribution `S4` (sub-)classes and hence better look at the implementation of some discrete and continuous parametric distribution classes in package "`distr`". Hint: download the `.tar.gz` file; extract it to some `temp` folder; look at subdirectories `R` and `man`

The general procedure is as follows

1. introduce a new subclass of class `Parameter`
2. introduce a new subclass of `LatticeDistribution`/`DiscreteDistribution` (if discrete) or of class `AbscontDistribution` (if continuous).
3. define accessor and replacement functions for the “slots” of the parameter (e.g. “`size`” and “`prob`” in the binomial case), possibly with new generics
4. (possibly) define a validity function
5. define a generating function
6. if existing, define particular convolution methods or similar particular methods for this new distribution class
7. create `.Rd` files for the
 - parameter class
 - distribution class
8. if analytic expressions are available, define particular `E`-, `var`-, `skewness`-, and `kurtosis`-methods and if so, also document¹ the corresponding methods in the distribution class `.Rd` file

Let’s go through the steps in the example case of the Binomial implementation in packages “`distr`” and “`distrEx`”:

1. in “`distr`”, see source in `R/AllClasses.R`,

```
## Class: BinomParameter
setClass("BinomParameter",
  representation = representation(size = "numeric", prob = "numeric"),
  prototype = prototype(size = 1, prob = 0.5, name =
    gettext("Parameter of a Binomial distribution")
  ),
  contains = "Parameter"
)
```

2. in “`distr`”, see source in `R/AllClasses.R`,

¹this is new, because so far, all `E`-, `var`-, `skewness`-, and `kurtosis`-methods for “basic” distributions are documented in the “`distrEx`” documentation to `E`, `var`, ..., but this would not be operational any longer for new derived classes, possibly defined in other, new packages

```

## Class: binomial distribution
setClass("Binom",
  prototype = prototype(
    r = function(n){ rbinom(n, size = 1, prob = 0.5) },
    d = function(x, log = FALSE){
      dbinom(x, size = 1, prob = 0.5, log = log)
    },
    p = function(q, lower.tail = TRUE, log.p = FALSE ){
      pbinom(q, size = 1, prob = 0.5,
        lower.tail = lower.tail, log.p = log.p)
    },
    q = function(p, lower.tail = TRUE, log.p = FALSE ){
      qbinom(p, size = 1, prob = 0.5,
        lower.tail = lower.tail, log.p = log.p)
    },
    img = new("Naturals"),
    param = new("BinomParameter"),
    support = 0:1,
    lattice = new("Lattice",
      pivot = 0, width = 1, Length = 2, name =
        gettext(
          "lattice of a Binomial distribution"
        )
      ),
    .logExact = TRUE,
    .lowerExact = TRUE
  ),
  contains = "LatticeDistribution"
)

```

3. in "distr", see source in R/BinomialDistribution.R,

```

## Access Methods
setMethod("size", "BinomParameter", function(object) object@size)
setMethod("prob", "BinomParameter", function(object) object@prob)
## Replace Methods
setReplaceMethod("size", "BinomParameter",
  function(object, value){ object@size <- value; object})
setReplaceMethod("prob", "BinomParameter",
  function(object, value){ object@prob <- value; object})

```

and R/AllGenerics,

```

if(!isGeneric("size"))
  setGeneric("size", function(object) standardGeneric("size"))

```



```
if(!isGeneric("prob"))
  setGeneric("prob", function(object) standardGeneric("prob"))
```

4. in "distr", see source in R/BinomialDistribution.R,

```
setValidity("BinomParameter", function(object){
  if(length(prob(object)) != 1)
    stop("prob has to be a numeric of length 1")
  if(prob(object) < 0)
    stop("prob has to be in [0,1]")
  if(prob(object) > 1)
    stop("prob has to be in [0,1]")
  if(length(size(object)) != 1)
    stop("size has to be a numeric of length 1")
  if(size(object) < 1)
    stop("size has to be a natural greater than 0")
  if(!identical(floor(size(object)), size(object)))
    stop("size has to be a natural greater than 0")
  else return(TRUE)
})
```

Class "BinomParameter" [in ".GlobalEnv"]

Slots:

Name: size prob name Class: numeric numeric character

Extends: Class "Parameter", directly Class "OptionalParameter", by class "Parameter", distance 2

5. in "distr", see source in R/BinomialDistribution.R,

```
Binom <- function(size = 1,prob = 0.5) new("Binom", size = size, prob = prob)
```

6. in "distr", see source in R/BinomialDistribution.R,

```
## Convolution for two binomial distributions Bin(n1,p1) and Bin(n2,p2)
## Distinguish cases
## p1 == p2 und p1 != p2

setMethod("+", c("Binom","Binom"),
  function(e1,e2){
    newsize <- size(e1) + size(e2)

    if(isTRUE(all.equal(prob(e1),prob(e2))))
      return(new("Binom", prob = prob(e1), size = newsize,
```

```

        .withArith = TRUE))
    return(as(e1, "LatticeDistribution") + e2)
})

```

7. in "distr", see sources in

- man/BinomParameter-class.Rd

```

\name{BinomParameter-class}
\docType{class}
\alias{BinomParameter-class}
\alias{initialize ,BinomParameter-method}

\title{Class "BinomParameter"}
\description{ The parameter of a binomial distribution , used by Binom-class }
\section{Objects from the Class}{
Objects can be created by calls of the form
  \code{new("BinomParameter", prob, size)}.
Usually an object of this class is not needed on its own, it is generated
automatically when an object of the class Binom
is instantiated.
}
\section{Slots}{
  \describe{
    \item{\code{prob}}{Object of class \code{"numeric"}:
      the probability of a binomial distribution }
    \item{\code{size}}{Object of class \code{"numeric"}:
      the size of a binomial distribution }
    \item{\code{name}}{Object of class \code{"character"}:
      a name / comment for the parameters }
  }
}
\section{Extends}{
Class \code{"Parameter"} , directly .
}
\section{Methods}{
  \describe{
    \item{initialize}{\code{signature(.Object = "BinomParameter")}:
      initialize method }
    \item{prob}{\code{signature(object = "BinomParameter")}: returns the slot
      \code{prob} of the parameter of the distribution }
    \item{prob<-}{\code{signature(object = "BinomParameter")}: modifies the slot
      \code{prob} of the parameter of the distribution }
    \item{size}{\code{signature(object = "BinomParameter")}: returns the slot
      \code{size} of the parameter of the distribution }
    \item{size<-}{\code{signature(object = "BinomParameter")}: modifies the slot
      \code{size} of the parameter of the distribution }
  }
}
\author{
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```

```
}
```

```
\seealso{  
\code{\link{Binom-class}}  
\code{\link{Parameter-class}}  
}
```

```
\examples{  
W <- new("BinomParameter", prob=0.5, size=1)  
size(W) # size of this distribution is 1.  
size(W) <- 2 # size of this distribution is now 2.  
}  
\keyword{distribution}  
\concept{parameter}  
\concept{Binomial distribution}  
\concept{S4 parameter class}
```

- man/Binom-class.Rd

```
\name{Binom-class}  
\docType{class}  
\alias{Binom-class}  
\alias{Binom}  
\alias{initialize, Binom-method}
```

```
\title{Class "Binom" }  
\description{The binomial distribution with size  $\text{eqn}{= n}$ , by default  
 $\text{eqn}{=1}$ , and  
prob  $\text{eqn}{= p}$ , by default  $\text{eqn}{=0.5}$ , has density  
 $\text{deqn}{p(x) = \binom{n}{x} p^x (1-p)^{n-x}}$   
 $p(x) = \text{choose}(n,x) p^x (1-p)^{(n-x)}$   
for  $\text{eqn}{x = 0, \dots, n}$ .
```

C. f. `\link[stats:Binomial]{rbinom}`

```
}  
\section{Objects from the Class}{  
Objects can be created by calls of the form Binom(prob, size).  
This object is a binomial distribution.  
}
```

```
\section{Slots}{  
\describe{  
\item{\code{img}}{Object of class "Naturals": The space of the  
image of this distribution has got dimension 1 and the  
name "Natural_Space". }  
\item{\code{param}}{Object of class "BinomParameter": the parameter  
of this distribution (prob, size), declared at its  
instantiation }  
\item{\code{r}}{Object of class "function": generates random  
numbers (calls function rbinom) }  
\item{\code{d}}{Object of class "function": density function (calls  
function dbinom) }  
\item{\code{p}}{Object of class "function": cumulative function  
(calls function pbinom) }  
\item{\code{q}}{Object of class "function": inverse of the  
cumulative function (calls function qbinom).  
The quantile is defined as the smallest value  $x$  such that  $F(x) \geq p$ , where  
 $F$  is the cumulative function. }  
\item{\code{support}}{Object of class "numeric": a (sorted)
```

```

        vector containing the support of the discrete density function}
\item{\code{withArith}}{\bcode{logical}: used internally to issue warnings as to
  interpretation of arithmetics}
\item{\code{withSim}}{\bcode{logical}: used internally to issue warnings as to
  accuracy}
\item{\code{logExact}}{\bcode{logical}: used internally to flag the case where
  there are explicit formulae for the log version of density, cdf, and
  quantile function}
\item{\code{lowerExact}}{\bcode{logical}: used internally to flag the case where
  there are explicit formulae for the lower tail version of cdf and quantile
  function}
\item{\code{Symmetry}}{object of class \code{"DistributionSymmetry"};
  used internally to avoid unnecessary calculations.}
}
}
\section{Extends}{
Class \code{"DiscreteDistribution"}, directly.\cr
Class \code{"UnivariateDistribution"}, by class \code{"DiscreteDistribution"}.\cr
Class \code{"Distribution"}, by class \code{"DiscreteDistribution"}.
}
\section{Methods}{
\describe{
\item{+}{\code{signature(e1 = "Binom", e2 = "Binom")}: For two binomial
  distributions with equal probabilities the exact convolution
  formula is implemented thereby improving the general numerical
  accuracy.}
\item{initialize}{\code{signature(.Object = "Binom")}: initialize method }
\item{prob}{\code{signature(object = "Binom")}: returns the slot \code{prob}
  of the parameter of the distribution }
\item{prob<-}{\code{signature(object = "Binom")}: modifies the slot
  \code{prob} of the parameter of the distribution }
\item{size}{\code{signature(object = "Binom")}: returns the slot \code{size}
  of the parameter of the distribution }
\item{size<-}{\code{signature(object = "Binom")}: modifies the slot
  \code{size} of the parameter of the distribution }
}
}
}

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}

\seealso{
\code{\link{BinomParameter-class}}
\code{\link{DiscreteDistribution-class}}
\code{\link{Naturals-class}}
\code{\link[stats:Binomial]{rbinom}}
}
\examples{
B <- Binom(prob=0.5,size=1) # B is a binomial distribution with prob=0.5 and size=1.
r(B)(1) # # one random number generated from this distribution, e.g. 1
d(B)(1) # Density of this distribution is 0.5 for x=1.
p(B)(0.4) # Probability that x<0.4 is 0.5.
}

```

```

q(B)(.1) # x=0 is the smallest value x such that p(B)(x)>=0.1.
## in RStudio or Jupyter IRKernel, use q.l(.) instead of q(.)
size(B) # size of this distribution is 1.
C <- 2 # size of this distribution is now 2.
C <- Binom(prob = 0.5, size = 1) # C is a binomial distribution with prob=0.5 and size=1.
D <- Binom(prob = 0.6, size = 1) # D is a binomial distribution with prob=0.6 and size=1.
E <- B + C # E is a binomial distribution with prob=0.5 and size=3.
F <- B + D # F is an object of class LatticeDistribution.
G <- B + as(D,"DiscreteDistribution") ## DiscreteDistribution
}
\keyword{distribution}
\concept{discrete distribution}
\concept{lattice distribution}
\concept{Binomial family}
\concept{Binomial distribution}
\concept{S4 distribution class}
\concept{generating function}

```

- you could have: `man/Binom.Rd` for the generating function; in the Binomial case, documentation is in `Binom-class.Rd`; but in case of the Gumbel distribution, in package "RobExtremes", there is such an extra `.Rd` file

8. in "distrEx", see sources in

```

## Loading required package: distrEx
## Warning: package 'distrEx' was built under R version 4.1.3
## Extensions of Package 'distr' (version 2.9.0)
## Note: Packages "e1071", "moments", "fBasics" should be attached /before/ package
"distrEx". See distrExMASK().Note: Extreme value distribution functionality has
been moved to
##      package "RobExtremes". See distrExMOVED().
## For more information see ?"distrEx", NEWS("distrEx"), as well as
## http://distr.r-forge.r-project.org/
## Package "distrDoc" provides a vignette to this package as well as to several
related packages; try vignette("distr").
##
## Attaching package: 'distrEx'
## The following objects are masked from 'package:stats':
##
##      IQR, mad, median, var

```

- Expectation.R,

```

setMethod("E", signature(object = "Binom",
                        fun = "missing",
                        cond = "missing"),
function(object, low = NULL, upp = NULL, ...){
  if(!is.null(low)) if(low <= min(support(object))) low <- NULL

```

```

if(!is.null(upp)) if(upp >= max(support(object))) upp <- NULL
if(is.null(low) && is.null(upp))
  return(size(object)*prob(object))
else{
  if(is.null(low)) low <- -Inf
  if(is.null(upp)) upp <- Inf
  if(low == -Inf){
    if(upp == Inf) return(size(object)*prob(object))
    else return(midf(object, upper = upp, ...))
  }else{
    E1 <- midf(object, upper = low, ...)
    E2 <- if(upp == Inf)
      size(object)*prob(object) else midf(object, upper = upp, ...)
    return(E2-E1)
  }
}
})

```

- `Functionals.R`,

```

setMethod("var", signature(x = "Binom"),
  function(x,...){
    dots <- match.call(call = sys.call(sys.parent(1)),
      expand.dots = FALSE)$"..."
    fun <- NULL; cond <- NULL; low <- NULL; upp <- NULL
    if(hasArg(low)) low <- dots$low
    if(hasArg(upp)) upp <- dots$upp
    if(hasArg(fun)||hasArg(cond)||is.null(low)||is.null(upp))
      return(var(as(x,"DiscreteDistribution"),...))
    else
      return(size(x)*prob(x)*(1-prob(x)))
  })

```

- `skewness.R`,

```

setMethod("skewness", signature(x = "Binom"),
  function(x, ...){
    dots <- match.call(call = sys.call(sys.parent(1)),
      expand.dots = FALSE)$"..."
    fun <- NULL; cond <- NULL; low <- NULL; upp <- NULL
    if(hasArg(low)) low <- dots$low
    if(hasArg(upp)) upp <- dots$upp
    if(hasArg(fun)||hasArg(cond)||is.null(low)||is.null(upp))
      return(skewness(as(x,"DiscreteDistribution"),...))
    else
      return((1-2*prob(x))/sqrt(size(x)*prob(x)*(1-prob(x))))
  })

```

- `kurtosis.R`,

```

setMethod("kurtosis", signature(x = "Binom"),
  function(x, ...){
    dots <- match.call(call = sys.call(sys.parent(1)),
                      expand.dots = FALSE)$"..."
    fun <- NULL; cond <- NULL; low <- NULL; upp <- NULL
    if(hasArg(low)) low <- dots$low
    if(hasArg(upp)) upp <- dots$upp
    if(hasArg(fun)||hasArg(cond)||!is.null(low)||!is.null(upp))
      return(kurtosis(as(x, "DiscreteDistribution"),...))
    else
      p <- prob(x)
      return(((1-6*p*(1-p))/(size(x)*p*(1-p)))
  })

```

The procedure will be similar for *any* new class of distributions.

Comment In the classes in package "`distr`" (historically the “oldest” in the development of this project), we still use `initialize` methods; this is no longer needed, if you provide generating functions; for this “more recent” approach, confer the realization of class `Gumbel` in package "`RobExtremes`".

4 Help needed / collaboration welcome

You are — as announced on <http://distr.r-forge.r-project.org> — very welcome to collaborate in this project! See in particular <https://distr.r-forge.r-project.org/HOWTO-collaborate.txt>. With this you should be able to start working.

References

- [1] Ruckdeschel P. and Kohl, M. (2014): General Purpose Convolution Algorithm for Distributions in S4-Classes by means of FFT. *J. Statist. Software*, **59**(4): 1–25.
- [2] Ruckdeschel P., Kohl M., Stabla T., and Camphausen F. (2006): S4 Classes for Distributions. *R-News*, **6**(2): 10–13. <https://CRAN.R-project.org/doc/Rnews/Rnews.2006-2.pdf>