

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

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Version control information:

Head URL: `file:///srv/svn/distr/pkg/distr/
vignettes/newDistributions.Rnw`
Last changed date: 2017-04-21 17:56:01 +0200 (Fri, 21 Apr 2017)
Last changes revision: 1132
Version: Revision 1132
Last changed by: Peter Ruckdeschel (ruckdeschel)

April 23, 2017

Abstract

In this vignette, we give short examples how to produce new distributions in packages **"distr"** and **"distrEx"**. This vignette refers to package version 2.6.2.

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

```
> plot(Z, panel.first = grid(), lwd=2)
> p(Z)(0.4)
```

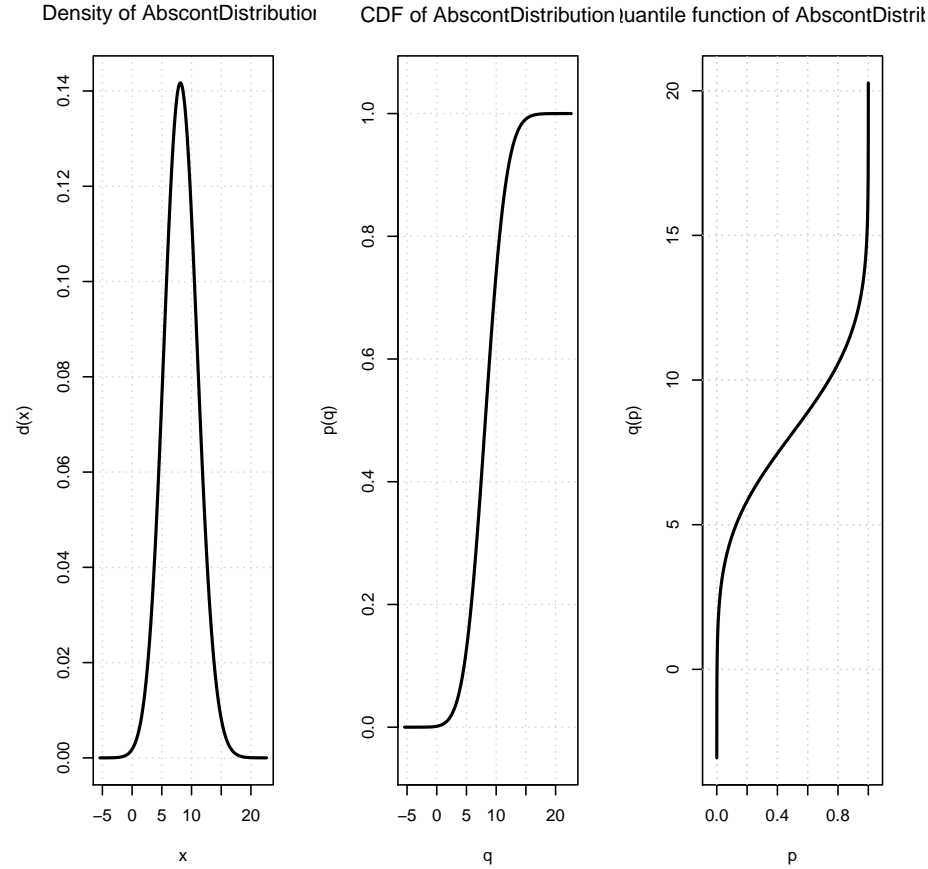
```
[1] 0.002415387
```

```
> q(Z)(0.3)
```

```
[1] 6.705068
```

```
> Zs ← r(Z)(50)
> Zs
```

```
[1] 5.068645 7.912046 7.442668 14.673498 7.333329 7.144065
[7] 3.415080 9.932782 10.440864 10.493407 9.599985 5.144201
[13] 4.505246 7.568920 5.373952 7.558651 11.735778 11.362026
[19] 12.517105 3.767145 6.925874 11.482374 8.557360 10.460119
[25] 8.199103 8.442570 6.710881 5.646527 10.969702 6.478136
[31] 11.052400 7.301359 3.666420 6.521919 16.584003 11.441482
[37] 10.743566 4.531499 5.064057 6.506858 10.142754 5.862923
[43] 9.710053 8.317134 8.442390 5.339604 9.608764 6.880354
[49] 7.751910 6.769732
```



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.

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 gen-

erated using the generating functions `LatticeDistribution()` resp. `DiscreteDistribution()` resp. `AbscontDistribution()`; see also the corresponding help.

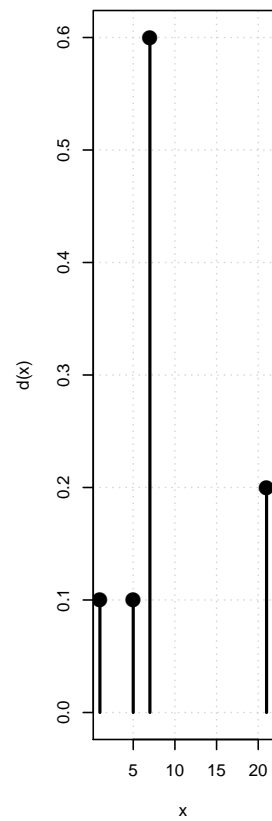
E.g., to produce a discrete distribution with support $(1, 5, 7, 21)$ with corresponding probabilities $(0.1, 0.1, 0.6, 0.2)$ we may write

```
> D ← DiscreteDistribution(supp = c(1, 5, 7, 21), prob = c(0.1, 0.1, 0.6, 0.2))
> D
```

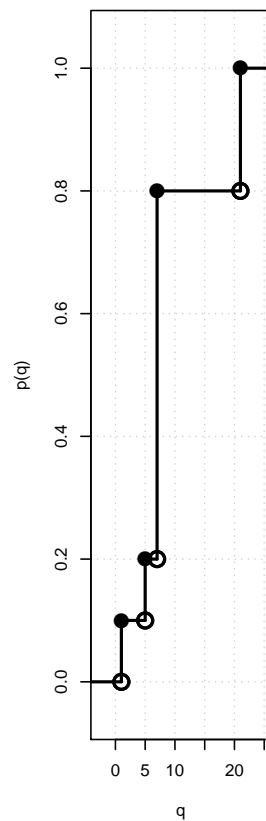
Distribution Object of Class: `DiscreteDistribution`

```
> plot(D, panel.first = grid(), lwd = 2)
```

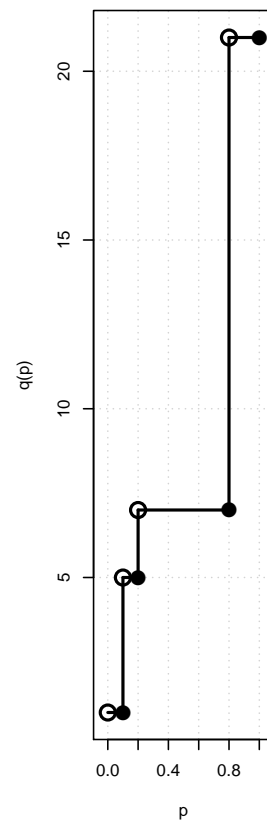
Probability function of `DiscreteDistribution`



CDF of `DiscreteDistribution`



Quantile function of `DiscreteDistribution`

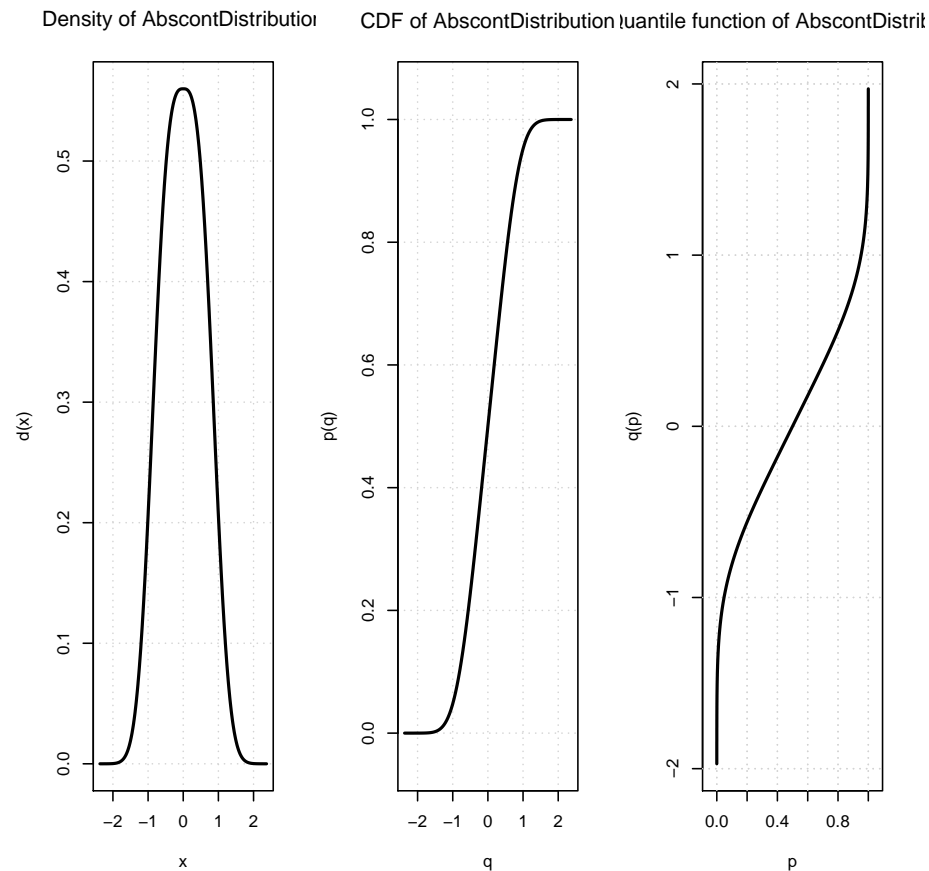


and to generate an absolutely continuous distribution with density proportional to $e^{-|x|^3}$, we write

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

Distribution Object of Class: `AbscontDistribution`

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



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`, lines 187–196

```
## 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`, lines 972–1000

```
## 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)
    },
  )
)
```

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

```

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, lines 9–16, and 44–54

```

## 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 })

## wrapped access methods
setMethod("prob", "Binom", function(object) prob(param(object)))
setMethod("size", "Binom", function(object) size(param(object)))
## wrapped replace methods
setMethod("prob←", "Binom",
  function(object, value) new("Binom", prob = value,
    size = size(object)))
setMethod("size←", "Binom",
  function(object, value) new("Binom", prob = prob(object),
    size = value))

```

and R/AllGenerics, lines 159–162

```

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, lines 19–33

```

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)
})

```

5. in "distr", see source in R/BinomialDistribution.R, line 42

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

6. in "distr", see source in R/BinomialDistribution.R, lines 55-69

```

## 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 }
  }
}
}

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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 \eqn{= n}, by default
\eqn{=1}, and
\code{prob} \eqn{= p}, by default \eqn{=0.5}, has density

$$p(x) = \binom{n}{x} p^x (1-p)^{n-x}$$

for \eqn{x = 0, \ldots, n}.

C.f. \link[stats:Binomial]{rbinom}
}
\section{Objects from the Class}{
Objects can be created by calls of the form \code{Binom(prob, size)}.
This object is a binomial distribution.
}
\section{Slots}{
\describe{
\item{\code{img}}{Object of class \code{"Naturals"}: The space of the
image of this distribution has got dimension 1 and the
name "Natural Space". }
\item{\code{param}}{Object of class \code{"BinomParameter"}: the parameter
of this distribution (\code{prob}, \code{size}), declared at its
instantiation }
\item{\code{r}}{Object of class \code{"function"}: generates random
numbers (calls function \code{rbinom}) }
\item{\code{d}}{Object of class \code{"function"}: density function (calls
function \code{dbinom}) }
\item{\code{p}}{Object of class \code{"function"}: cumulative function
(calls function \code{pbinom}) }
\item{\code{q}}{Object of class \code{"function"}: inverse of the
cumulative function (calls function \code{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 \code{"numeric"}: a (sorted)
vector containing the support of the discrete density function}
\item{\code{.withArith}}{logical: used internally to issue warnings as to
interpretation of arithmetics}
\item{\code{.withSim}}{logical: used internally to issue warnings as to
accuracy}
\item{\code{.logExact}}{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}}{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.
  size(B) # size of this distribution is 1.
  size(B) <- 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 "`distrEx`", there is such an extra `.Rd` file

8. in "`distrEx`", see sources in

- Expectation.R, lines 446–467

```

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(mldf(object, upper = upp, ...))
    }else{
      E1 ← mldf(object, upper = low, ...)
      E2 ← if(upp == Inf)
        size(object)*prob(object) else mldf(object, upper = upp, ...)
      return(E2-E1)
    }
  }
})

```

- Functionals.R, lines 219–230

```

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, lines 69–80

```

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`, lines 90–102

```
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 "`distrEx`".

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 <http://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