

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

Peter Ruckdeschel*
Matthias Kohl†

Fraunhofer ITWM
Fraunhofer Platz 1
67663 Kaiserslautern
Germany

e-Mail: `Peter.Ruckdeschel@itwm.fraunhofer.de`

November 24, 2008

Abstract

In this vignette, we give short examples how to produce new distributions in packages "**distr**" and "**distrEx**". This vignette refers to package version 2.0.3.

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.

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`

*Fraunhofer ITWM, Kaiserslautern

†Universität Bayreuth

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

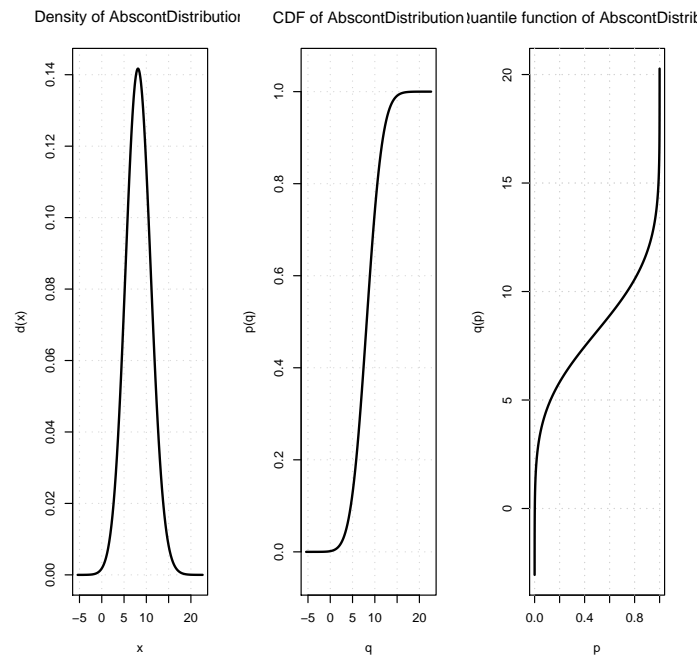
```
[1] 0.002415384
```

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

```
[1] 6.70507
```

```
> Zs <- r(Z)(50)
> Zs
```

```
[1] 10.236557 2.552043 4.969227 6.873640 6.298105 8.442099
[7] 10.139824 6.839227 6.696352 7.893704 10.863458 6.876425
[13] 8.626976 5.023080 5.991502 13.157409 10.866722 5.759084
[19] 8.440876 10.128442 5.779582 7.024034 5.991766 9.566532
[25] 9.970152 11.905532 8.159997 7.852816 9.170110 3.055171
[31] 9.238421 7.011009 9.921294 9.501393 10.987617 10.553510
[37] 7.852325 9.424557 9.629389 8.422982 16.679772 11.586883
[43] 8.463006 4.740794 7.232575 12.610345 8.169857 3.944295
[49] 7.605050 9.984153
```



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

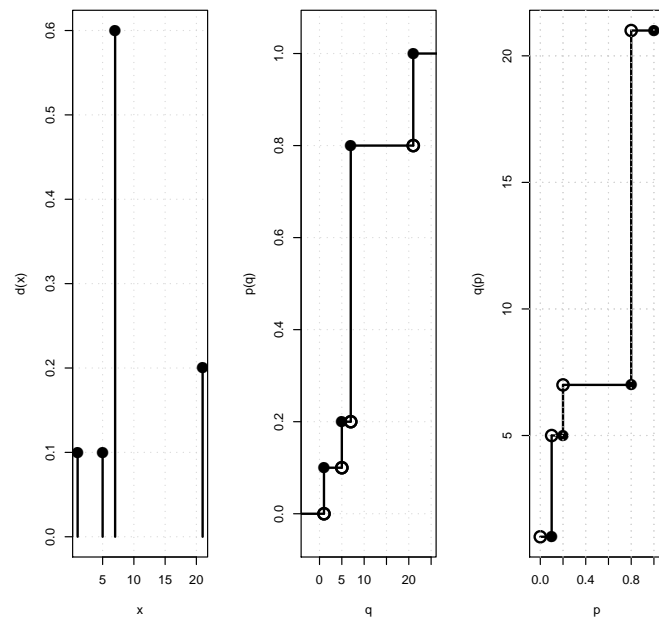
E.g., to produce a discrete distribution with support (1, 5, 7, 21) with corresponding probabilities (0.1, 0.1, 0.6, 0.2) we may write

```
> 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)
```

Probability function of DiscreteDistribution CDF of DiscreteDistribution Quantile function of DiscreteDistribution

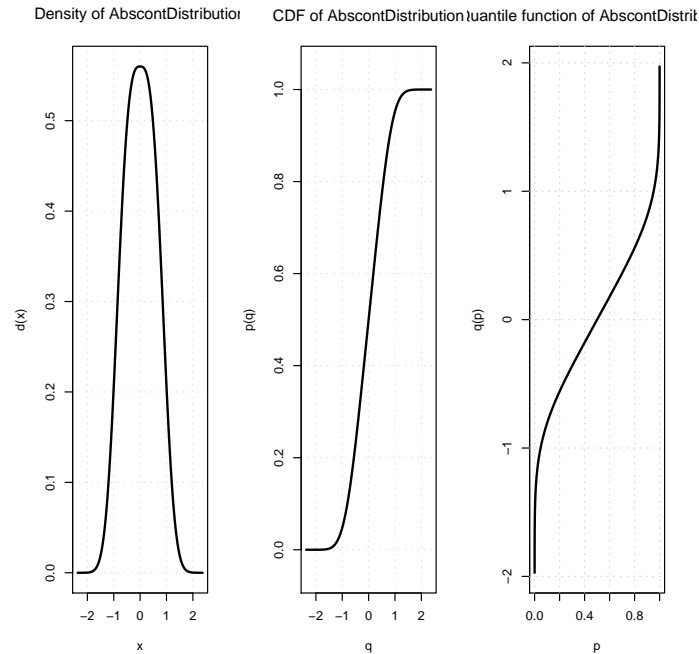


and to generate an absolutely continuous distribution with density proportional to $e^{-|x|^3}$, we write

```
> 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 180–189

```
## 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 829–855

```
## 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 =
```

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

```

                                gettext(
                                  "lattice_of_a_Binomial_distribution"
                                )
                                )
                                ),
  contains = "LatticeDistribution"
)

```

3. in "distr", see source in R/BinomialDistribution.R, lines 8–15, and 43–53

```

## 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 142–145

```

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 18–32

```

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 41

```

Binom ← function(size = 1, prob = 0.5) new("Binom", size = size, prob = prob)

```

6. in "distr", see source in R/BinomialDistribution.R, lines 54–68

```

## 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{
Thomas Stabla \email{statho3@web.de},\cr
Florian Camphausen \email{fcampi@gmx.de},\cr
Peter Ruckdeschel \email{Peter.Ruckdeschel@itwm.fraunhofer.de},\cr
Matthias Kohl \email{Matthias.Kohl@stamats.de}
}

\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 \code{size} \eqn{= n}, by default
\eqn{=1}, and
\code{prob} \eqn{= p}, by default \eqn{=0.5}, has density
\deqn{p(x) = \binom{n}{x} p^x (1-p)^{n-x}}{
p(x) = choose(n,x) p^x (1-p)^(n-x)}
for \eqn{x = 0, \ldots, n}.

C.f. \code{\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
}
}
}
\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 }
}
}
}
\author{
Thomas Stabla \email{statho3@web.de},\cr
Florian Camphausen \email{fcampi@gmx.de},\cr
Peter Ruckdeschel \email{Peter.Ruckdeschel@itwm.fraunhofer.de},\cr
Matthias Kohl \email{Matthias.Kohl@stamats.de}
}

```

```

\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 309–314

```

setMethod("E", signature(object = "Binom",
                          fun = "missing",
                          cond = "missing"),
function(object, fun, cond){
  return(size(object)*prob(object))
})

```

- `Functionals.R`, lines 158–164

```

setMethod("var", signature(x = "Binom"),
function(x, ...){
  if((hasArg(fun)) || (hasArg(cond)))
    return(var(as(x, "DiscreteDistribution"), ...))
  else
    return(size(x)*prob(x)*(1-prob(x)))
})

```

- `skewness.R`, lines 59–65

```

setMethod("skewness", signature(x = "Binom"),
function(x, ...){

```

```

    if((hasArg(fun))||(hasArg(cond)))
      return(skewness(as(x,"DiscreteDistribution"),...))
    else
      return((1-2*prob(x))/sqrt(size(x)*prob(x)*(1-prob(x))))
  })

```

- `kurtosis.R`, lines 69–76

```

setMethod("kurtosis", signature(x = "Binom"),
  function(x, ...){
    if((hasArg(fun))||(hasArg(cond)))
      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] Kohl M., Ruckdeschel P. and Stabla T. General Purpose Convolution Algorithm for Distributions in S4-Classes by means of FFT. unpublished manual
- [2] Ruckdeschel P., Kohl M., Stabla T., and Camphausen F. S4 Classes for Distributions. *R-News*, **6**(2): 10–13. http://CRAN.R-project.org/doc/Rnews/Rnews_2006-2.pdf