Using **RcppTN** in R and C++

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This brief document shows simple usage of the function `rtn()` provided by the R package **RcppTN** for drawing from an arbitrary sequence of truncated Normal distributions. Much of the value added by the **RcppTN** package comes from providing a C++-level API to call in development of other **Rcpp**-based C++ codes. Use of this API is also demonstrated. While no other R packages currently provide this functionality in an API, some existing implementations for drawing from a truncated Normal distribution at the R-level include **truncnorm** and **msm**.

1 Installation

Currently, there is no CRAN version of the package, so the simplest installation mechanism is using the `install_github()` function from the `devtools` package.

```
library("devtools")
install_github(repo = "RcppTN",
               username = "olmjo",
               subdir = "pkg",
               ref = "development"
               )
```

2 R-level Usage

2.1 RNG

Usage of the `rtn()` function in R is straightforward (albeit not feature-rich). Without any options, we get a single draw from the standard Normal distribution. And, this draw respects R's RNG state so the stream of output is reproducible.

```
library("RcppTN")
set.seed(1)
rtn()

## [1] -0.6264538

set.seed(1)
rtn()

## [1] -0.6264538
```

Under this implementation of the Robert (1995) algorithm, a request for a single draw from a Standard Normal distribution truncated from $-\infty$ to ∞ — the default behavior of the function when called without any arguments — results in the same return value as a single draw from a Standard Normal distribution using `rnorm()`. This is just a by-product of the implementation and holds no practical significance.[1]

```
set.seed(1)
rtn()

## [1] -0.6264538

set.seed(1)
rtn(.mean = 0, .sd = 1, .low = -Inf, .high = Inf)

## [1] -0.6264538

set.seed(1)
rtn()

## [1] -0.6264538

set.seed(1)
rnorm(1)

## [1] -0.6264538
```

Of course, `rtn()`'s behavior given RNG seeds is exactly as you would expect for any other generator in **R**.

```
set.seed(11)
rtn()

## [1] -0.5910311

rtn()

## [1] 0.02659437

set.seed(1)
rtn()

## [1] -0.6264538

rtn()

## [1] 0.1836433

set.seed(11)
rtn()
```

[1]See the R package documentation for the citation to the algorithm.

```
## [1] -0.5910311

rtn()

## [1] 0.02659437
```

In practice, this **R**-level function will likely be used in one of two ways:

1. drawing many values from the same truncated Normal distribution
2. drawing many values from different truncated Normal distributions

For the `rtn()` function, these two uses look very similar. The function accepts a `.mean` argument, an `.sd` argument, a `.low` argument, and a `.high` argument. Each should be a vector of length K corresponding to the K distributions of interest. The function does not handle value recycling for the user, so the construction of these vectors must be done *before or during* the call of the `rtn()` function. Incorrectly sized inputs result in an error.

```
## Not Run -- will cause error
rtn(.mean = c(0, 1), .sd = 1)
```

Importantly, this function returns an `NA` value for draws corresponding to invalid input parameters along with a warning. `NA`-inducing input parameters don't interfere with other valid parameters and a vector of the requested length is returned.

For example,

```
rtn(0, -1, 0, 1)

## Warning in checkOutputs(out):  NAs returned.  Check for invalid parameters.

## [1] NA

rtn(0, 1, 0, -1)

## Warning in checkOutputs(out):  NAs returned.  Check for invalid parameters.

## [1] NA

rtn(c(0,0), c(1,1), c(0,0), c(-Inf,Inf))

## Warning in checkOutputs(out):  NAs returned.  Check for invalid parameters.

## [1]       NA 1.178489
```

To suppress input and output checks, use the following:

```
## Not Run -- no warning given
rtn(0, -1, 0, 1, .checks = FALSE)
```

However, this is not recommended unless inputs are being checked before use. Skipping checks in `rtn()` provides a slight performance advantage, but most applications will benefit more from safer code.

2.1.1 Multiple Draws from a Single Distribution

Multiple draws from the same distribution may be requested with a function call like the following:

```
set.seed(1)
output <- rtn(.mean = rep(0, 1000),
              .sd = rep(1, 1000),
              .low = rep(1, 1000),
              .high = rep(2, 1000)
              )
length(output)

## [1] 1000

mean(output)

## [1] 1.388858
```

Here, we are generating 1,000 draws, with each draw, x, coming from $N(0,1)$ truncated below at 1 and above at 2. The population mean of this distribution is

$$E[x] = \mu + \frac{\phi(\frac{a-\mu}{\sigma}) - \phi(\frac{b-\mu}{\sigma})}{\Phi(\frac{b-\mu}{\sigma}) - \Phi(\frac{a-\mu}{\sigma})} \cdot \sigma,$$

where $\mu = 0$, $\sigma = 1$, ϕ denotes the pdf of the standard Normal distribution, Φ denotes the standard cdf of the standard Normal distribution, and a and b are the lower and upper bounds of truncation, respectively. So, for the above parameter values we have

$$\begin{aligned} E[x] &= \mu + \frac{\phi(\frac{a-\mu}{\sigma}) - \phi(\frac{b-\mu}{\sigma})}{\Phi(\frac{b-\mu}{\sigma}) - \Phi(\frac{a-\mu}{\sigma})} \cdot \sigma \\ &= 0 + \frac{.242 - .054}{.977 - .841} \cdot 1 \\ &\approx 1.383 \end{aligned}$$

Our sample mean for the 1,000 draws (1.389) is close to the population mean (1.383). To get a better sense of how dispersed the sampling distribution for the mean of a sample of 1,000 draws from this distribution is, we can simulate it.

```
bigoutput <- rep(NA, 1000)
for (i in 1:length(bigoutput)) {
    bigoutput[i] <- mean(rtn(.mean = rep(0, 1000),
                             .sd = rep(1, 1000),
                             .low = rep(1, 1000),
                             .high = rep(2, 1000)
                             )
                         )
}
summary(bigoutput)
```

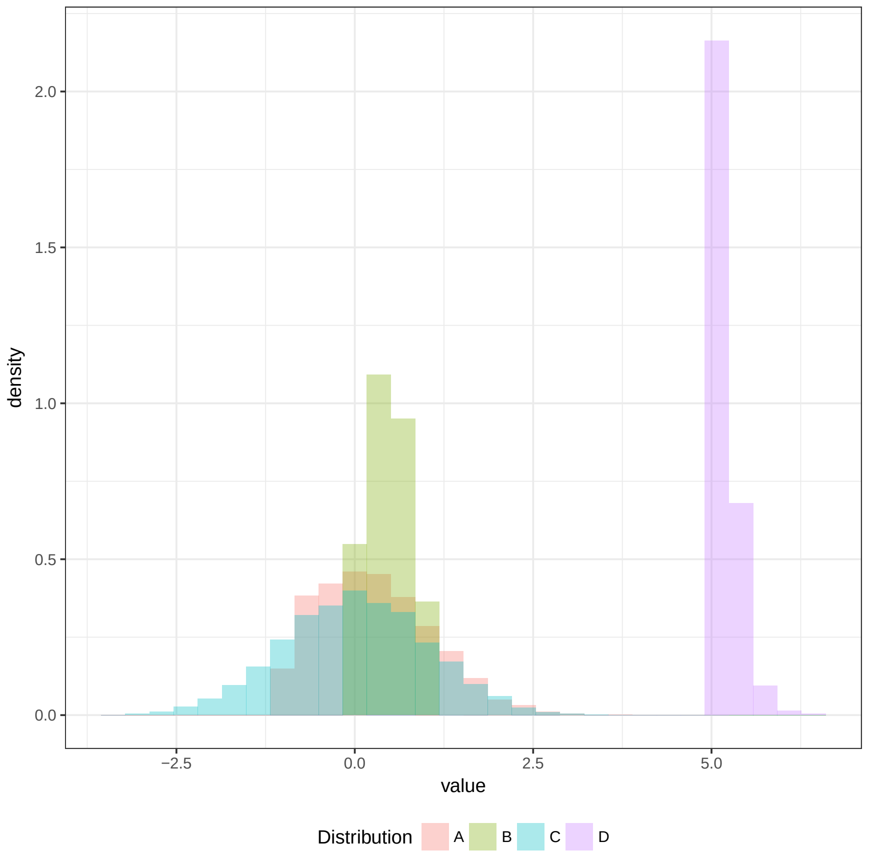
```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.357   1.377   1.383   1.383   1.389   1.409
```

Looking at the summary of the sample means, we see that the sampling distribution of sample means is centered directly on the population mean.

As shown above, valid input for `rtn()` includes `-Inf` and `Inf`. Below are histograms for four different truncated Normal distributions. The `rtn()` function works perfectly well in simulating draws from regions that have a low (read nearly 0) density in a non-truncated Normal distribution. Distribution "D" is an example of this.

```
outputA <- rtn(.mean = rep(0, 5000),
               .sd = rep(1, 5000),
               .low = rep(-1, 5000),
               .high = rep(Inf, 5000)
               )
outputB <- rtn(.mean = rep(0, 5000),
               .sd = rep(1, 5000),
               .low = rep(0, 5000),
               .high = rep(1, 5000)
               )
outputC <- rtn(.mean = rep(0, 5000),
               .sd = rep(1, 5000),
               .low = rep(-Inf, 5000),
               .high = rep(Inf, 5000)
               )
outputD <- rtn(.mean = rep(0, 5000),
               .sd = rep(1, 5000),
               .low = rep(5, 5000),
               .high = rep(Inf, 5000)
               )

dfOutput <- rbind(data.frame(value = outputA, dist = "A"),
                  data.frame(value = outputB, dist = "B"),
                  data.frame(value = outputC, dist = "C"),
                  data.frame(value = outputD, dist = "D")
                 )
```



2.1.2 Multiple Draws from Different Distributions

Taking multiple draws from different distributions proceeds in a similar way, though the construction of the arguments passed to `rtn()` changes a bit. If we were interested in characterizing a distribution of draws from a truncated Normal distribution where one (or more) of the parameters was, itself, stochastic, `rtn()` could easily be put to use. Here, the vector of lower bounds and upper bounds are each the result of an `rtn()` function call (notice that $a < b$ by construction).

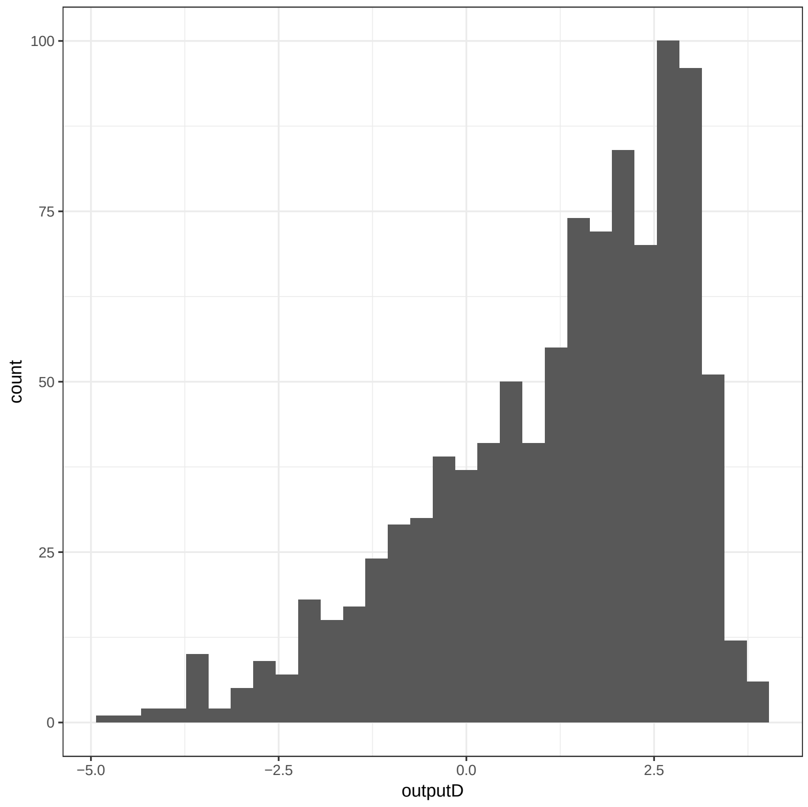
Then, we cam sample 1,000 draws from this truncated Normal distribution of interest where the mean and standard deviation are fixed, but the bounds of truncation, themselves, are taken from a distribution (in this case, a truncated Normal distribution).

```
lows <- rtn(rep(0, 1000),
            rep(3, 1000),
            rep(-10, 1000),
            rep(3, 1000)
            )
highs <- rtn(rep(0, 1000),
             rep(3, 1000),
             rep(3, 1000),
             rep(4, 1000)
             )
all(lows < highs)
```

```
## [1] TRUE

outputD <- rtn(.mean = rep(0, 1000),
               .sd = rep(3, 1000),
               .low = lows,
               .high = highs
               )

ggplot() +
    geom_histogram(aes(x = outputD))
```



This sampling distribution is non-standard and the easiest way to characterize it would be through a simulation like the above.

2.2 Other Functions

In additional to random number generation, functions are provided for calculating other quantities of interest.

To calculate the expectation of a given truncated Normal distribution, use `etn()`:

```
etn(.mean = 0,
    .sd = 1,
    .low = 0,
    .high = 10
    )
```

```
## [1] 0.7978846

etn(0, 1, 3.5, 3.7)

## [1] 3.588118
```

The variance can be found in a similar way using `vtn()`:

```
vtn(.mean = 0,
    .sd = 1,
    .low = 0,
    .high = 10
    )

## [1] 0.3633802

vtn(0, 1, 3.5, 3.7)

## [1] 0.003244555
```

The density at a specific value for a given Truncated normal distribution is found with `dtn()`:

```
dtn(.x = 4,
    .mean = 0,
    .sd = 1,
    .low = 0,
    .high = 10
    )

## [1] 0.0002676605

dtn(3.6, 0, 1, 3.5, 3.7)

## [1] 4.901908
```

Finally, the entropy of a given truncation Normal distribution is found with `enttn()`:

```
enttn(.mean = rep(0, 2),
      .sd = c(.01, 100),
      .low = rep(-1, 2),
      .high = rep(1, 2)
      )

## [1] -3.1862317  0.6931472
```

3 C++-level Usage

This section documents how to use the C++-level functionality in subsequent C++ development. Specifically, using the **RcppTN** C++ API via `sourceCpp()` and an **Rcpp**-based R package are shown. Presently, the following functions are exposed at the C++ level.

rtn1

```
double rtn1(double mean, double sd, double low, double high) ;
```

etn1

```
double etn1(double mean, double sd, double low, double high) ;
```

vtn1

```
double vtn1(double mean, double sd, double low, double high) ;
```

dtn1

```
double dtn1(double x, double mean, double sd, double low, double high) ;
```

enttn1

```
double enttn1(double mean, double sd, double low, double high) ;
```

Caveats. The R-level function ultimately calls these C++-level functions. So, all of the features of the R-level function apply here (e.g., respecting R' RNG state). However, as is true in **Rcpp**, this is left to the user to enforce. No checking or error handling is provided with these functions. These functions live in the `RcppTN` namespace.

3.1 Examples

Via `sourceCpp()`. In non-package R code, use is very straightforward due to the mechanisms provided by **Rcpp**. Include the appropriate header file as you would for **Rcpp**. In addition, use the depends pseudo-attribute with "`// [[Rcpp::depends(RcppTN)]]`" to ensure that linker finds the symbols. From there, use is as you would expect.

```
library("Rcpp")
sourceCpp(code = "
#include <Rcpp.h>

#include <RcppTN.h>
// [[Rcpp::depends(RcppTN)]]

using namespace Rcpp ;

// [[Rcpp::export]]
List rcpp_hello_world() {
  double a = RcppTN::rtn1(0.0, 1.0, 3.5, 3.7) ;
  double b = RcppTN::etn1(0.0, 1.0, 3.5, 3.7) ;
  double c = RcppTN::vtn1(0.0, 1.0, 3.5, 3.7) ;
  double d = RcppTN::dtn1(3.6, 0.0, 1.0, 3.5, 3.7) ;
  double e = RcppTN::enttn1(0.0, 1.0, 3.5, 3.7) ;
  NumericVector y = NumericVector::create(a, b, c, d, e) ;
  List z = List::create(y) ;
  return(z) ;
}
"
          )

rcpp_hello_world()
```

Via an Rcpp-based package. In R, use `Rcpp.package.skeleton()` from **Rcpp** to create an empty, but functional, R package.

```
library("Rcpp")
Rcpp.package.skeleton(path="~/Desktop")
```

Navigate inside the newly created `anRpackage` directory and edit the `DESCRIPTION` file. Add `RcppTN` to the `Depends:` and `LinkingTo:` lines of the file as in

```
Depends: RcppTN
LinkingTo: Rcpp, RcppTN
```

Now, edit the C++ function `rcpp_hello_world()` in `anRpackage/src/rcpp_hello_world.cpp` to read

```
#include <Rcpp.h>
#include <RcppTN.h>

using namespace Rcpp;

// [[Rcpp::export]]
List rcpp_hello_world() {
  double a = RcppTN::rtn1(0.0, 1.0, 3.5, 3.7) ;
  double b = RcppTN::etn1(0.0, 1.0, 3.5, 3.7) ;
  double c = RcppTN::vtn1(0.0, 1.0, 3.5, 3.7) ;
  double d = RcppTN::dtn1(3.6, 0.0, 1.0, 3.5, 3.7) ;
  double e = RcppTN::enttn1(0.0, 1.0, 3.5, 3.7) ;
  NumericVector y = NumericVector::create(a, b, c, d, e) ;
  List z = List::create( y ) ;
  return(z) ;
}
```

To see the effect of this, install the "anRpackage" package and the load it in R. From there, make subsequent calls to the `rcpp_hello_world()` function. With a similar approach, the `rtn1()` function can be called in a more useful way within other C++-level codes without the need for re-coding the wheel. The only difference between this approach and the `sourceCpp()` approach is that the `depends` pseudo-attribute is no longer needed and is replaced by the modification to the `LinkingTo:` field of the `DESCRIPTION` file.