Hands-on Rcpp by Examples

Dirk Eddelbuettel
edd@debian.org
@eddelbuettel

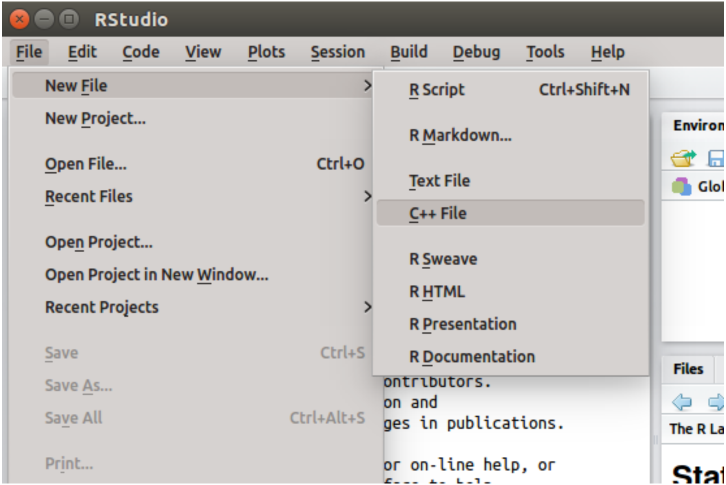
R User Group
München
24 June 2014

Outline

1. Intro
2. Usage
3. Sugar
4. Examples
5. More

Jumping right in

RStudio makes starting very easy:



```
ontributors.
on and
ges in publications.

or on-line help, or
```

A First Example: Cont'ed

The following file gets created:

```
#include <Rcpp.h>
using namespace Rcpp;

// Below is a simple example of exporting a C++ function to R.
// You can source this function into an R session using the
// Rcpp::sourceCpp function (or via the Source button on the
// editor toolbar)

// For more on using Rcpp click the Help button on the editor
// toolbar

// [[Rcpp::export]]
int timesTwo(int x) {
   return x * 2;
}
```

A First Example: Cont'ed

We can easily deploy the file ("press the button") and call the resulting function:

```
Rcpp::sourceCpp('files/timesTwo.cpp')
timesTwo(21)

## [1] 42
```

A First Example: Cont’ed

So what just happened?

- We defined a simple C++ function
- It operates on a single integer argument
- We asked Rcpp to ’source it’ for us
- Behind the scenes Rcpp creates a wrapper
- Rcpp then compiles, links, and loads the wrapper
- The function is available in R under its C++ name

A First Example: Related

Two related functions related to `sourceCpp()`:

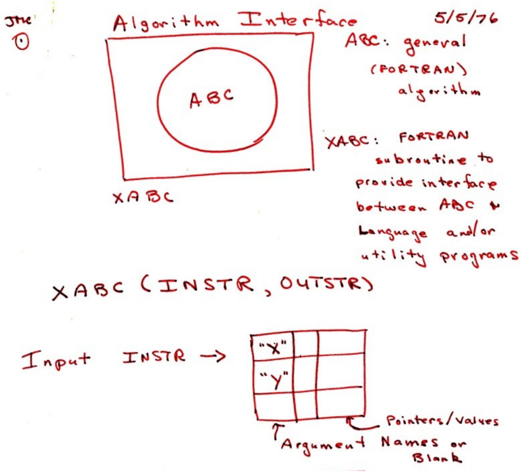
```
evalCpp("2 * 2")

## [1] 4

cppFunction("int times2(int x) { return 2*x;}")
times2(123)

## [1] 246
```

A “vision” from Bell Labs from 1976



JMC

Algorithm Interface 5/5/76

ABC: general (FORTRAN) algorithm

XABC: FORTRAN subroutine to provide interface between ABC & language and/or utility programs

XABC (INSTR, OUTSTR)

Input INSTR →

Source: John Chambers’ talk at Stanford in October 2010; personal correspondence.

An Introductory Example

Consider a function defined as

$$f(n) \quad \text{such that} \quad \begin{cases} n & \text{when} \quad n < 2 \\ f(n-1) + f(n-2) & \text{when} \quad n \geq 2 \end{cases}$$

An Introductory Example: Simple R Implementation

R implementation and use:

```
f <- function(n) {
    if (n < 2) return(n)
    return(f(n-1) + f(n-2))
}
## Using it on first 11 arguments
sapply(0:10, f)

##  [1]  0  1  1  2  3  5  8 13 21 34 55
```

An Introductory Example: Timing R Implementation

Timing:

```
library(rbenchmark)
benchmark(f(10), f(15), f(20))[,1:4]

##    test replications elapsed relative
## 1 f(10)          100   0.017      1.0
## 2 f(15)          100   0.204     12.0
## 3 f(20)          100   2.129    125.2
```

An Introductory Example: C++ Implementation

```
int g(int n) {
    if (n < 2) return(n);
    return(g(n-1) + g(n-2));
}
```

Deployed as:

```
library(Rcpp)
cppFunction('int g(int n) {
   if (n < 2) return(n);
   return(g(n-1) + g(n-2)); }')
## Using it on first 11 arguments
sapply(0:10, g)

##  [1]  0  1  1  2  3  5  8 13 21 34 55
```

An Introductory Example: Comparing timing

Timing:

```
library(rbenchmark)
benchmark(f(20), g(20))[,1:4]

##     test replications elapsed relative
## 1 f(20)          100   2.197    439.4
## 2 g(20)          100   0.005      1.0
```

A nice gain of a few orders of magnitude.

Well-known packages using Rcpp

Amelia	by G King et al
lme4	by D Bates, M Maechler et al
forecast	by R Hyndman et al
RStan	by A Gelman et al
rugarch	by A Ghalanos
plyr	by H Wickham (plus **roxygen2**, **dplyr**, ...)
httpuv	by J Cheng / RStudio
MTS	by R Tsay

Rcpp is currently used by 223 CRAN packages, and a further 27 BioConductor packages.

Type mapping

Standard R types (integer, numeric, list, function, ... and compound objects) are mapped to corresponding C++ types using extensive template meta-programming – it just works:

```
library(Rcpp)
cppFunction("NumericVector la(NumericVector x){
  return log(abs(x));
}")
la(seq(-5, 5, by=2))

## [1] 1.609 1.099 0.000 0.000 1.099 1.609
```

Also note: vectorized C++!

Type mapping also with C++ STL types

Use of `std::vector<double>` and STL algorithms:

```
#include <Rcpp.h>
using namespace Rcpp;

inline double f(double x) { return ::log(::fabs(x)); }

// [[Rcpp::export]]
std::vector<double> logabs2(std::vector<double> x) {
  std::transform(x.begin(), x.end(), x.begin(),  f);
  return x;
}
```

Type mapping also with C++ STL types

Used via

```
library(Rcpp)
sourceCpp("code/logabs2.cpp")
logabs2(seq(-5, 5, by=2))

## [1] 1.609 1.099 0.000 0.000 1.099 1.609
```

Type mapping is seamless

Simple outer product of a column vector (using Armadillo / RcppArmadillo):

```
cppFunction("arma::mat v(arma::colvec a) {
             return a*a.t();}",
            depends="RcppArmadillo")
v(1:5)

##      [,1] [,2] [,3] [,4] [,5]
## [1,]    1    2    3    4    5
## [2,]    2    4    6    8   10
## [3,]    3    6    9   12   15
## [4,]    4    8   12   16   20
## [5,]    5   10   15   20   25
```

This uses implicit conversion via `as<>` and `wrap` – cf package vignette Rcpp-extending.

C++11: lambdas, auto, and much more

We can simplify the `log(abs(...))` example further:

```
#include <Rcpp.h>

// [[Rcpp::plugins(cpp11)]]

using namespace Rcpp;

// [[Rcpp::export]]
std::vector<double> logabs3(std::vector<double> x) {
   std::transform(x.begin(), x.end(), x.begin(),
                  [](double x) {
                    return ::log(::fabs(x));
                  } );
   return x;
}
```

C++11: lambdas, auto, and much more

Used via

```
library(Rcpp)
sourceCpp("code/logabs3.cpp")
logabs3(seq(-5, 5, by=2))

## [1] 1.609 1.099 0.000 0.000 1.099 1.609
```

Outline

1. Intro
2. Usage
3. Sugar
4. Examples
5. More

Basic Usage: `evalCpp`

`evalCpp()` evaluates a single C++ expression. Includes and dependencies can be declared.
This allows us to quickly check C++ constructs.

```
evalCpp("2 + 2")        # simple test

## [1] 4

evalCpp("std::numeric_limits<double>::max()")

## [1] 1.798e+308
```

Basic Usage: `cppFunction()`

`cppFunction()` creates, compiles and links a C++ file, and creates an R function to access it.

```
cppFunction("
    int useCpp11() {
        auto x = 10;
        return x;
}", plugins=c("cpp11"))
useCpp11()  # same identifier as C++ function

## [1] 10
```

Basic Usage: `sourceCpp()`

`sourceCpp()` is the actual workhorse behind `evalCpp()` and `cppFunction()`. It is described in more detail in the package vignette Rcpp-attributes.

`sourceCpp()` builds on and extends `cxxfunction()` from package inline, but provides even more ease-of-use, control and helpers – freeing us from boilerplate scaffolding.

A key feature are the plugins and dependency options: other packages can provide a plugin to supply require compile-time parameters (cf RcppArmadillo, RcppEigen, RcppGSL).

Basic Usage: Packages

Package are *the* standard unit of R code organization.

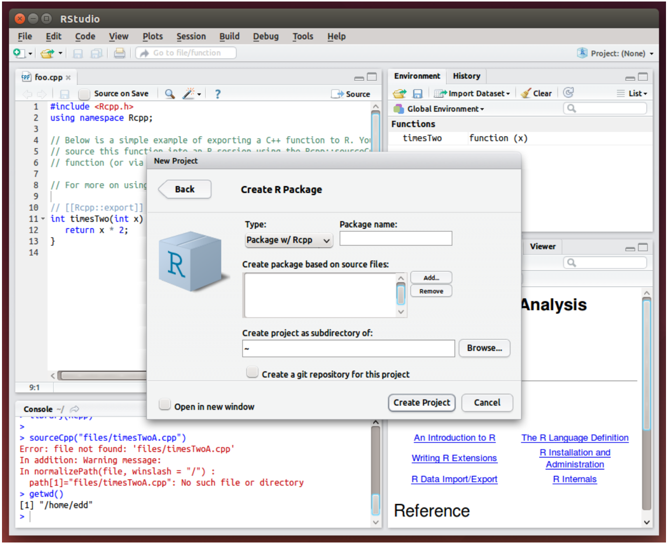
Creating packages with Rcpp is easy; an empty one to work from can be created by `Rcpp.package.skeleton()`

The vignette Rcpp-package has fuller details.

As of mid June 2014, there are 223 packages on CRAN which use Rcpp, and a further 27 on BioConductor — with working, tested, and reviewed examples.

Packages and Rcpp

Best way to organize R code with Rcpp is via a package:



```
#include <Rcpp.h>
using namespace Rcpp;

// Below is a simple example of exporting a C++ function to R. You
// source this function into an R session using the Rcpp::sourceC
// function (or via

// For more on using

// [[Rcpp::export]]
int timesTwo(int x)
   return x * 2;
}
```

Functions

timesTwo function (x)

New Project

Create R Package

Type: Package w/ Rcpp

Package name:

Create package based on source files:

Create project as subdirectory of: ~

□ Create a git repository for this project

□ Open in new window

```
>
> sourceCpp("files/timesTwoA.cpp")
Error: file not found: 'files/timesTwoA.cpp'
In addition: Warning message:
In normalizePath(file, winslash = "/") :
  path[1]="files/timesTwoA.cpp": No such file or directory
> getwd()
[1] "/home/edd"
> 
```

Packages and Rcpp

`Rcpp.package.skeleton()` and its derivatives. e.g. `RcppArmadillo.package.skeleton()` create working packages.

```
// another simple example: outer product of a vector,
// returning a matrix
//
// [[Rcpp::export]]
arma::mat rcpparma_outerproduct(const arma::colvec & x) {
    arma::mat m = x * x.t();
    return m;
}

// and the inner product returns a scalar
//
// [[Rcpp::export]]
double rcpparma_innerproduct(const arma::colvec & x) {
    double v = arma::as_scalar(x.t() * x);
    return v;
}
```

Outline

1. Intro
2. Usage
3. Sugar
4. Examples
5. More

Syntactive 'sugar': Simulating π in R

Basic idea: for point (x, y), compute distance to origin. Do so repeatedly, and ratio of points below one to number N of simulations will approach $\pi/4$ as we fill the area of one quarter of the unit circle.

```r
piR <- function(N) {
    x <- runif(N)
    y <- runif(N)
    d <- sqrt(x^2 + y^2)
    return(4 * sum(d <= 1.0) / N)
}

set.seed(5)
sapply(10^(3:6), piR)

## [1] 3.156 3.155 3.139 3.141
```

Syntactive 'sugar': Simulating π in C++

The neat thing about Rcpp sugar enables us to write C++ code that looks almost as compact.

```
#include <Rcpp.h>
using namespace Rcpp;

// [[Rcpp::export]]
double piSugar(const int N) {
  RNGScope scope;   // ensure RNG gets set/reset
  NumericVector x = runif(N);
  NumericVector y = runif(N);
  NumericVector d = sqrt(x*x + y*y);
  return 4.0 * sum(d <= 1.0) / N;
}
```

Apart from RNG set/reset, the code is essentially identical.

Syntactive 'sugar': Simulating π

And by using the same RNG, so are the results.

```
sourceCpp("code/piSugar.cpp")
set.seed(42); a <- piR(1.0e7)
set.seed(42); b <- piSugar(1.0e7)
identical(a,b)

## [1] TRUE

print(c(a,b), digits=7)

## [1] 3.140899 3.140899
```

Syntactive ’sugar’: Simulating π

The performance is close with a small gain for C++ as R is already vectorised:

```
library(rbenchmark)
benchmark(piR(1.0e6), piSugar(1.0e6))[,1:4]

##             test replications elapsed relative
## 1     piR(1e+06)          100   11.38    1.683
## 2 piSugar(1e+06)          100    6.76    1.000
```

More about Sugar is in the package vignette Rcpp-sugar.

Outline

1. Intro
2. Usage
3. Sugar
4. Examples
5. More

Cumulative Sum

http://gallery.rcpp.org/articles/vector-cumulative-sum/

A basic looped version:

```
#include <Rcpp.h>
#include <numeric>      // for std::partial_sum
using namespace Rcpp;

// [[Rcpp::export]]
NumericVector cumsum1(NumericVector x){
    // initialize an accumulator variable
    double acc = 0;

    // initialize the result vector
    NumericVector res(x.size());

    for(int i = 0; i < x.size(); i++){
         acc += x[i];
         res[i] = acc;
    }
    return res;
}
```

Cumulative Sum

See http://gallery.rcpp.org/articles/vector-cumulative-sum/

An STL variant:

```
// [[Rcpp::export]]
NumericVector cumsum2(NumericVector x){
    // initialize the result vector
    NumericVector res(x.size());
    std::partial_sum(x.begin(), x.end(), res.begin());
    return res;
}
```

Cumulative Sum

http://gallery.rcpp.org/articles/vector-cumulative-sum/

Or just Rcpp sugar:

```
// [[Rcpp::export]]
NumericVector cumsum_sug(NumericVector x){
    return cumsum(x);   // compute + return result vector
}
```

Of course, all results are the same.

```
cppFunction('NumericVector cumsum2(NumericVector x) {
                                   return cumsum(x); }')
x <- 1:10
all.equal(cumsum(x), cumsum2(x))

## [1] TRUE
```

Calling an R function from C++

http://gallery.rcpp.org/articles/r-function-from-c++/

```
#include <Rcpp.h>

using namespace Rcpp;

// [[Rcpp::export]]
NumericVector callFunction(NumericVector x,
                           Function f) {
    NumericVector res = f(x);
    return res;
}

/*** R
callFunction(x, fivenum)
*/
```

Using Boost via BH

http://gallery.rcpp.org/articles/boost-foreach/

```
#include <Rcpp.h>
#include <boost/foreach.hpp>
using namespace Rcpp;
// [[Rcpp::depends(BH)]]

// the C-style upper-case macro name is a bit ugly
#define foreach BOOST_FOREACH

// [[Rcpp::export]]
NumericVector square( NumericVector x ) {

  // elem is a reference to each element in x
  // we can re-assign to these elements as well
  foreach( double& elem, x ) {
    elem = elem*elem;
  }
  return x;

}
```

C++11 now has something similar in a smarter `for` loop.

Vector Subsetting

http://gallery.rcpp.org/articles/subsetting/

New in **Rcpp** 0.11.1:

```
#include <Rcpp.h>
using namespace Rcpp;

// [[Rcpp::export]]
NumericVector positives(NumericVector x) {
    return x[x > 0];
}

// [[Rcpp::export]]
List first_three(List x) {
    IntegerVector idx = IntegerVector::create(0, 1, 2);
    return x[idx];
}

// [[Rcpp::export]]
List with_names(List x, CharacterVector y) {
    return x[y];
}
```

Armadillo Eigenvalues

http://gallery.rcpp.org/articles/armadillo-eigenvalues/

```
#include <RcppArmadillo.h>

// [[Rcpp::depends(RcppArmadillo)]]

// [[Rcpp::export]]
arma::vec getEigenValues(arma::mat M) {
    return arma::eig_sym(M);
}
```

```
set.seed(42)
X <- matrix(rnorm(4*4), 4, 4)
Z <- X %*% t(X)
getEigenValues(Z)

# R gets the same results (in reverse)
# and also returns the eigenvectors.
```

Creating xts objects in C++

http://gallery.rcpp.org/articles/creating-xts-from-c++/

```
#include <Rcpp.h>
using namespace Rcpp;

NumericVector createXts(int sv, int ev) {
    IntegerVector ind = seq(sv, ev);     // values

    NumericVector dv(ind);               // date(time)s == reals
    dv = dv * 86400;                     // scaled to days
    dv.attr("tzone")    = "UTC";         // index has attributes
    dv.attr("tclass")   = "Date";

    NumericVector xv(ind);               // data has same index
    xv.attr("dim")         = IntegerVector::create(ev-sv+1,1);
    xv.attr("index")       = dv;
    CharacterVector cls = CharacterVector::create("xts","zoo");
    xv.attr("class")       = cls;
    xv.attr(".indexCLASS") = "Date";
    // ... some more attributes ...

    return xv;
}
```

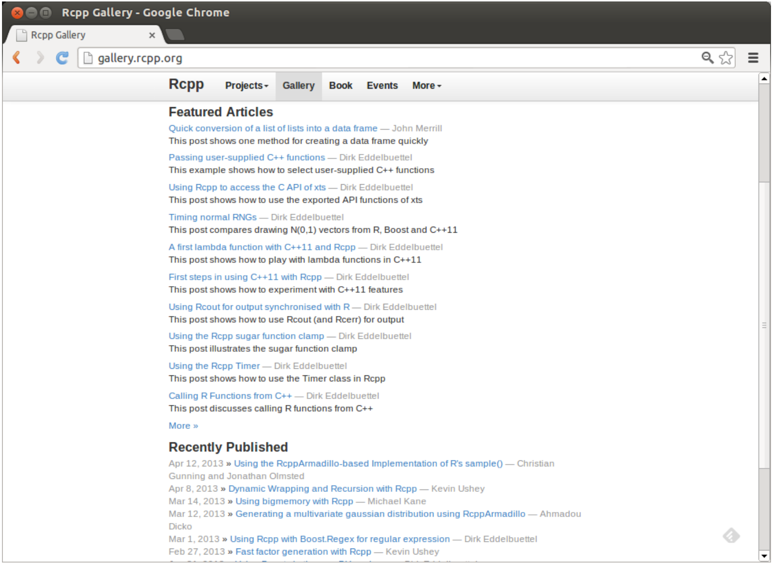
Outline

1. Intro
2. Usage
3. Sugar
4. Examples
5. More

Documentation

- The package comes with eight pdf vignettes, and numerous help pages.
- The introductory vignettes are now published (Rcpp and RcppEigen in *J Stat Software*, RcppArmadillo in *Comp. Stat.& Data Anal.*).
- The rcpp-devel list is *the* recommended resource, generally very helpful, and fairly low volume.
- By now StackOverflow has more than 500 posts too.
- And a number of blog posts introduce/discuss features.

Rcpp Gallery



Featured Articles

Quick conversion of a list of lists into a data frame — John Merrill
This post shows one method for creating a data frame quickly

Passing user-supplied C++ functions — Dirk Eddelbuettel
This example shows how to select user-supplied C++ functions

Using Rcpp to access the C API of xts — Dirk Eddelbuettel
This post shows how to use the exported API functions of xts

Timing normal RNGs — Dirk Eddelbuettel
This post compares drawing N(0,1) vectors from R, Boost and C++11

A first lambda function with C++11 and Rcpp — Dirk Eddelbuettel
This post shows how to play with lambda functions in C++11

First steps in using C++11 with Rcpp — Dirk Eddelbuettel
This post shows how to experiment with C++11 features

Using Rcout for output synchronised with R — Dirk Eddelbuettel
This post shows how to use Rcout (and Rcerr) for output

Using the Rcpp sugar function clamp — Dirk Eddelbuettel
This post illustrates the sugar function clamp

Using the Rcpp Timer — Dirk Eddelbuettel
This post shows how to use the Timer class in Rcpp

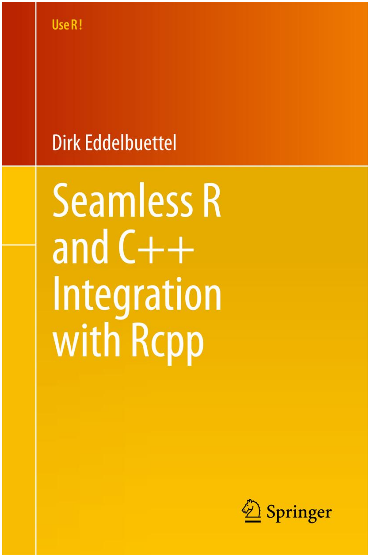
Calling R Functions from C++ — Dirk Eddelbuettel
This post discusses calling R functions from C++

More »

Recently Published

Apr 12, 2013 » Using the RcppArmadillo-based Implementation of R's sample() — Christian Gunning and Jonathan Olmsted
Apr 8, 2013 » Dynamic Wrapping and Recursion with Rcpp — Kevin Ushey
Mar 14, 2013 » Using bigmemory with Rcpp — Michael Kane
Mar 12, 2013 » Generating a multivariate gaussian distribution using RcppArmadillo — Ahmadou Dicko
Mar 1, 2013 » Using Rcpp with Boost.Regex for regular expression — Dirk Eddelbuettel
Feb 27, 2013 » Fast factor generation with Rcpp — Kevin Ushey

The Rcpp book



On sale since June 2013.