An Introduction to Rcpp

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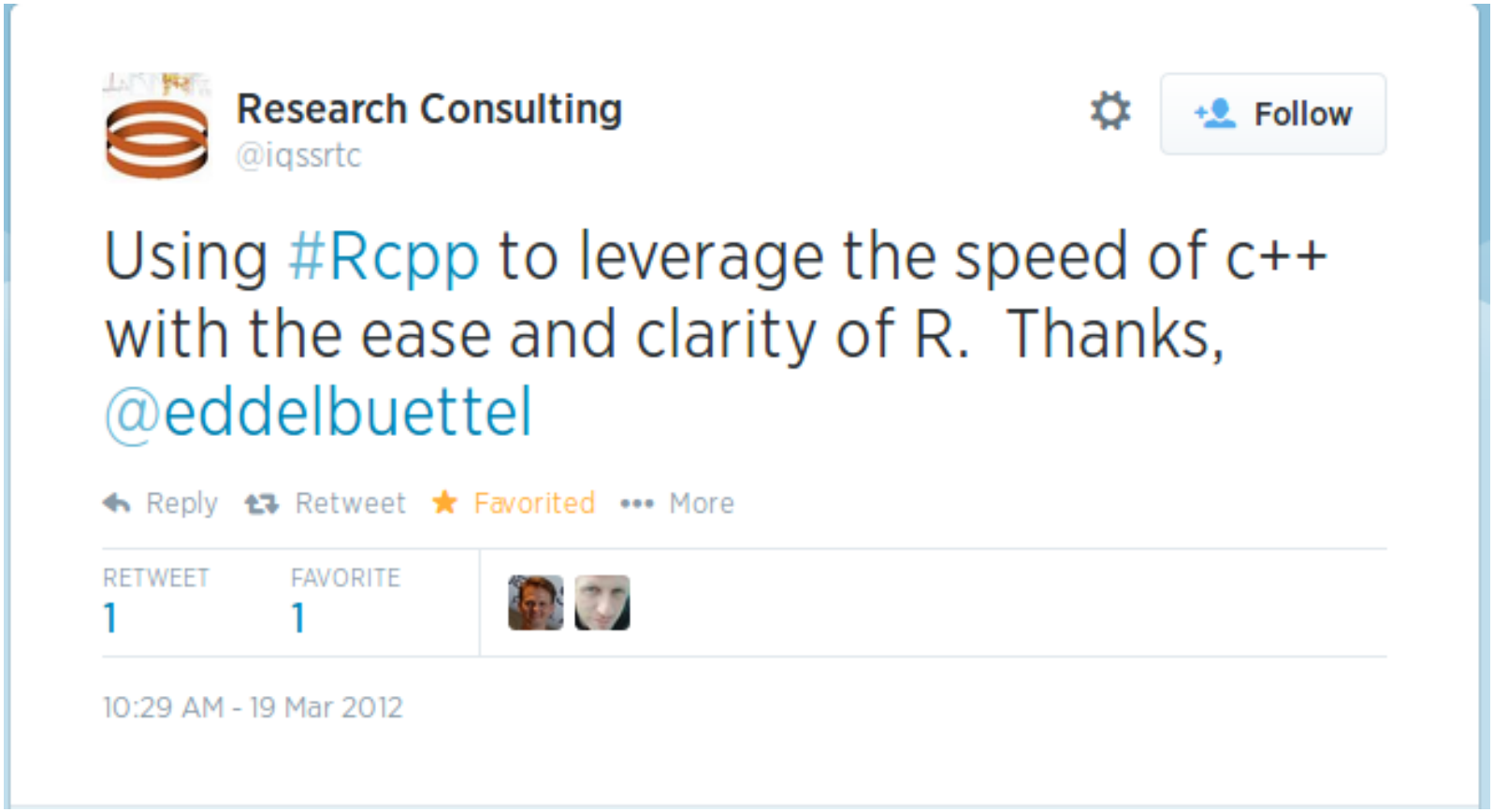
Outline

A tweet about Rcpp from IQSS / Harvard



Another tweet about Rcpp

Peter Hickey
@PeteHaitch

Follow

Love that my reaction almost every time I rewrite R code in Rcpp is "holy shit that's fast" thanks @eddelbuettel & @romain_francois #rstats

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9:08 PM - 18 Oct 2013

Alternative Title of Talk

Rcpp: The Good Parts

- Ease of use
- R -> C++
- C++ as Glue

Why R?
Interactive

R enables us to

- work interactively
- explore and visualize data
- access, retrieve and/or generate data
- summarize and report into pdf, html, ...

making it a preferred environment for many data analysts.

Why R?
Extensible

R has always been extensible via

- **C** via a bare-bones interface described in *Writing R Extensions*
- **Fortran** which is also used internally by R
- **Java** via **rJava** by S Urbanek
- **C++** but essentially at the bare-bones level of C

So 'in theory' this worked – yet tedious 'in practice'.

Why C++?

- Asking Google [currently] leads to about 42 million hits.
- Wikipedia: *C++ is a statically typed, free-form, multi-paradigm, compiled, general-purpose, powerful programming language.*
- C++ is industrial-strength, vendor-independent, widely-used, and *still evolving*.
- In science & research, one of the most frequently-used languages: If there is something you want to use / connect to, it probably has a C/C++ API.
- As a widely used language it also has good tool support (debuggers, profilers, code analysis).

Why C++?

Scott Meyers: *"View C++ as a federation of languages"*

C provides a rich inheritance and interoperability as Unix, Windows, ... are all build on C.

Object-Oriented C++ just to provide endless discussions about exactly what OO is or should be.

Templated C++ which is mighty powerful; template meta programming unequalled in other languages.

The STL which is a specific template library which is powerful but has its own conventions.

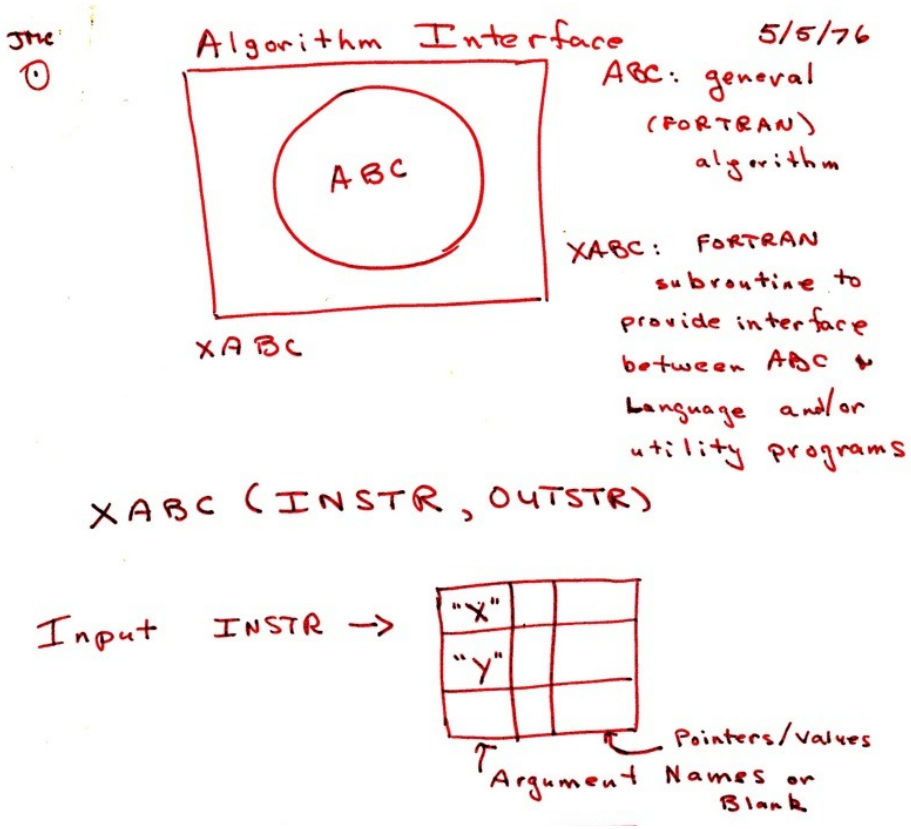
C++11 adds enough to be called a fifth language.

NB: Meyers original list of four language appeared years before C++11.

Why C++?

- Mature yet current
- Strong performance focus:
  - “You don’t pay for what you don’t use”
  - “Leave no room for a language between the machine level and C++”
- Yet also powerfully abtract and high-level
- C++11 and beyond are a big deal giving us new language features
- While there are complexities, Rcpp users are mostly shielded

Interface Vision



Source: John Chambers, personal communication.

Interface Vision

- Use trusted numerical libraries (mostly/exclusively written in Fortran)
- Provide environment which statistician could use more easily
- Enable interactive and iterative data exploration
- Make it extensibilty for research into statistical methods
- C.f. John Chambers (2008) regarding “Mission” and “Directive”

Interface Vision

R offers us the best of both worlds:

Compiled code with

- Access to proven libraries and algorithms in C/C++/Fortran
- Extremely high performance (in both serial and parallel modes)

Interpeted code with

- An accessible high-level language made for *Programming with Data*
- An interactive workflow for data analysis
- Support for rapid prototyping, research, and experimentation

Why Rcpp?

Easy to learn it really does not have to be that complicated – we will look at a few examples

Easy to use as it avoids build and OS system complexities thanks to the R infrastrucure

Expressive it allows for *vectorised* C++ using *Rcpp Sugar*

Seamless access to all R objects: vector, matrix, list, S3/S4/RefClass, Environment, Function, ...

Speed gains for a variety of tasks **Rcpp** excels precisely where R struggles: loops, function calls, ...

Extensions greatly facilitates access to external libraries using eg *Rcpp modules*

Rcpp Playground: Defined by .Call

R side

```
res <- .Call("nameOfFunction", a, b, c,
             ..., PACKAGE="name")
```

C++ side

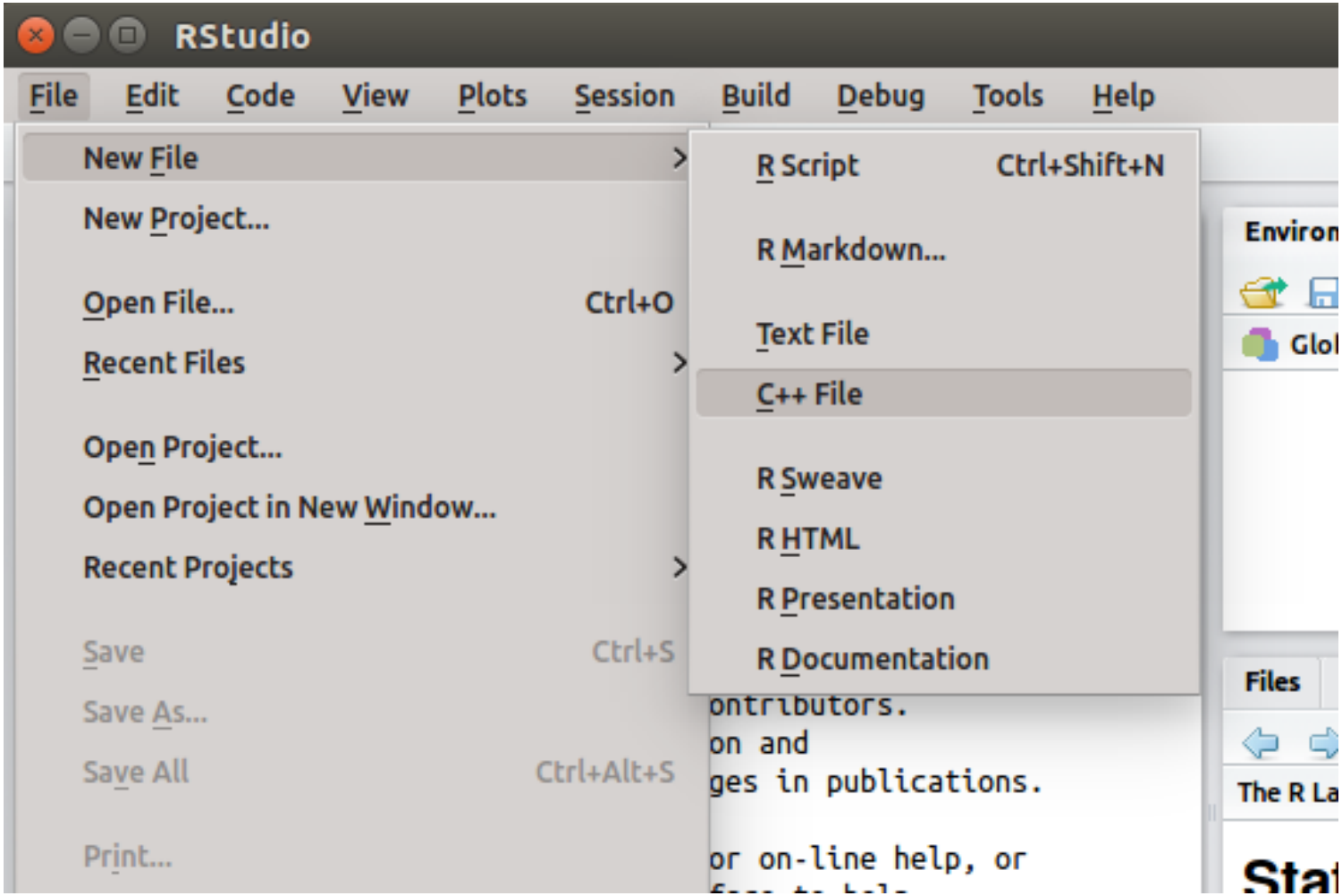
```
extern "C"
SEXP nameOfFunction(SEXP a, SEXP b,
                    SEXP c, ...,)
```

Outline

2. Rcpp
   - How
   - Example: VAR(1)
   - Packages

How do we use Rcpp?

RStudio makes it very easy: Single File



How do we use Rcpp?

RStudio example cont'ed

The following file used to get 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;
}
```

How do we use Rcpp?

RStudio example cont'ed

The following file gets created now:

```
#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]]
NumericVector timesTwo(NumericVector x) {
  return x * 2;
}
```

How do we use Rcpp?

Rcpp Attributes: evalCpp, cppFunction, sourceCpp

```
## evaluate a C++ expression, retrieve result
evalCpp("2 + 2")

## [1] 4

## create ad-hoc R function 'square'
cppFunction('int square(int x) { return x*x;}')
square(7L)

## [1] 49

## or source an entire file (including R code)
#sourceCpp("code/squareWithRCall.cpp")
```

When would we use Rcpp?

Easy speed gain: VAR(1) Simulation

Let's consider a simple possible VAR(1) system of k variables.

For $k = 2$:

$$X_t = X_{t-1} B + E_t$$

where X_t is a row vector of length 2, B is a 2 by 2 matrix and E_t is a row of the error matrix of 2 columns.

When do we use Rcpp?

Easy speedup:: VAR(1) Simulation

In R code, given both the coefficient and error matrices (revealing *k* and *n*):

```
rSim <- function(B,E) {
    n <- nrow(E); k <- ncol(E)
    X <- matrix(0, n, k)
    for (r in 2:n) {
        X[r,] = X[r-1, ] %*% B + E[r, ]
    }
    return(X)
}
```

When do we use Rcpp?

Easy speed gain: VAR(1) Simulation

```
cppFunction('
arma::mat cppSim(const arma::mat& B,
                 const arma::mat& E) {
    int n = E.n_rows; int k = E.n_cols;
    arma::mat X = arma::zeros<arma::mat>(n,k);
    for (int r=1; r < n; r++) {
        X.row(r) = X.row(r-1) * B + E.row(r);
    }
    return X;
}', depends="RcppArmadillo")
```

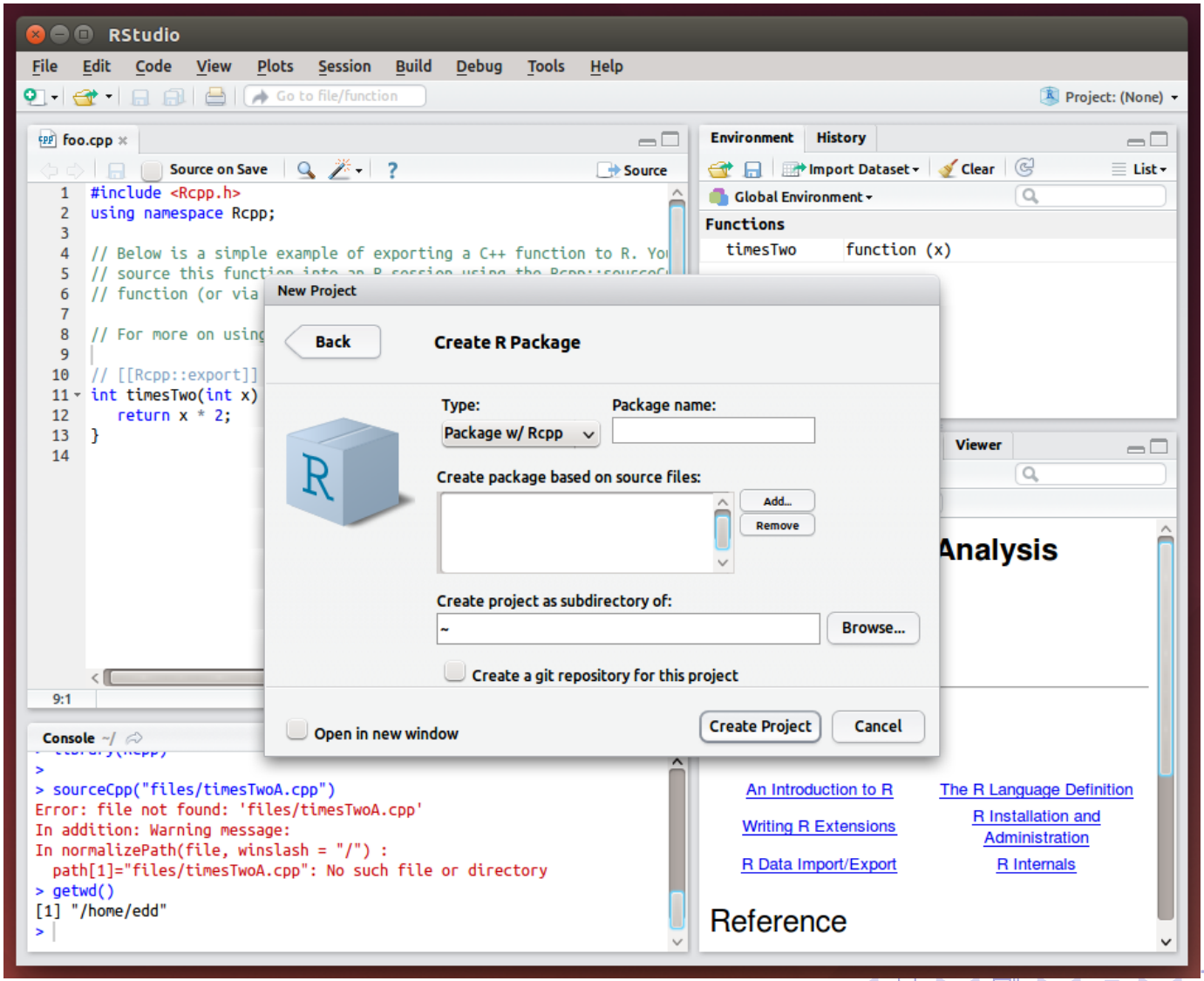
When do we use Rcpp?

Easy speed gain: VAR(1) Simulation

```
a <- matrix(c(0.5,0.1,0.1,0.5),nrow=2)
e <- matrix(rnorm(10000),ncol=2)
all.equal(cppSim(a,e), rSim(a,e))

## [1] TRUE

benchmark(cppSim(a,e), rSim(a,e),
          order="relative")[,1:4]

##           test replications elapsed relative
## 1 cppSim(a, e)          100   0.044    1.000
## 2   rSim(a, e)          100   2.633   59.841
```

How do we use Rcpp?

RStudio makes it very easy (using Rcpp.package.skeleton()



How do we use Rcpp?

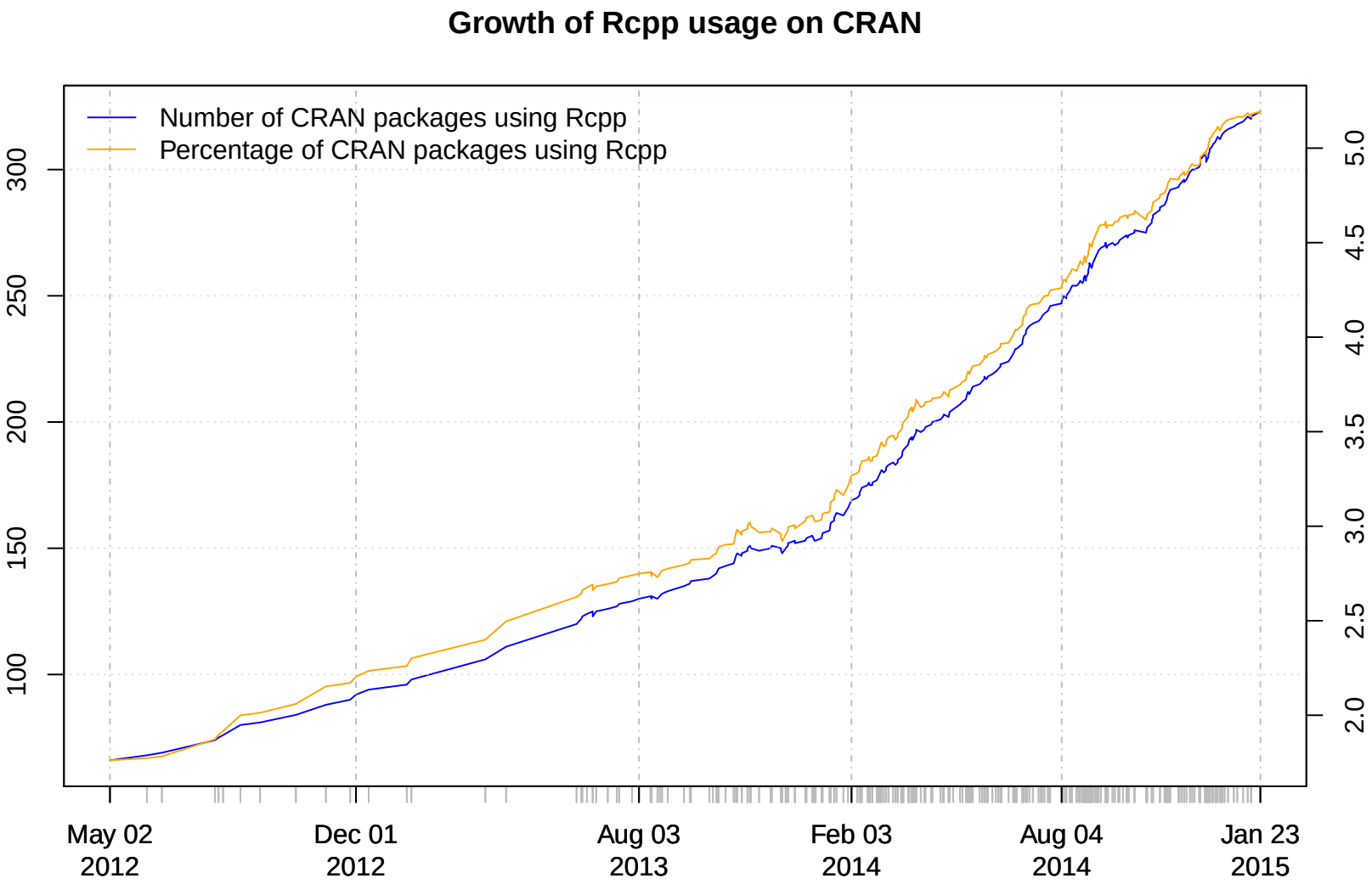
Key Features

As we just saw in the small example:

- No build system issues: We just use R
- No operating system dependencies
- No (manual or explicit) memory management
- No complicated C++ code (though we could if we wanted to)
- Easy transition from exploration (“one-liners”) to deployment (“packages”)

Outline

Rcpp on CRAN: Now at 323 packages



Outline

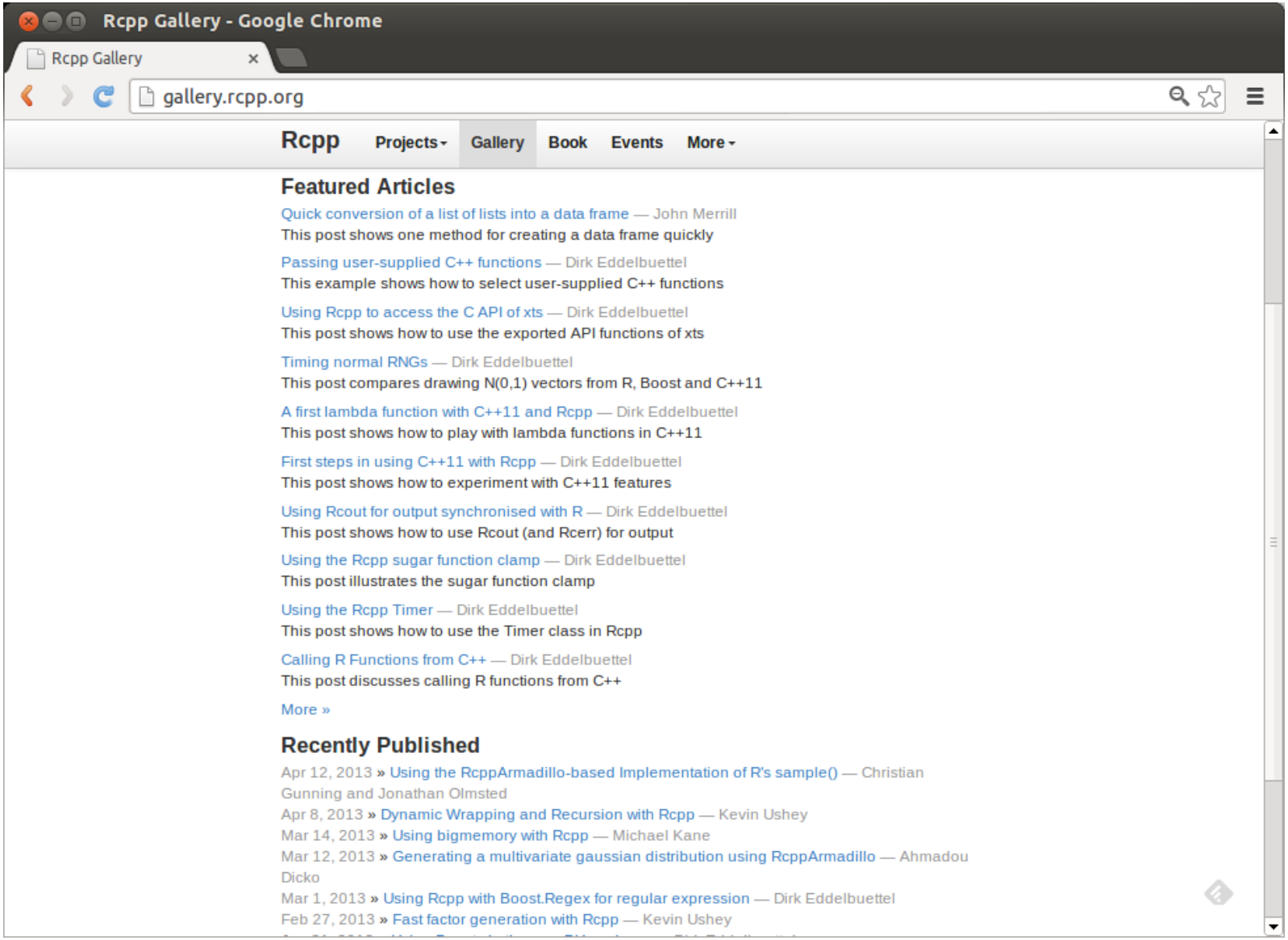
4. Doc
   - Basics
   - Gallery
   - Book

What Else?
Basic 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.
- **StackOverflow** has over 670 posts too.
- Several blog posts introduce/discuss features.

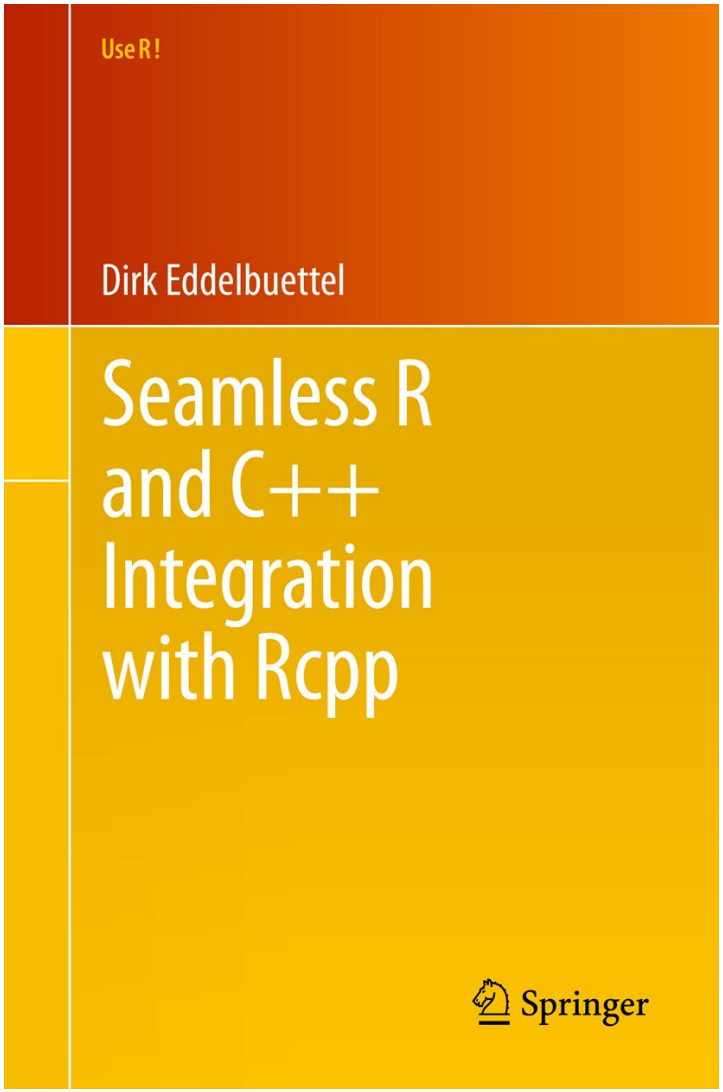
What Else?

Rcpp Gallery: 90+ working and detailed examples



What Else?

The Rcpp book



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