Computational Statistics in Practice

Some Observations

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10 November 2016

Invited Presentation

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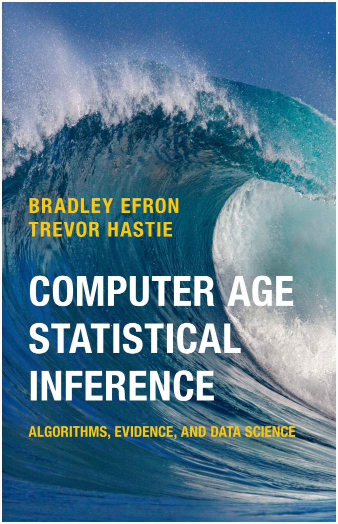
Motivation



Almost all topics in twenty-first-century statistics are now computer-dependent [...]

Here and in all our examples we are employing the language R, itself one of the key developments in computer-based statistical methodology.

Efron and Hastie, 2016,
pages xv and 6 (footnote 3)

A View of the World

Computational Statistics in Practice

- Statistics is now computational (Efron & Hastie, 2016)
- Within (computational) statistics, reigning tool is R
- Given R, Rcpp key for two angles:
  - *Performance* always matters, ease of use a sweetspot
  - *"Extending R"* (Chambers, 2016)
- Time permitting
  - *Being nice to other (languages)*
  - an underdiscussed angle in industry

Drawing on three Talks

- Rcpp Introduction (from recent workshops / talks / courses)
- [if time] If You Can't Beat 'em (from JSS session at JSM)
- [if time] Open Source Finance (from an industry conference)

About Me

Brief Bio

- PhD, MA Econometrics; MSc Ind.Eng. (Comp.Sci./OR)
- Finance Quant for 20 years
- Open Source for 22 years
  - Debian developer
  - R package author / contributor
- R Foundation Board member, R Consortium ISC member
- JSS Associate Editor

Rcpp: Introduction via Tweets

Research Consulting
@iqssrtc

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Using #Rcpp to leverage the speed of c++ with the ease and clarity of R. Thanks, @eddelbuettel

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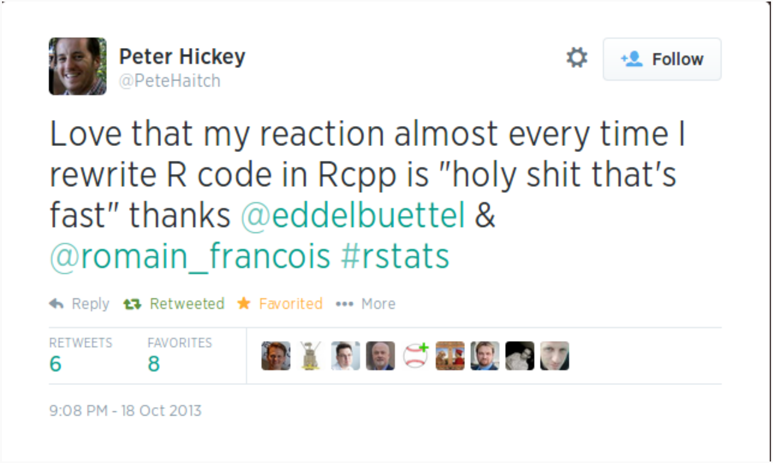
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Love that my reaction almost every time I rewrite R code in Rcpp is "holy shit that's fast" thanks @eddelbuettel & @romain_francois #rstats
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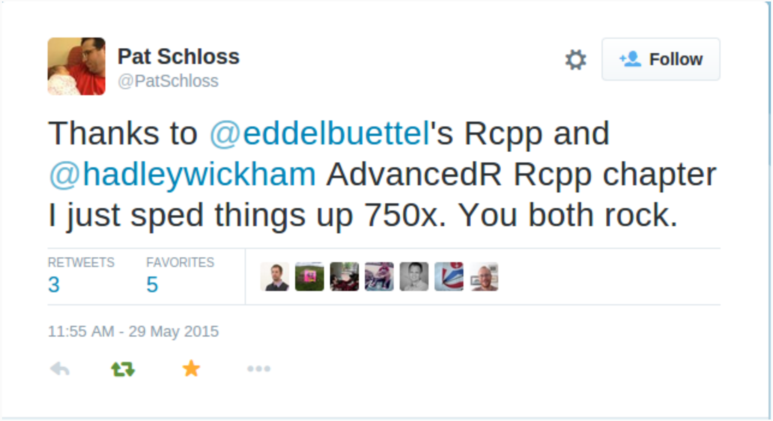
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Thanks to @eddelbuettel's Rcpp and @hadleywickham AdvancedR Rcpp chapter I just sped things up 750x. You both rock.
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Writing some code using #rstats plain C API and realising/remembering quite how much work Rcpp saves - thanks @eddelbuettel
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@kwbroman
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@eddelbuettel @romain_francois Have I emphasized how much I ❤ #Rcpp?
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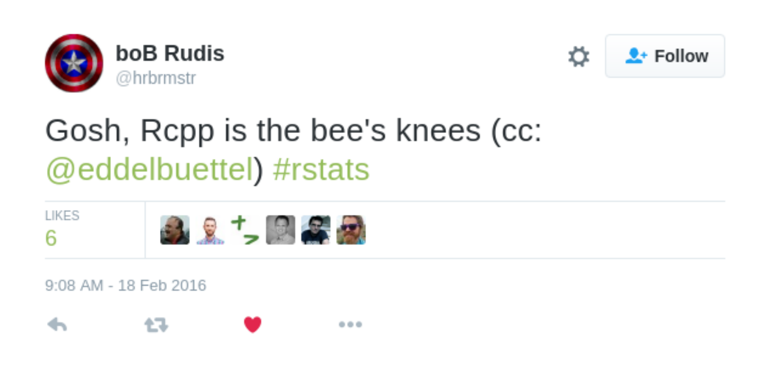
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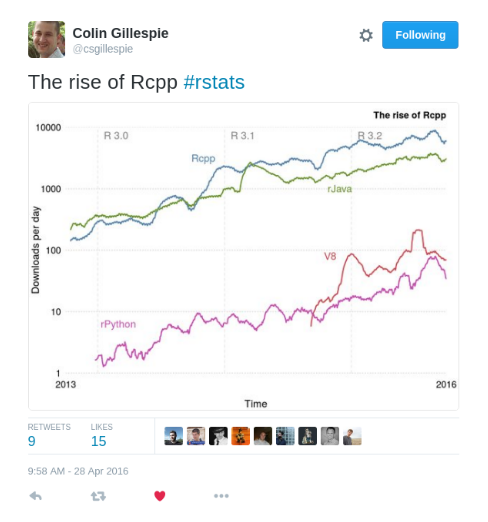
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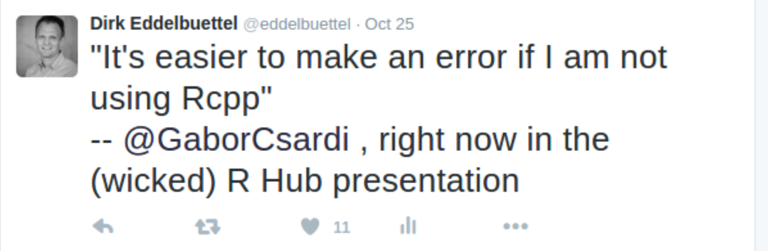
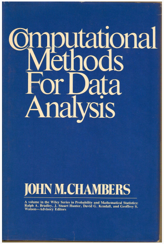
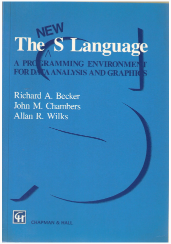
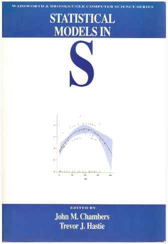

Dirk Eddelbuettel @eddelbuettel · Oct 25
"It's easier to make an error if I am not using Rcpp"
-- @GaborCsardi , right now in the (wicked) R Hub presentation
11

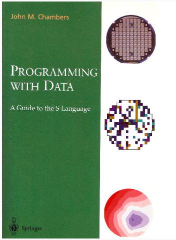
Extending R

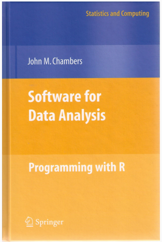
WHY R? : *PROGRAMMING WITH DATA* FROM 1977 TO 2016

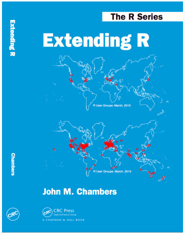










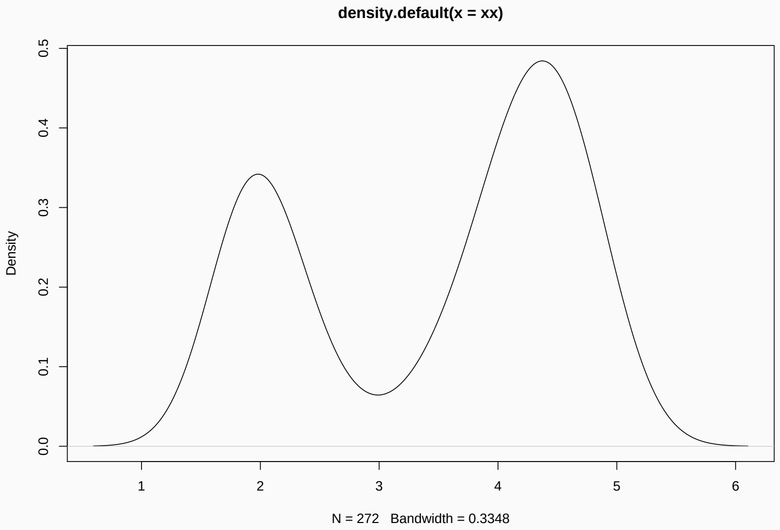


Thanks to John Chambers for high-resolution cover images. The publication years are, respectively, 1977, 1988, 1992, 1998, 2008 and 2016.

A Simple Example

```
xx <- faithful[,"eruptions"]
fit <- density(xx)
plot(fit)
```

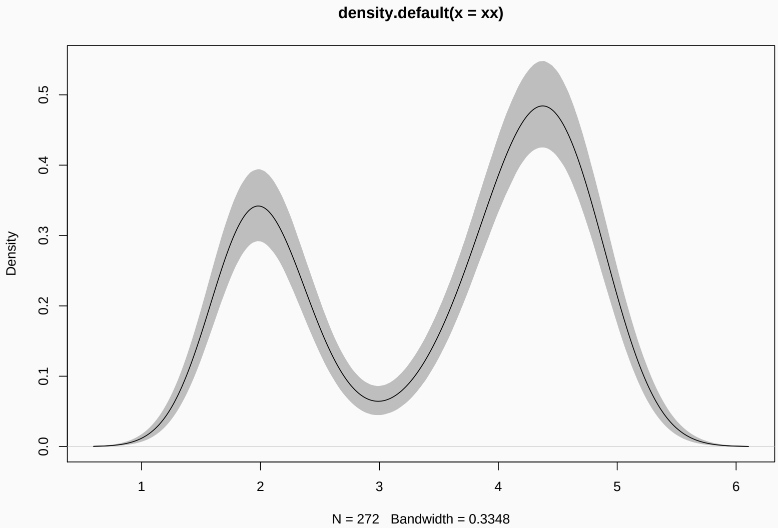
A Simple Example



A Simple Example - Refined

```
xx <- faithful[,"eruptions"]
fit1 <- density(xx)
fit2 <- replicate(10000, {
    x <- sample(xx,replace=TRUE);
    density(x, from=min(fit1$x), to=max(fit1$x))$y
})
fit3 <- apply(fit2, 1, quantile,c(0.025,0.975))
plot(fit1, ylim=range(fit3))
polygon(c(fit1$x,rev(fit1$x)), c(fit3[1,],rev(fit3[2,])),
    col='grey', border=F)
lines(fit1)
```

A Simple Example - Refined



So Why R?

R enables us to

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

making it the key language for statistical computing, and a preferred environment for many data analysts.

So Why R?

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 Simon Urbanek
- C++ but essentially at the bare-bones level of C

So while *in theory* this always worked – it was tedious *in practice*

Why Extend R?

Chambers (2008), opens Chapter 11 *Interfaces I: Using C and Fortran*:

> *Since the core of R is in fact a program written in the C language, it's not surprising that the most direct interface to non-R software is for code written in C, or directly callable from C. All the same, including additional C code is a serious step, with some added dangers and often a substantial amount of programming and debugging required. You should have a good reason.*

Why Extend R?

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Why Extend R?

Chambers proceeds with this rough map of the road ahead:

- Against:
    - It's more work
    - Bugs will bite
    - Potential platform dependency
    - Less readable software
- In Favor:
    - New and trusted computations
    - Speed
    - Object references

Why Extend R?

The *Why?* boils down to:

- speed: Often a good enough reason for us … and a focus for us in this workshop.
- new things: We can bind to libraries and tools that would otherwise be unavailable in R
- references: Chambers quote from 2008 foreshadowed the work on *Reference Classes* now in R and built upon via Rcpp Modules, Rcpp Classes (and also RcppR6)

And Why C++?

- Asking Google leads to tens of million of 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++* (maybe 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 Standard Template Library* (STL) is a specific template library which is powerful but has its own conventions.
- *C++11* and C++14 (and beyond) add enough to be called a fifth language.

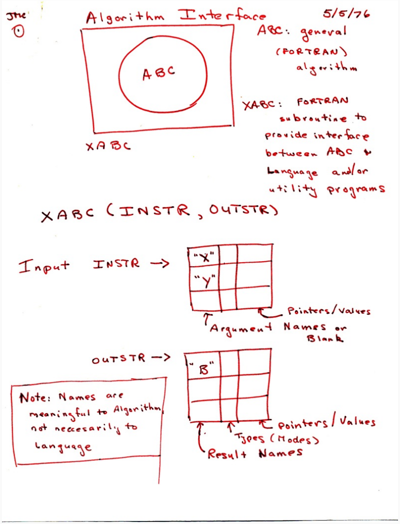
NB: Meyers original list of four languages appeared years before C++11.

Why C++?

- Mature yet current
- Strong performance focus:
    - *You don't pay for what you don't use*
    - *Leave no room for another language between the machine level and C++*
- Yet also powerfully abstract and high-level
- C++11 + C++14 are a big deal giving us new language features
- While there are complexities, Rcpp users are mostly shielded

Interface Vision

Bell Labs, May 1976



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)
- Interpreted code with
  - A 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 as it really does not have to be that complicated – we will see numerous few examples
- Easy to use as it avoids build and OS system complexities thanks to the R infrastrucure
- Expressive as 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*

Speed

Speed Example (due to StackOverflow)

Consider a function defined as

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

Speed Example in R

R implementation and use:

```r
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
```

Speed Example Timed

Timing:

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

```
##     test replications elapsed relative
## 1 f(10)          100   0.016    1.000
## 2 f(15)          100   0.140    8.750
## 3 f(20)          100   1.505   94.063
```

Speed Example in C / C++

A C or C++ solution can be equally simple

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

But how do we call it from R?

But Rcpp makes this *much* easier:

```
Rcpp::cppFunction("int g(int n) {
   if (n < 2) return(n);
   return(g(n-1) + g(n-2)); }")
sapply(0:10, g)
```

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

Speed Example Comparing R and C++

Timing:

```r
Rcpp::cppFunction("int g(int n) {
   if (n < 2) return(n);
   return(g(n-1) + g(n-2)); }")
library(rbenchmark)
benchmark(f(25), g(25), order="relative")[,1:4]
```

```
##    test replications elapsed relative
## 2 g(25)          100   0.035      1.0
## 1 f(25)          100  16.037    458.2
```

A nice gain of a few orders of magnitude.

Another Angle on Speed

Run-time performance is just one example.

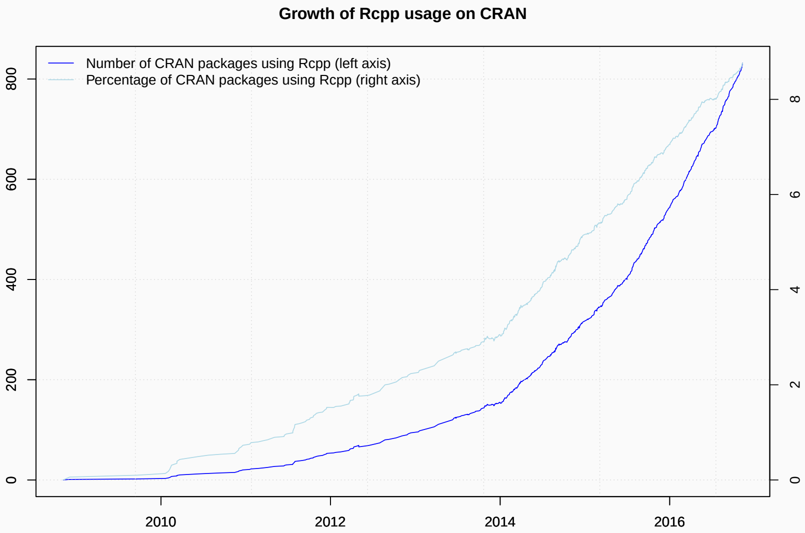
Time to code is another metric.

We feel quite strongly that helps you code more succinctly, leading to fewer bugs and faster development.

A good environment helps. RStudio integrates R and C++ development quite nicely (eg the compiler error message parsing is very helpful) and also helps with package building.

Empirics

Growth



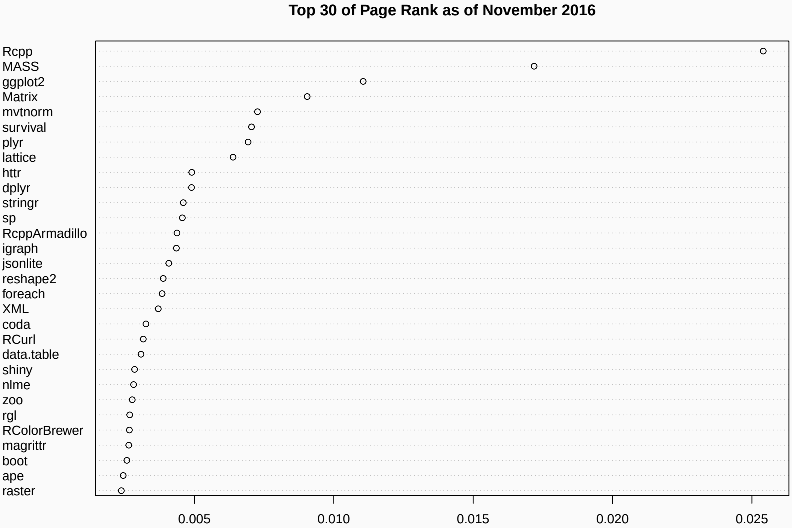
Growth of Rcpp usage on CRAN
Number of CRAN packages using Rcpp (left axis)
Percentage of CRAN packages using Rcpp (right axis)
0
200
400
600
800
0
2
4
6
8
2010
2012
2014
2016

PageRank

```r
library(pagerank)  # github.com/andrie/pagerank

cran <- "http://cloud.r-project.org"

pr <- compute_pagerank(cran)
round(100*pr[1:5], 3)
```

```
##    Rcpp    MASS ggplot2  Matrix mvtnorm
##   2.541   1.719   1.105   0.905   0.726
```

Pagerank



Top 30 of Page Rank as of November 2016
Rcpp
MASS
ggplot2
Matrix
mvtnorm
survival
plyr
lattice
httr
dplyr
stringr
sp
RcppArmadillo
igraph
jsonlite
reshape2
foreach
XML
coda
RCurl
data.table
shiny
nlme
zoo
rgl
RColorBrewer
magrittr
boot
ape
raster
0.005
0.010
0.015
0.020
0.025

Rcpp: A Better C API for R

The R API

In a nutshell:

- R is a C program, and C programs can be extended
- R exposes an API with C functions and MACROS
- R also supports C++ out of the box with `.cpp` extension
- R provides several calling conventions:
    - `.C()` provides the first interface, is fairly limited, and discouraged
    - `.Call()` provides access to R objects at the C level
    - `.External()` and `.Fortran()` exist but can be ignored
- We will use `.Call()` exclusively

The .Call Interface

At the C level, everything is a `SEXP`, and every `.Call()` access uses this interface pattern:

```
SEXP foo(SEXP x1, SEXP x2){
...
}
```

which can be called from R via

```
.Call("foo", var1, var2)
```

Note that we need to compile, and link, and load, this manually in wasy which are OS-dependent.

Example: Convolution

```c
#include <R.h>
#include <Rinternals.h>

SEXP convolve2(SEXP a, SEXP b) {
    int na, nb, nab;
    double *xa, *xb, *xab;
    SEXP ab;

    a = PROTECT(coerceVector(a, REALSXP));
    b = PROTECT(coerceVector(b, REALSXP));
    na = length(a);
    nb = length(b);
    nab = na + nb - 1;
    ab = PROTECT(allocVector(REALSXP, nab));
    xa = REAL(a);
    xb = REAL(b);
    xab = REAL(ab);
    for (int i = 0; i < nab; i++)
        xab[i] = 0.0;
    for (int i = 0; i < na; i++)
        for (int j = 0; j < nb; j++)
            xab[i + j] += xa[i] * xb[j];
    UNPROTECT(3);
    return ab;
}
```

Example: Convolution

```
#include <Rcpp.h>

// [[Rcpp::export]]
Rcpp::NumericVector
convolve2cpp(Rcpp::NumericVector a,
             Rcpp::NumericVector b) {
    int na = a.length(), nb = b.length();
    Rcpp::NumericVector ab(na + nb - 1);
    for (int i = 0; i < na; i++)
        for (int j = 0; j < nb; j++)
            ab[i + j] += a[i] * b[j];
    return(ab);
}
```

Types Overview: RObject

- The `RObject` can be thought of as a basic class behind many of the key classes in the `Rcpp` API.
- `RObject` (and our core classes) provide a thin wrapper around `SEXP` objects
- This is sometimes called a *proxy object* as we do not copy the R object.
- `RObject` manages the life cycle, the object is protected from garbage collection while in scope—so we do not have to do memory management.
- Core classes define several member common functions common to all objects (e.g. `isS4()`, `attributeNames`, ...); classes then add their specific member functions.

Overview of Classes: Comparison

Rcpp class	R `typeof`
`Integer(Vector|Matrix)`	`integer` vectors and matrices
`Numeric(Vector|Matrix)`	`numeric` ...
`Logical(Vector|Matrix)`	`logical` ...
`Character(Vector|Matrix)`	`character` ...
`Raw(Vector|Matrix)`	`raw` ...
`Complex(Vector|Matrix)`	`complex` ...
`List`	`list` (aka generic vectors) ...
`Expression(Vector|Matrix)`	`expression` ...
`Environment`	`environment`
`Function`	`function`
`XPtr`	`externalptr`
`Language`	`language`
`S4`	`S4`
...	...

Overview of key vector / matrix classes

- `IntegerVector` vectors of type `integer`
- `NumericVector` vectors of type `numeric`
- `RawVector` vectors of type `raw`
- `LogicalVector` vectors of type `logical`
- `CharacterVector` vectors of type `character`
- `GenericVector` generic vectors implementing `list` types

Common core functions for Vectors and Matrices

Key operations for all vectors, styled after STL operations:

- `operator()` access elements via `()`
- `operator[]` access elements via `[]`
- `length()` also aliased to `size()`
- `fill(u)` fills vector with value of `u`
- `begin()` pointer to beginning of vector, for iterators
- `end()` pointer to one past end of vector
- `push_back(x)` insert `x` at end, grows vector
- `push_front(x)` insert `x` at beginning, grows vector
- `insert(i, x)` insert `x` at position *i*, grows vector
- `erase(i)` remove element at position *i*, shrinks vector

Basic Usage

Basic Usage: evalCpp()

`evalCpp()` evaluates a single C++ expression. Includes and dependencies can be declared.

This allows us to quickly check C++ constructs.

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

```
## [1] 4
```

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

```
## [1] 1.797693e+308
```

Basic Usage: cppFunction()

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

```
cppFunction("
    int exampleCpp11() {
        auto x = 10;
        return x;
}", plugins=c("cpp11"))
exampleCpp11()  # same identifier as C++ function
```

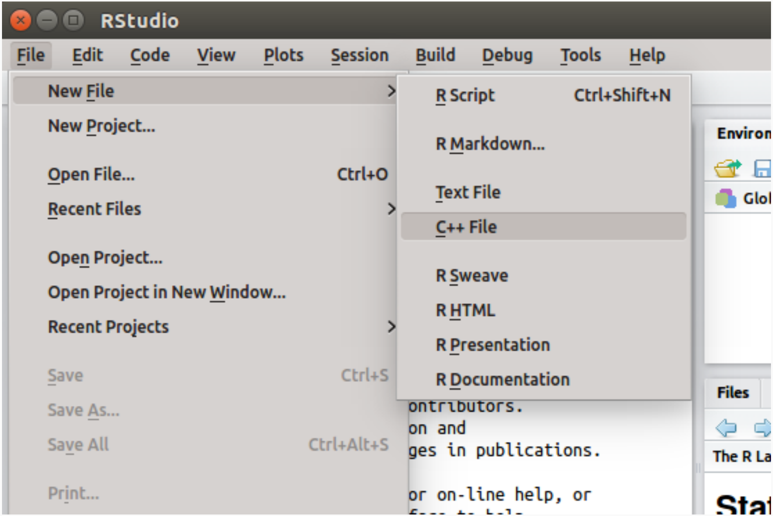
Basic Usage: sourceCpp()

`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 Uage: RStudio



Basic Uage: RStudio (Cont'ed)

The following file gets created:

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

// This 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). ...

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

// You can include R code blocks in C++ files processed with sourceCpp
// (useful for testing and development). The R code will be automatically
// run after the compilation.

/*** R
timesTwo(42)
*/
```

Basic Uage: RStudio (Cont'ed)

So what just happened?

- We defined a simple C++ function
- It operates on a numeric vector 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

Basic Usage: Packages

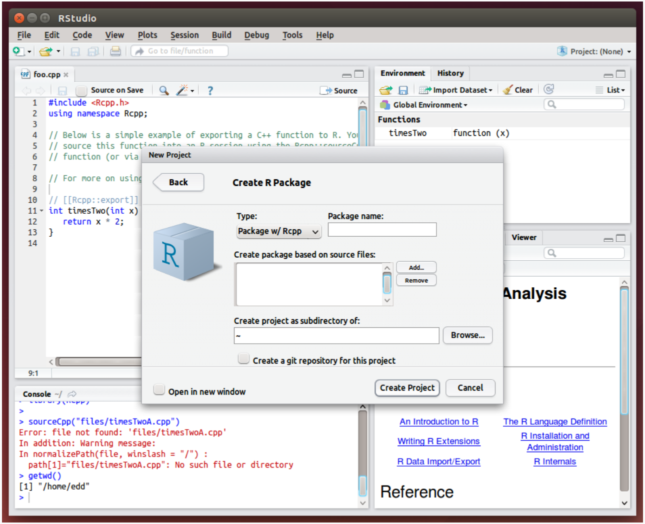
Package are *the* standard unit of R code organization.

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

The vignette Rcpp-packages has fuller details.

As of November 10, 2016, there are 832 packages on CRAN which use Rcpp, and a further 89 on BioConductor — with working, tested, and reviewed examples.

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



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;
}
```

Two ways to link to external libraries

- *With linking of libraries:* Do what RcppGSL does and use hooks in the package startup to store compiler and linker flags, pass to environment variables
- *With C++ template headers only:* Do what RcppArmadillo and other do and just point to the headers

More details in extra vignettes.

Sugar Example

Syntactic 'sugar': Simulating π in R

Draw (x, y), compute dist d to origin. Repeat. Ratio of points with $\sum I(d \leq 1)/N$ goes to $\pi/4$ as we fill the 1/4 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] 3.156000 3.155200 3.139000 3.141008
```

Syntactic 'sugar': Simulating π in C++

Rcpp sugar enables us to write C++ code that is almost as compact.

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

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

The code is essentially identical.

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

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

```
## [1] TRUE
```

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

```
## [1] 3.140899 3.140899
```

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

```r
library(rbenchmark)
sourceCpp("code/piSugar.cpp")
benchmark(piR(1.0e6), piSugar(1.0e6))[,1:4]
```

```
##              test replications elapsed relative
## 1     piR(1e+06)          100   6.946    2.693
## 2 piSugar(1e+06)          100   2.579    1.000
```

Takeaways

- We can prototype in R to derive a first solution
- We can then rewrite performance-critical parts
- Key R functions are often available in C++ via Rcpp Sugar
- Random Number Simulation will work on identical streams

Other Examples

Cumulative Sum: vector-cumulative-sum

A basic looped version:

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

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

    NumericVector res(x.size());  // init result vector

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

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;
}
```

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.

R Function Call from C++: `r-function-from-c++`

```cpp
#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: using-boost-with-bh

```cpp
// [[Rcpp::depends(BH)]]
#include <Rcpp.h>

// One include file from Boost
#include <boost/date_time/gregorian/gregorian_types.hpp>

using namespace boost::gregorian;

// [[Rcpp::export]]
Rcpp::Date getIMMDate(int mon, int year) {
    // compute third Wednesday of given month / year
    date d = nth_day_of_the_week_in_month(
                   nth_day_of_the_week_in_month::third,
                   Wednesday, mon).get_date(year);
    date::ymd_type ymd = d.year_month_day();
    return Rcpp::wrap(Rcpp::Date(ymd.year, ymd.month, ymd.day));
}
```

Using Boost via BH: using-boost-with-bh

```
#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: subsetting

```cpp
#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: armadillo-eigenvalues

```cpp
#include <RcppArmadillo.h>

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

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

ARMADILLO EIGENVALUES: armadillo-eigenvalues

```r
sourceCpp("code/armaeigen.cpp")

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

```
##            [,1]
## [1,]  0.3318872
## [2,]  1.6855884
## [3,]  2.4099205
## [4,] 14.2100108
```

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

Create xts from in C++: 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;
}
```

RcppMLPACK: K-Means Example

```
#include "RcppMLPACK.h"

using namespace mlpack::kmeans;
using namespace Rcpp;

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

// [[Rcpp::export]]
List cppKmeans(const arma::mat& data, const int& clusters) {

    arma::Col<size_t> assignments;
    KMeans<> k;     // Initialize with the default arguments.
    k.Cluster(data, clusters, assignments);

    return List::create(Named("clusters") = clusters,
                        Named("result")   = assignments);
}
```

Timing

Table 1: Benchmarking result

test	replications	elapsed	relative	user.self	sys.self
mlKmeans(t(wine), 3)	100	0.028	1.000	0.028	0.000
kmeans(wine, 3)	100	0.947	33.821	0.484	0.424

Table taken ‘as is’ from RcppMLPACK vignette.

RcppMLPACK: Nearest Neighbors Example

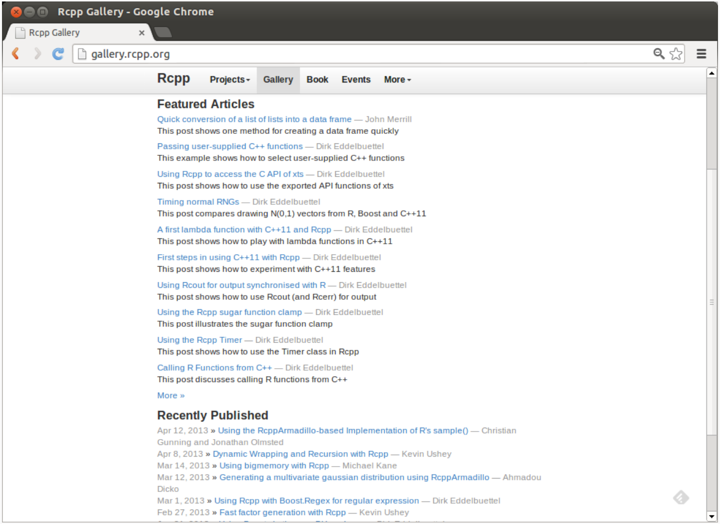
```cpp
#include "RcppMLPACK.h"

using namespace Rcpp;
using namespace mlpack;          using namespace mlpack::neighbor;
using namespace mlpack::metric;   using namespace mlpack::tree;

// [[Rcpp::depends(RcppMLPACK)]]
// [[Rcpp::export]]
List nn(const arma::mat& data, const int k) {
    // using a test from MLPACK 1.0.10 file src/mlpack/tests/allknn_test.cpp
    CoverTree<LMetric<2>, FirstPointIsRoot,
              NeighborSearchStat<NearestNeighborSort> > tree =
        CoverTree<LMetric<2>, FirstPointIsRoot,
                  NeighborSearchStat<NearestNeighborSort> >(data);

    NeighborSearch<NearestNeighborSort, LMetric<2>,
                   CoverTree<LMetric<2>, FirstPointIsRoot,
                             NeighborSearchStat<NearestNeighborSort> > >
        coverTreeSearch(&tree, data, true);

    arma::Mat<size_t> coverTreeNeighbors;
    arma::mat coverTreeDistances;
    coverTreeSearch.Search(k, coverTreeNeighbors, coverTreeDistances);

    return List::create(Named("clusters") = coverTreeNeighbors,
                        Named("result")   = coverTreeDistances);

}
```

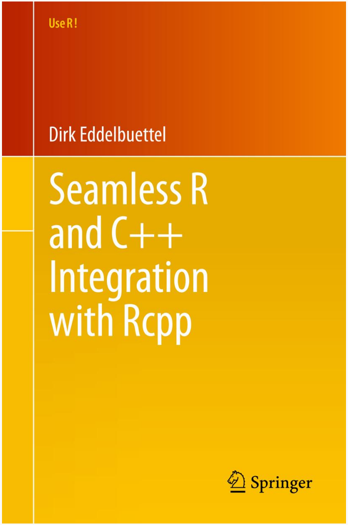
More

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 Anlys*)
- The rcpp-devel list is *the* recommended resource, generally very helpful, and fairly low volume.
- StackOverflow has a large collection of posts too.
- And a number of blog posts introduce/discuss features.

Rcpp Gallery





On sale since June 2013.

Appendix: If You Can't Beat 'em

Overview

Content

- Single- or Multi-Language ?
- Interlude
- Illustration
- Conclusion

Single- Or Multi-Language ?

Better with more than one?

- No one language fits all
- Real-world projects are frequently multi-language
- See *e.g.* job ads which rarely ever list just one language

Counter-claim: 1 + 1 < 2

Or better with just one?

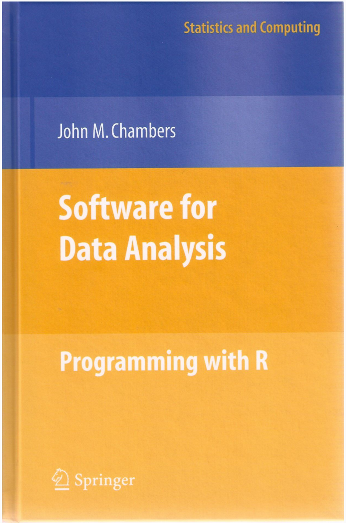
- Mental switching cost between languages? Possibly
- Interop difficult and less portable? Maybe, but that is an argument against weak systems / OSs
- Easier / less to learn?
- “More hoops” to code?


Dirk Eddelbuettel
@eddelbuettel
Forcing us to alternate between comment characters %, # and // may have been the biggest trick ever pulled by the Devil.
RETWEETS
6
LIKES
5
10:22 AM - 10 Aug 2014
6
5

Open Question

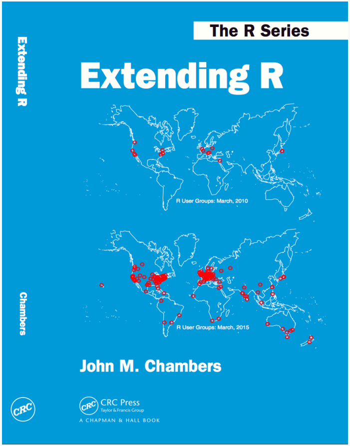
- Hard to measure or test: Any empirics on real world projects?
- Code competition / comparisons (*e.g.* Project Euler): Are they realistic?

INTERLUDE



Chambers (2008) Software For Data Analysis

Chapters 10 and 11 devoted to *Interfaces I: C and Fortran* and *Interfaces II: Other Systems*.



Chambers (2016) Extending R

An entire book about this with *concrete* Python, Julia and C++ code and examples

Chambers 2016, Chapter 1

- *Everything that exists in R is an object*
- *Everything happens in R is a function call*
- *Interfaces to other software are part of R*

Chambers 2016, Chapter 4

> *The fundamental lesson about programming in the large is that requires a correspondingly broad and flexible response. In particular, no single language or software system os likely to be ideal for all aspects. Interfacing multiple systems is the essence. Part IV explores the design of of interfaces from R.*

Illustration

Setup

```
py_cflags <- system("python2.7-config --cflags", intern=TRUE)
se <- Sys.setenv; ge <- Sys.getenv # shorthands to typeset
se("PKG_CFLAGS"=sprintf("%s %s", ge("PKG_CFLAGS"), py_cflags))
se("PKG_CXXFLAGS"=sprintf("%s %s", ge("PKG_CXXFLAGS"), py_cflags))
py_ldflags <- system("python2.7-config --ldflags", intern=TRUE)
se("PKG_LIBS"=sprintf("%s %s %s", ge("PKG_CFLAGS"),
                      "-lboost_python-py27", py_ldflags))
```

Using R to C++ to Boost to Python, and back

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

// [[Rcpp::export]]
void initialize_python() {
    Py_SetProgramName("");  /* optional but recommended */
    Py_Initialize();
}

// [[Rcpp::export]]
void hello_python() {
    PyRun_SimpleString("from time import time,ctime\n"
                       "print 'Today is',ctime(time())\n");
}
```

Hello, World: Called from R

```r
initialize_python()
hello_python()
```

```
## Today is Thu Nov 10 09:40:26 2016
```

More at `http://gallery.rcpp.org/articles/rcpp-python/`

Disclaimer: *For illustration purposes*. Works as designed on Ubuntu. Not meant to be universally portable to all three OSs.

(Section) Conclusion

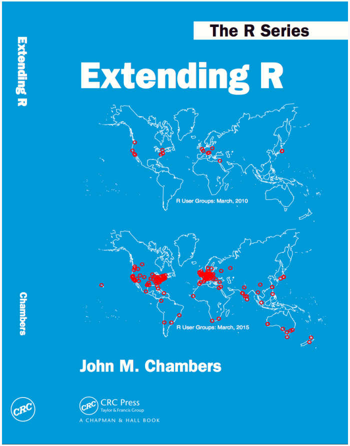
Mixing Languages

- Common
- Natural
- Unavoidable

Consequences

- Must make it easier to interoperate
- Stop bickering among ourselves
- Build systems that are larger that the sum of their parts

Just Do It


The R Series
Extending R
R User Groups: March, 2010
R User Groups: March, 2015
John M. Chambers
Extending R
Chambers
CRC Press
Taylor & Francis Group
A CHAPMAN & HALL BOOK

Lars Wirzenius "Which license is the most free?"

Free software licences can be roughly grouped into permissive and copyleft ones. [...] A permissive licence lets you do things that a copyleft one forbids, so clearly the permissive licence is more free. A copyleft licence means software using it won't ever become non-free against the wills of the copyright holders, so clearly a copyleft licence is more free than a permissive one.

Both sides are both right and wrong, of course, which is why this argument will continue forever. [...]

If a discussion about the relative freedom of licence types becomes heated, step away. It's not worth participating anymore.

http://yakking.branchable.com/posts/comparative-freeness/

Appendix: Open Source Finance

Agenda

Issues

- History: How did we get here?
- Status: What is happening now
- Onward: What may happen

Context

To clarify

- This talk reflects views of a quantitative analyst
- *Software* to us is predominantly a collection of analysis and modeling tools including programming languages, libraries, OSs
- The focus is on *Open Source Finance* — and much less about Open Source and Software in general
- Insert your favourite disclaimer here

History

Terms and Players

- *Open Source* dominates commercial discussions
- *Free Software* predates it; academic roots / MIT
- past friction between sponsoring entities
- OSI and FSF are closer now

Image by NicoBZH from Saint Etienne, Loire, France - Richard Stallman - “Le logiciel libre et ta liberté”

Free Software and Four Freedoms

Free as in the Freedom to ...

- run the program as you wish, for any purpose
- study how the program works, and change it
- redistribute copies so you can help your neighbor
- distribute copies of your modified versions to others

Access to source code is a precondition

Free Software and the GNU Public License (GPL)

GPL: A key Free Software License

- ‘Copyleft’: right to freely distribute copies and modified versions
- Stipulates that the same rights be preserved in derivative works
- ‘Viral’: Combined works have same (aggregate) license
- Some claim that this is not ‘permissive’

GPL versus BSD/MIT/Apache

BSD/MIT/Apache Licenses

- These license calls themselves ‘more permissive’ – ie not viral
- Allows re-use and re-licensing: “can be taken private”
- One way to think about this is
  - user-focus of GPL: nobody can ever take current (or future versions) away
  - author-focus of BSD/MIT as not limiting (?) deployment

Perceived “conflict” overblown – both are Open Source licenses

Legal Details

“It’s complicated”

- This gets into ‘need a lawyer’ territory real fast
- Good (neutral) website: `http://tldrlegal.com`
- Main thing: Just pick *any* good recognized license

Key Aspects

- Focus on Software: ‘Infinitely copyable’
- Consider recent ‘newsworthy’ software releases (e.g. TensorFlow)
- ‘Open by Default’ a (related) winning concept:
  - Wikipedia
  - GitHub

For Software, Debate is Over

- From Ballmer's Microsoft: *Linux is a Cancer*
- To Nadella's Microsoft: *We love Linux*
- Today, few areas of the software industry remain unchanged
- Now frequently seen: 'Open Core' base with add-on services

Microsoft embracing R

Openness

First off, Microsoft's embrace of open source is now a fact, rather than an issue. The company gets that open source platforms are de facto industry standards, and that customers like products that support them. Microsoft already has a version of HDInsight, its Big Data platform based on open source Hadoop and Spark technologies, that runs on Linux. It is also developing a version of SQL Server itself for Linux. Then there's Visual Studio Code, which runs on Windows, Mac or Linux. And a large portion of the virtual machines in the Microsoft Azure cloud are running Linux too.

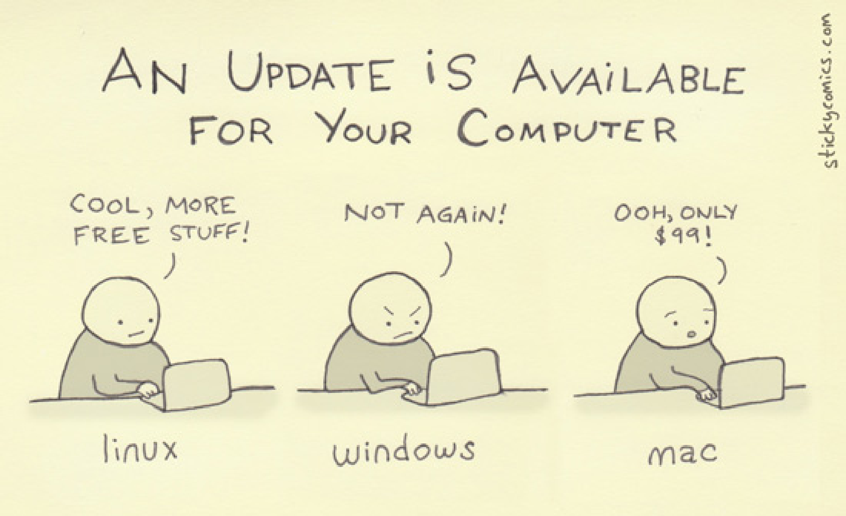
Source: http://www.zdnet.com/article/microsofts-r-strategy/ (retrieved on 2016-May-14)

Trading and Trading Firms

So Where Does that leave us?

Status Quo Somewhat Obvious and Boring

- Open Source is simply how software is done / used
- Trading / Wall St have used Open Source since *forever*
- Niche applications with premiums remain closed
  - As do 'aggregations' and OSs
  - OS X, Windows, ... as well, but at lower prices
- Hence: 'Default is Open'
- I.e. last relevant + closed source programming language?



Source: http://www.stickycomics.com/computer-update/

So Yes, It is 80/20

Open Source Is

- what you use for your (scripting) languages
- what you use for your domain language
- what you use for your (No-)SQL backends
- and on and on an on

And That's A Good Thing

Leaves Focus on Value-Added

- Strategies
- Analysis
- Core (in-house) Technology

to differentiate

Participate

Why?

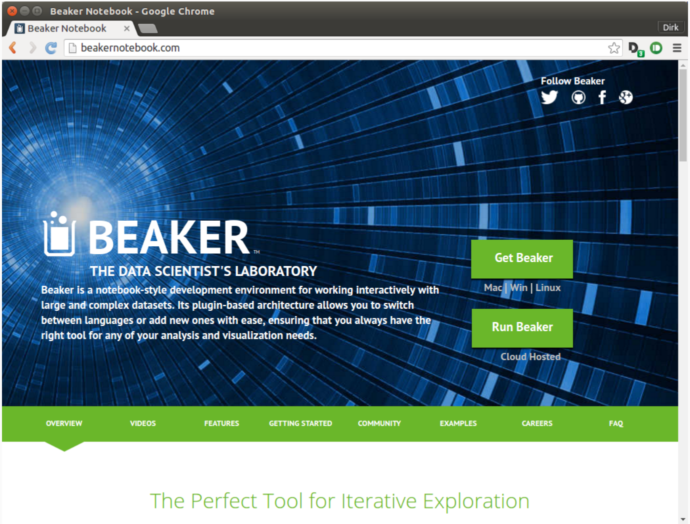
Signalling !

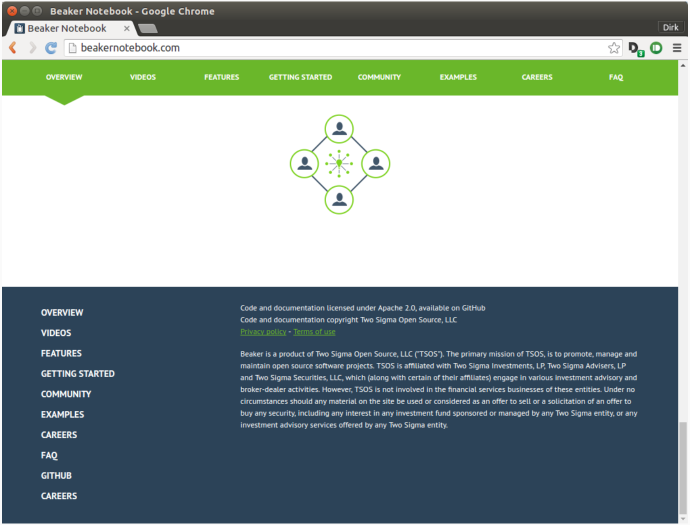
- Better hiring
- Better staff morale
- Better code

Who plays?

A very incomplete list

- TwoSigma Beaker Notebook
- Bloomberg via
  - large C++ libraries
  - OpenBloomberg API libraries
- Goldman Sachs Java Collections Framework


Beaker Notebook - Google Chrome
Beaker Notebook
Dirk
beakernotebook.com
Follow Beaker
BEAKER
THE DATA SCIENTIST'S LABORATORY
Beaker is a notebook-style development environment for working interactively with large and complex datasets. Its plugin-based architecture allows you to switch between languages or add new ones with ease, ensuring that you always have the right tool for any of your analysis and visualization needs.
Get Beaker
Mac | Win | Linux
Run Beaker
Cloud Hosted
OVERVIEW
VIDEOS
FEATURES
GETTING STARTED
COMMUNITY
EXAMPLES
CAREERS
FAQ
The Perfect Tool for Iterative Exploration


Beaker Notebook - Google Chrome
Beaker Notebook
Dirk
beakernotebook.com
OVERVIEW
VIDEOS
FEATURES
GETTING STARTED
COMMUNITY
EXAMPLES
CAREERS
FAQ
OVERVIEW
VIDEOS
FEATURES
GETTING STARTED
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So Here is Where it falls short

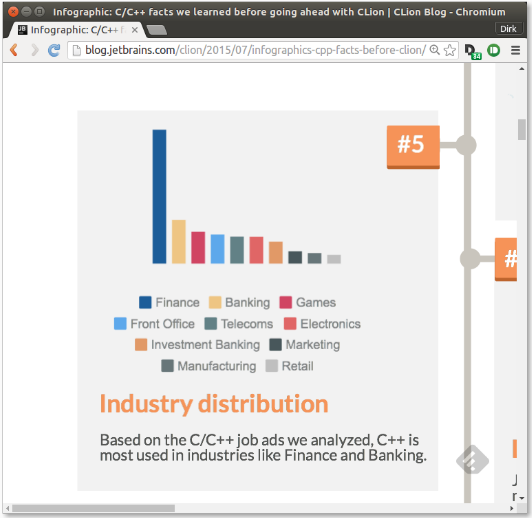
Main Issue:

- Finance / Trading **not** known as a supporter / contributor
    - I.e. Morgan Stanley employs Stroustrup
    - But e.g. why is van Rossum not employed in the industry?
    - Not aware of other key OS developers employed
- But could this be changing?

Change in the Air?

Small Steps

- UseR! 2016 co-sponsored by RenTec, TwoSigma, Bridgewater
- Ketchum has sponsored NIPS, R/Finance and R Consortium
- Funding opportunities:
    - R now has the R Consortium
    - Python (et al) have NumFocus
    - Linux has the Linux Foundation
- But also
    - Software Freedom Conservancy
    - Software in the Public Interest



Source: http://blog.jetbrains.com/clion/2015/07/infographics-cpp-facts-before-clion/
With thanks to Michael Wong and his STAC Chicago presentation on May 17, 2016.

(Section) Summary

Trading

- Benefits hugely as a ‘shadow IT industry’
- By and large does not seem to contribute back
- Let’s try to change that

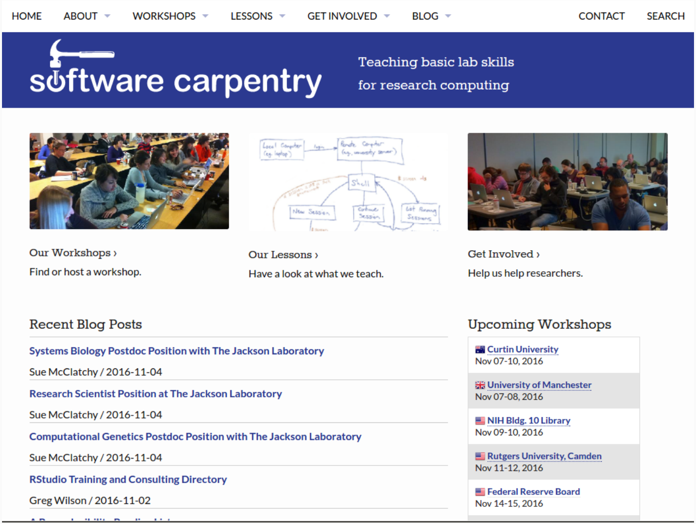
One More Thing

Software Carpentry (and Data Carpentry)

- Basic shell skills
- Basics of version control
- Good programming practice (R, Python, Matlan, ...)

are essential for today's students and tomorrow's researchers

Computing Literacy



Concluding

Summary

Key Themes

- Statistics largely computational
- R is a key ingredient
- Rcpp is a performant and expressive API extension
- Extending R is a key feature
    - Programming is (often) multi-lingual
    - Extending to other systems / languages natural
- Open Source is a key aspect
- Important to teach more than just single language

Thank You!

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