Using Rcpp* packages for easy and fast extension of R with C++

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Outline

1. Short presentation of Rcpp* packages
   - Rcpp : extending R with C++
   - RcppGSL for fast random draws
   - RcppArmadillo for high-performance linear algebra
2. Application examples
   - Distance computation
   - Simple linear regression
   - Exercise to do yourself
3. Build of R package using Rcpp
   - Usefull functions
   - Example of package using Rcpp

Rcpp R package

- **Rcpp** is an R package to extend R with C++ code
- Main advantage : C++ is fast, it accelerates R (see next sections)
- Written by **Dirk EDDELBUETTEL** and **Romain FRANCOIS**
- http://www.rcpp.org/

Simple Rcpp example

C++ code (in file `Code/addition.cpp`)

```
#include <Rcpp.h>
using namespace Rcpp;
// [[Rcpp::export]]
int addition(int a, int b) {
  return a + b;
}
```

R code

```
Rcpp::sourceCpp("Code/addition.cpp")
addition(2, 2)
```

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

Rcpp advantages

Thanks to `Rcpp::sourceCpp()`

- Compile the C++ code
- Export the function to the R session
- Direct interchange of R objects (including S3, S4) between R and C++
- ... (many more, see `vignette("Rcpp-package")`)

GSL and RcppGSL

GNU Scientific Library

- Numerical library for C and C++ programmers
- Reliable random number generator algorithms
- Thoroughly tested and fast random number distributions
- Linear algebra (matrices and vectors)
- https://www.gnu.org/software/gsl/

RcppGSL

- Interface between R and GSL
- Using Rcpp to interface R and C
- http://dirk.eddelbuettel.com/code/rcpp.gsl.html

GSL random number distributions

- GSL v2.6 includes **38 random number distributions** (see GNU GSL)
- It's easy to implement additional random number distributions from the GSL base distributions (e.g. truncated normal distribution)
- For comparison, R API includes "only" 24 random number distributions (see Writing R Extensions)
- Random draws are faster with GSL than with R (eg. `gsl_ran_gamma()` vs. `R::rgamma()`)

RcppGSL example

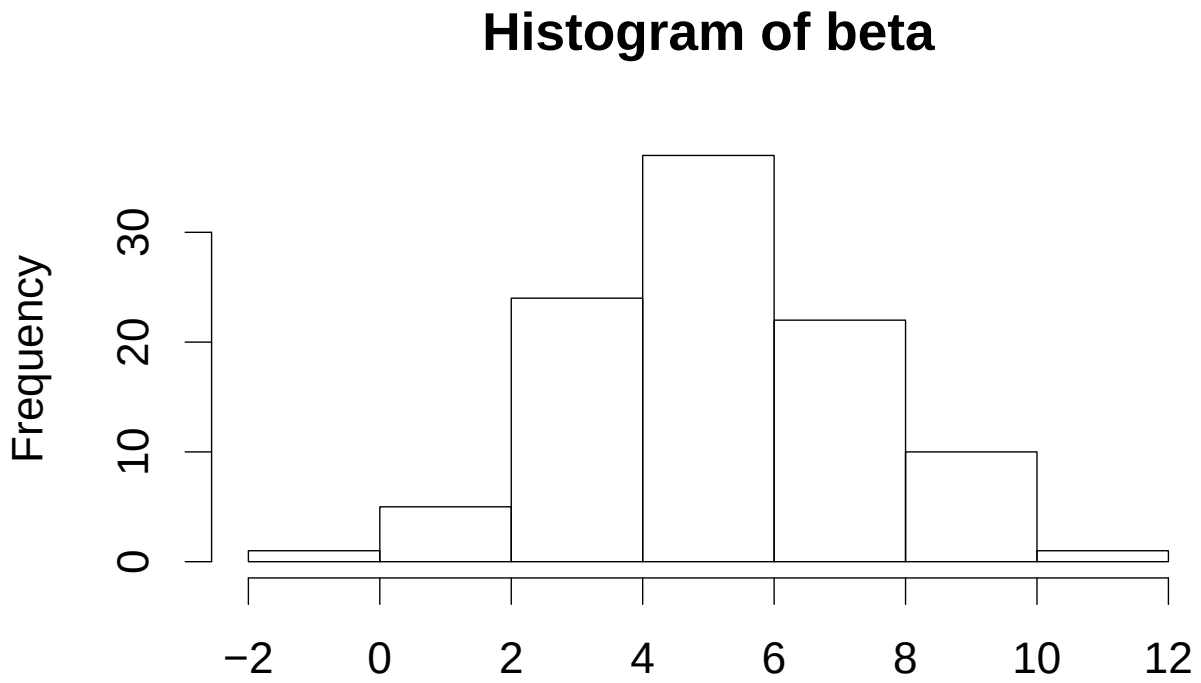
C++ code

```
#include <Rcpp.h>
#include <gsl/gsl_rng.h>
#include <gsl/gsl_randist.h>
using namespace Rcpp;
// [[Rcpp::depends(RcppGSL)]]
// [[Rcpp::export]]
Rcpp::NumericVector my_rnorm(int nsamp, double mu,
                             double sigma) {
    gsl_rng *s = gsl_rng_alloc(gsl_rng_mt19937); // Random seed
    Rcpp::NumericVector beta(nsamp);
    for (int i = 0; i < nsamp; i++) {
        beta[i] = mu + gsl_ran_gaussian(s, sigma); // Random draw
    }
    return beta;
}
```

RcppGSL example

R code

```
library(Rcpp)
library(RcppGSL)
beta <- my_rnorm(100, 5, 2)
par(cex=2)
hist(beta)
```



Armadillo and RcppArmadillo

Armadillo

- C++ library for linear algebra and scientific computing
- Provides high-level syntax and functionality : speed and ease of use
- Classes for vectors, matrices and cubes
- Matrix operations, matrix decomposition, linear model solver, etc.
- http://arma.sourceforge.net/

RcppArmadillo

- Interface between R and Armadillo
- Using Rcpp to interface R and C++
- http://dirk.eddelbuettel.com/code/rcpp.armadillo.html

RcppArmadillo example

C++ code

```
#include <RcppArmadillo.h>
// [[Rcpp::depends(RcppArmadillo)]]
// [[Rcpp::export]]
arma::mat arma_scale(const arma::mat& X) {
    int n = X.n_rows, k = X.n_cols;
    arma::rowvec col_means = arma::mean(X,0); // means
    arma::rowvec col_sd  = arma::stddev(X,0); // standard deviations
    arma::mat X_scaled(n,k);
    for (int  p= 0; p < k; p++) {
    X_scaled.col(p) = (X.col(p)-col_means(p))/col_sd(p);
    }
    return X_scaled;
}
```

RcppArmadillo example

R code

```
library(Rcpp)
library(RcppArmadillo)

# Center and reduce a matrix
X <- matrix(rnorm(50),ncol=5)
X_scaled <- arma_scale(X)
colMeans(X_scaled)
```

```
## [1] -1.040834e-17 -3.573530e-17 -7.806256e-18 -1.429412e-16  1.804112e-17
```

```
var(X_scaled)
```

```
##             [,1]       [,2]         [,3]         [,4]       [,5]
## [1,]  1.0000000  0.3190694  0.111468029  0.204951028 -0.2880433
## [2,]  0.3190694  1.0000000 -0.234062859 -0.400487032 -0.5187358
## [3,]  0.1114680 -0.2340629  1.000000000 -0.004137387 -0.3039397
## [4,]  0.2049510 -0.4004870 -0.004137387  1.000000000  0.4316258
## [5,] -0.2880433 -0.5187358 -0.303939700  0.431625778  1.0000000
```

Licenses

- Licenses : GNU General Public License, Apache License 2.0 for Armadillo
- Free software licenses : we can use, modify and redistribute these softwares

Distance computation

C++ code (in file Code/arma_distmat.cpp)

```
#include <RcppArmadillo.h>
// [[Rcpp::depends(RcppArmadillo)]]
using namespace Rcpp;
using namespace arma;

// [[Rcpp::export]]
arma::mat arma_distmat(const arma::mat& x) {
  int np = x.n_rows;
  arma::mat distmat; distmat.zeros(np, np);
  for (int i = 0; i < np; i++) {
    arma::vec p0 = x.row(i).t();
    for (int j = i + 1; j < np; j++) {
      arma::vec p1 = x.row(j).t();
      arma::vec diff = p0 - p1;
      double squared_diff = as_scalar(diff.t() * diff);
      distmat(j, i) = distmat(i, j) = sqrt(squared_diff);
    }
  }
  return distmat;
}
```

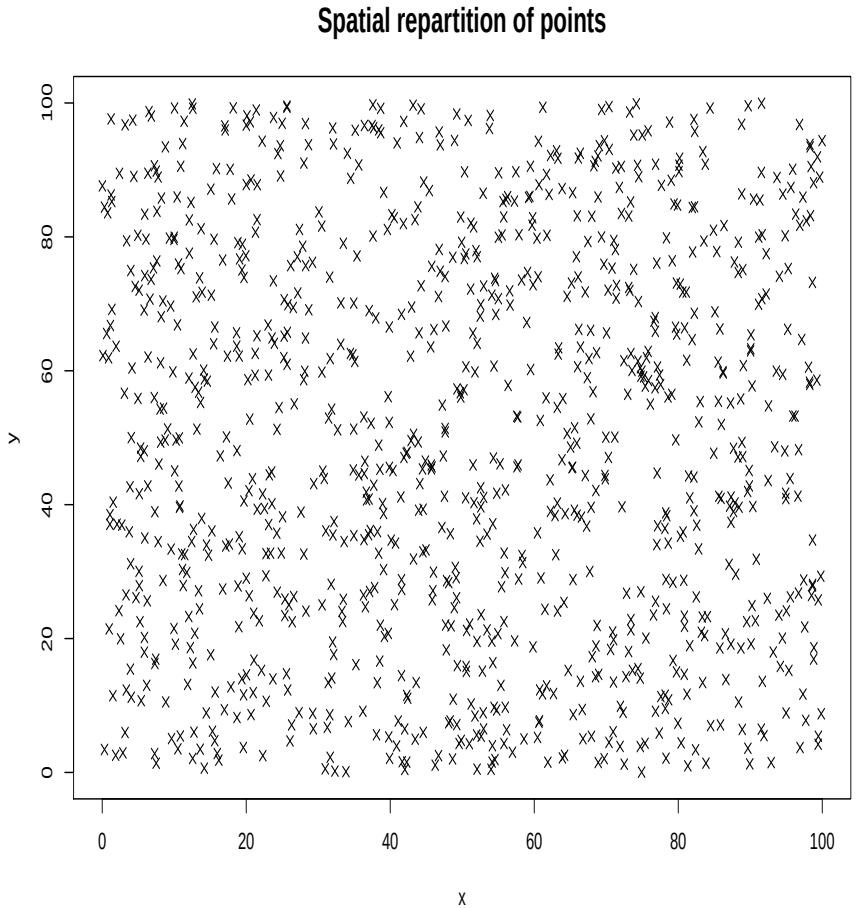
Distance computation

R code

```
R_distmat <- function(X){
  np <- nrow(X)
  distmat <- matrix(0,nrow=np,ncol=np)
  for (i in 1:(np-1)) {
    p0 <- X[i,]
    for (j in (i+1):np){
    p1 <- X[j,]
    diff <- p0-p1
    squared_diff <- t(diff)%*% diff
    distmat[j,i] <- distmat[i,j] <- sqrt(squared_diff)
    }
  }
 return(distmat)
}
```

Distance computation

1000 points dispersed all over the space :



Distance matrix for 6 points :

0.0	36.0	48.6	61.4	57.3	95.8
36.0	0.0	25.8	68.2	76.8	100.2
48.6	25.8	0.0	50.7	66.5	78.8
61.4	68.2	50.7	0.0	24.9	34.5
57.3	76.8	66.5	24.9	0.0	47.9
95.8	100.2	78.8	34.5	47.9	0.0

Distance computation

Comparison of compilation times

```
Rcpp::sourceCpp("Code/arma_distmat.cpp")
library(rdist)
# Benchmark
library(rbenchmark)
Benchmark <- benchmark(
  "arma_distmat" = {arma_distmat(X)},
  "cdist" = {cdist(X,X)},
  "R_distmat" = {R_distmat(X)},
  replications=30,
  columns = c("test", "elapsed", "relative"))
```

test	elapsed	relative
arma_distmat	0.5	1.0
cdist	1.5	3.2
R_distmat	63.9	136.0

Simple linear regression

C++ code

```
#include <RcppArmadillo.h>
// [[Rcpp::depends(RcppArmadillo)]]
// [[Rcpp::export]]
Rcpp::List arma_fastLm(const arma::mat& X, const arma::colvec& y) {
    int n = X.n_rows, k = X.n_cols;

    arma::colvec coef = arma::inv(X.t()*X)*X.t()*y;    // fit model y ~ X
    arma::colvec res  = y - X*coef;           // residuals
    // std.errors of coefficients
    double s2 = arma::sum(res.t()*res);
    arma::colvec std_err = arma::sqrt(s2*arma::diagvec(arma::inv(X.t()*X)));
    return Rcpp::List::create(Rcpp::Named("coefficients") = coef,
                              Rcpp::Named("stderr") = std_err,
                              Rcpp::Named("residuals")  = res,
                              Rcpp::Named("df.residual")  = n - k);
}
```

Simple linear regression

R code

```
R_fastLm <- function(X, y) {
n <- nrow(X)
k <- ncol(X)

# fit model y ~ X
coef <-solve(t(X) %*% X) %*% t(X) %*% y
# residuals
res <- y - X %*% coef
# std.errors of coefficients
s2 = sum(t(res) %*% res)/(n - k);
std_err = sqrt(s2 %*% diag(solve(t(X)%*%X)))
return(list("coefficients" = coef,
            "stderr" = std_err,
            "residuals" = res,
            "df.residual" = n - k))
}
```

Simple linear regression

Comparison of compilation times

```
# airquality data-set
library(datasets)
y <- airquality$Ozone
X <- cbind(1, airquality$Solar.R, airquality$Temp, airquality$Wind)
# Call C++ function
Rcpp::sourceCpp("Code/arma_fastLm.cpp")
# Benchmark
library(rbenchmark)
Benchmark <- benchmark(
  "arma_fastLm" = {arma_fastLm(X,y)},
  "R_fastLm" = {R_fastLm(X,y)},
  replications=100,
  columns = c("test", "elapsed", "relative"))
```

test	elapsed	relative
arma_fastLm	0.003	1.000
R_fastLm	0.008	2.667

Representation of results

Exercise to do yourself

Implement a function in C++ to select in a matrix the lines identified by a vector of integer and return the corresponding matrix.

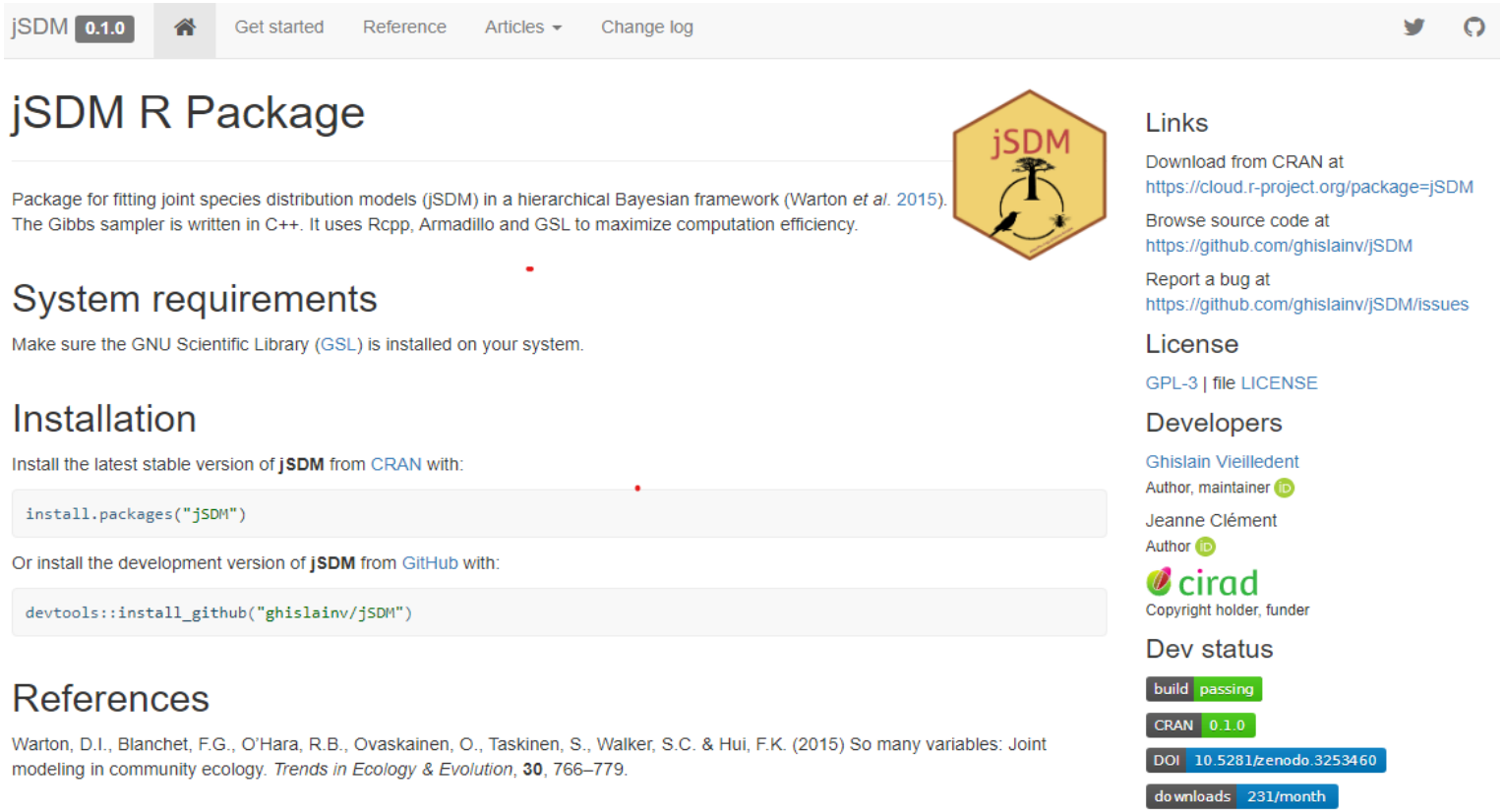
C++ code

```
#include <RcppArmadillo.h>
// [[Rcpp::depends(RcppArmadillo)]]
// [[Rcpp::export]]
arma::mat mat_select_lines(arma::mat& X, arma::uvec& rowId) {
  int nrows = rowId.n_elem;
  int ncols = X.n_cols;
  arma::mat R(nrows, ncols);
  for(int i = 0; i < nrows; i++) {
    for(int j = 0; j < ncols; j++) {
      R(i, j) = X(rowId(i), j);
    }
  }
  return R;
}
```

How to build an R package around C++ functions

- `Rcpp.package.skeleton()` to generate a new Rcpp package (modifying `DESCRIPTION` and `NAMESPACE`)
- `Rcpp::compileAttributes()` scans the C++ files and generates the `RcppExports.cpp` file to make the functions preceded by `// [[Rcpp::export]]` available in R.
- Implement R functions that checks the conformity of user-defined parameters, calls functions in C++ and returns the results in an easy-to-use format.

jSDM R package



- https://ecology.ghislainv.fr/jSDM
- Made with Rcpp* packages

. . . Thank you for attention . . .

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