Distributed Computing Patterns in R

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KLS Diversified Asset Management

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Messaging patterns

- Messaging patterns are ways of combining sockets to communicate effectively.
- In a messaging pattern each socket has a defined role and fulfills the responsibilities of that role.
- ZMQ offers several built-in messaging patterns which make it easy to rapidly design a distributed application:
  - Request-reply, which connects a set of clients to a set of services.
  - Pub-sub, which connects a set of publishers to a set of subscribers.
  - Pipeline, which connects nodes in a fan-out/fan-in pattern that can have multiple steps and loops.
  - Exclusive pair, which connects two sockets exclusively.
What does ZMQ give us?

- ZMQ is a highly specialized networking toolkit.
- It implements the basics of socket communications while letting the user focus on the application.
- Very complex messaging patterns can be built on top of these simple ZMQ sockets (Paranoid Pirate, Majordomo, Binary Star, Suicidal Snail, etc.).
- http://zguide.zeromq.org/page:all
Request / Reply example

- Req / Rep is the most basic message pattern.
- Both the request socket and reply socket are synchronous.
- The reply socket can only service one request at a time, however, many clients may connect to it and queue requests.
require(rzmq)

ctx <- init.context()
responder <- init.socket(ctx, "ZMQ_REP")
bind.socket(responder, "tcp://*:5555")

while (1) {
  req <- receive.socket(responder)
  send.socket(responder, "World")
}
require(rzmq)

requester <- init.socket(ctx, "ZMQ_REQ")
connect.socket(requester, "tcp://localhost:5555")

for (request.number in 1:5) {
  print(paste("Sending Hello", request.number))
  send.socket(requester, "Hello")
  reply <- receive.socket(requester)
  print(paste("Received: ", reply, "number ", request.number))
}

## [1] "Sending Hello 1"
## [1] "Received: World number 1"
## [1] "Sending Hello 2"
## [1] "Received: World number 2"
## [1] "Sending Hello 3"
## [1] "Received: World number 3"
## [1] "Sending Hello 4"
## [1] "Received: World number 4"
## [1] "Sending Hello 5"
## [1] "Received: World number 5"
require(rzmq)

ctx <- init.context()
responder <- init.socket(ctx, "ZMQ_REP")
bind.socket(responder, "tcp://*:5557")

while (1) {
  req <- receive.socket(responder)
  send.socket(responder, req * req)
}

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require(rzmq)

requester <- init.socket(ctx, "ZMQ_REQ")
connect.socket(requester, "tcp://localhost:5557")

x <- 10
send.socket(requester, x)
reply <- receive.socket(requester)
all.equal(x * x, reply)

## [1] TRUE

print(reply)

## [1] 100
Request / Reply client – rpc server with user function

```r
require(rzmq)

ctx <- init.context()
responder <- init.socket(ctx, "ZMQ_REP")
bind.socket(responder, "tcp://*:5558")

while (1) {
  msg <- receive.socket(responder)
  fun <- msg$fun
  args <- msg$args
  result <- do.call(fun, args)
  send.socket(responder, result)
}
```

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Request / Reply client – rpc client with user function

```r
require(rzmq)

requester <- init.socket(ctx, "ZMQ_REQ")
connect.socket(requester, "tcp://localhost:5558")

foo <- function(x) {
  x * pi
}

req <- list(fun = foo, args = list(x = 100))
send.socket(requester, req)
reply <- receive.socket(requester)
print(reply)
## [1] 314.2
```

```r
## [1] 314.2
```
# include <string>
# include <iostream>
# include <stdexcept>
# include <unistd.h>
# include <zmq.hpp>
# include <boost/date_time/posix_time/posix_time.hpp>
# include <order.pb.h>
# include <fill.pb.h>
using namespace boost::posix_time;
using std::cout; using std::endl;

int main () {
    zmq::context_t context(1);
    zmq::socket_t socket (context, ZMQ_REP);
    socket.bind ("tcp://*:5559");

    while (true) {
        // wait for order
        zmq::message_t request;
        socket.recv (&request);

        tutorial::Order o;
        o.ParseFromArray (request.data(), request.size ()) ;

        std::string symbol (o.symbol());
        double price (o.price());
        int size (o.size());

        // send fill to client
        tutorial::Fill f;
        f.set_timestamp (to_simple_string (microsec_clock::universal_time ()));
        f.set_symbol (symbol); f.set_price (price); f.set_size (size);

        zmq::message_t reply (f.ByteSize ());
        if (!f.SerializeToArray (reply.data(), reply.size ())) {
            throw std::logic_error ("unable to SerializeToArray.");
        }
        socket.send (reply);
    }
    return 0;
}
Realistic example – R client

```r
broker <- init.socket(ctx, "ZMQ_REQ")
connect.socket(broker, "tcp://*:5559")

## read the proto file
readProtoFiles(files = c("code/proto.example/order.proto", "code/proto.example/fill.proto"))

aapl.order <- new(tutorial.Order, symbol = "AAPL", price = 420.5, size = 100L)
aapl.bytes <- serialize(aapl.order, NULL)

## send order
send.socket(broker, aapl.bytes, serialize = FALSE)
## pull back fill information
aapl.fill.bytes <- receive.socket(broker, unserialize = FALSE)
aapl.fill <- tutorial.Fill$read(aapl.fill.bytes)
writeLines(as.character(aapl.fill))

## timestamp: "2013-May-16 17:33:41.619589"
## symbol: "AAPL"
## price: 420.5
## size: 100

esgr.order <- new(tutorial.Order, symbol = "ESGR", price = 130.9, size = 1000L)
esgr.bytes <- serialize(esgr.order, NULL)

## send order
send.socket(broker, esgr.bytes, serialize = FALSE)
## pull back fill information
esgr.fill.bytes <- receive.socket(broker, unserialize = FALSE)
esgr.fill <- tutorial.Fill$read(esgr.fill.bytes)
writeLines(as.character(esgr.fill))

## timestamp: "2013-May-16 17:33:41.627151"
## symbol: "ESGR"
## price: 130.9
## size: 1000
```
Pub / Sub example

- Pub / Sub is a more interesting pattern.
- The Pub socket is asynchronous, but the sub socket is synchronous.
require(rzmq)

context = init.context()
pub.socket = init.socket(context, "ZMQ_PUB")
bind.socket(pub.socket, "tcp://*:5556")

node.names <- c("2yr", "5yr", "10yr")
usd.base.curve <- structure(rep(2, length(node.names)), names = node.names)
eur.base.curve <- structure(rep(1, length(node.names)), names = node.names)

while (1) {
  ## updates to USD swaps
  new.usd.curve <- usd.base.curve + rnorm(length(usd.base.curve))/100
  send.raw.string(pub.socket, "USD-SWAPS", send.more = TRUE)
  send.socket(pub.socket, new.usd.curve)

  ## updates to EUR swaps
  new.eur.curve <- eur.base.curve + rnorm(length(eur.base.curve))/100
  send.raw.string(pub.socket, "EUR-SWAPS", send.more = TRUE)
  send.socket(pub.socket, new.eur.curve)
}
Pub / Sub, USD Client

```r
require(rzmq)

subscriber = init.socket(ctx, "ZMQ_SUB")
connect.socket(subscriber, "tcp://localhost:5556")
topic <- "USD-SWAPS"
subscribe(subscriber, topic)

i <- 0
while (i < 5) {
  ## throw away the topic msg
  res.topic <- receive.string(subscriber)
  if (get.rcvmore(subscriber)) {
    res <- receive.socket(subscriber)
    print(res)
  }
  i <- i + 1
}

## 2yr 5yr 10yr
## 1.989 1.996 1.992
## 2yr 5yr 10yr
## 2.006 2.005 1.996
## 2yr 5yr 10yr
## 2.001 1.992 2.003
## 2yr 5yr 10yr
## 2.005 1.997 1.998
## 2yr 5yr 10yr
## 1.998 2.010 2.006
```
require(rzmq)

subscriber = init.socket(ctx, "ZMQ_SUB")
connect.socket(subscriber, "tcp://localhost:5556")

subscribe(subscriber, "EUR-SWAPS")

i <- 0
while (i < 5) {
    ## throw away the topic msg
    res.topic <- receive.string(subscriber)
    if (get.rcvmore(subscriber)) {
        res <- receive.socket(subscriber)
        print(res)
    }
    i <- i + 1
}

## 2yr 5yr 10yr
## 0.9991 1.0146 0.9962
## 2yr 5yr 10yr
## 1.0268 0.9912 1.0090
## 2yr 5yr 10yr
## 1.001 1.001 1.000
## 2yr 5yr 10yr
## 1.0075 0.9881 0.9972
Obligatory deathstar example

```r
require(deathstar, quietly = TRUE)

estimatePi <- function(seed) {
  set.seed(seed)
  numDraws <- 10000
  r <- 0.5
  x <- runif(numDraws, min = -r, max = r)
  y <- runif(numDraws, min = -r, max = r)
  inCircle <- ifelse((x^2 + y^2)^0.5 < r, 1, 0)
  sum(inCircle)/length(inCircle) * 4
}

cluster <- c("localhost")
run.time <- system.time(ans <- zmq.cluster.lapply(cluster = cluster, as.list(1:1000), estimatePi))

print(mean(unlist(ans)))
## [1] 3.142

print(run.time)
## user  system elapsed
## 1.276 0.816 6.575

print(attr(ans, "execution.report"))
## jobs.completed
## krypton:9297 84
## krypton:9300 83
## krypton:9306 83
## krypton:9308 83
## krypton:9311 83
## krypton:9314 83
## krypton:9318 84
## krypton:9325 83
## krypton:9329 84
## krypton:9332 83
## krypton:9377 84
## krypton:9380 83
```
doDeathstar foreach example

require(doDeathstar, quietly = TRUE)
registerDoDeathstar("localhost")

z <- foreach(i = 1:100) %dopar% {
  set.seed(i)
  numDraws <- 10000
  r <- 0.5
  x <- runif(numDraws, min = -r, max = r)
  y <- runif(numDraws, min = -r, max = r)
  inCircle <- ifelse((x^2 + y^2)^0.5 < r, 1, 0)
  sum(inCircle)/length(inCircle) * 4
}

print(mean(unlist(z)))

## [1] 3.142
Thanks for listening!

Many people contributed ideas and helped debug work in progress as the rzmq package was being developed.

Bryan Lewis for collaborating and planning this talk with me.
JD Long for my excessive reuse of the estimatePi example.
Kurt Hornik for putting up with my packaging.
John Laing for finding bugs in my code.
Prof Brian Ripley for just being himself.
Elastic Computing with R and Redis
What does "elastic" mean?

- Computational resources can be added or removed at any time.
- Running computations benefit from added resources automatically.
- Computations on de-allocated resources are rescheduled automatically.
Why Elastic?

- Bursty/intermittent computational workloads
- Periodic resource availability
- Resource contention and dynamic reallocation
Components

Interactive R Session or Main Program

Redis Server
doRedis Workers
The components can:

- all be on a single computer
- all be on separate computers
- a mix of the above
- connected by intra- or inter-networks (departmental network, EC2, Azure, etc.)
doRedis and EC2

Ready to roll AMI available. Linux magic is in the `redis-worker-installer.sh` file distributed with the package (a generic doRedis service for any LSB system).

EC2 Example I: Start doRedis workers

- Launch *one* new instance--this can serve as the Redis host and as a worker node.
- Obtain the IP address of the new instance.
- Additional instances may be specified at any time by supplying EC2 user-data:

  ```
  host: <ip address of redis>
  queue: <job queue name>
  port: <redis port if not std.>
  ```
library("doRedis"); library("quantmod")

SP500 <- getSymbols("^GSPC", auto.assign=FALSE)
GOOG  <- getSymbols("GOOG", auto.assign=FALSE)
GOOG  <- diff(log(GOOG[,6])); SP500 <- diff(log(SP500[,6]))

# Estimate beta from the data:
beta = coef(lm(GOOG ~ SP500))[2]

# Bootstrap to get a sense of variation:
n    <- length(GOOG)
registerDoRedis(queue="RJOBS", host="HOST")
b <- foreach(j=1:5000,.combine=c,.packages="xts") %dopar% {
  i <- sample(n,n,replace=TRUE)
  coef(lm(GOOG[i] ~ SP500[i]))[2]
}

hist(b,col="yellow",main="bootstrapped beta",xlab="")
abline(v=beta,col="blue",lwd=2)
Example program output

This example is from Pat Burns' website: http://www.burns-stat.com/
Redis server configuration (redis.conf)

- Comment out the bind line to listen on all interfaces:
  ```
  # bind 127.0.0.1
  ```

- Set the timeout to zero to let workers wait indefinitely:
  ```
  timeout 0
  ```
- chunkSize option
  Preferred number of loop iterations per job

- redisWorker iter and timeout options
  Number of jobs to execute before exiting/time to wait before exiting when queue is removed.

- set.seed.worker function
  Fine control over worker RNG state--see also the doRNG package and others.

setChunkSize, setExport, setPackages implement global ways to set some options, useful with plyR and others...
Caveat!

- Distributing data to workers through Redis...
  - Can be a bottleneck.
  - Redis largest value allowed is 512MB.

One solution: Access big data from **within** parallel jobs if possible. Easy to set this up to happen just once per worker even if many jobs are processed.
Revised example program

```r
library("doRedis");

n    <- length(GOOG)
registerDoRedis(queue="RJOBS", host="HOST")

b <- foreach(j=1:5000,.combine=c, .packages="quantmod") %
dopar% {

  if(!exists("GOOG",envir=globalenv())) {
    S <- getSymbols("^GSPC",auto.assign=FALSE)
    G <- getSymbols("GOOG",auto.assign=FALSE)
    assign("GOOG",diff(log(GOOG[,6])),envir=globalenv())
    assign("SP500",diff(log(SP500[,6])),envir=globalenv())
  }

  i <- sample(n,n,replace=TRUE)
  coef(lm(GOOG[i] ~ SP500[i]))[2]
}
```
foreach tips and tricks
library("doRedis")
registerDoRedis("RJOBS")
startLocalWorkers(n=1, queue="RJOBS")

# Use %:% to nest foreach loops. This trivial example creates
# one set of 15 tasks:

foreach(x=0:2) %:%
  foreach(y=1:5,.combine=c) %dopar% { x+y }

[[1]]
[1] 1 2 3 4 5

[[2]]
[1] 2 3 4 5 6

[[3]]
[1] 3 4 5 6 7
Parallel list comprehensions

# Use %:% and when to form list comprehensions. Conditions
# are evaluated in parallel, which can be an advantage
# if there is a huge amount of data to evaluate.

foreach(x=0:2) %:%
    foreach(y=1:5,.combine=c) %:%
        when(x<y) %dopar% {x+y}

[[1]]
[1] 1 2 3 4 5

[[2]]
[1] 3 4 5 6

[[3]]
[1] 5 6 7
On CRAN

development version at:

https://github.com/bwlewis/doRedis
http://goo.gl/Hn0Ro
Free and open-source array database

Sparse/dense, multi-dimensional arrays

Distributed storage, parallel processing

Excels at parallel sparse/dense linear algebra

ACID, data replication, versioned data
The package defines two main ways to interact with SciDB:

1. Iterable data frame interface using SciDB query language directly

2. N-dimensional sparse/dense array class for R backed by SciDB arrays
library("scidb")
scidbconnect(host="localhost")

# An example reference to a SciDB matrix:
A <- scidb("A")
dim(A)
[1] 50000 50000
Subarrays return new SciDB array objects

\[ A[c(0,49000,171), 5:8] \]

Reference to a 3x4 SciDB array
Use \[\] to materialize data to R

\[A[c(0,49000,171), 5:8][]\]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.9820799</td>
<td>-0.4563357</td>
<td>-1.2947495</td>
<td>-0.8085465</td>
</tr>
<tr>
<td>1</td>
<td>-1.5090126</td>
<td>0.1547963</td>
<td>-0.2435732</td>
<td>-0.1836875</td>
</tr>
<tr>
<td>2</td>
<td>1.3296710</td>
<td>-1.5006536</td>
<td>-0.5980172</td>
<td>0.3752186</td>
</tr>
</tbody>
</table>
Arithmetic

X <- A %*% A[,1:5]
dim(X)

[1] 50000     5
Mixed **SciDB** and **R** object arithmetic

\[
Z <- A[c(0,49000,171), 5:7]
\]

\[
(0.5*(Z + t(Z)) \%*% rnorm(3))[, drop=FALSE]
\]

\[
[,1]
\]
\[
[1,]  3.707263
[2,] -2.833560
[3,]  3.518370
\]
Basic aggregation (scidbdf class)

A <- as.scidb(iris)
Warning message:
In df2scidb :Attribute names have been changed

aggregate(A, Petal_Length ~ Species, "avg (Petal_Length) as mean")

<table>
<thead>
<tr>
<th></th>
<th>Species</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>setosa</td>
<td>1.462</td>
</tr>
<tr>
<td>2</td>
<td>versicolor</td>
<td>4.260</td>
</tr>
<tr>
<td>3</td>
<td>virginica</td>
<td>5.552</td>
</tr>
</tbody>
</table>
It is sometimes possible to use SciDB arrays in R packages with little modification.

```
library("biclust")
library("s4vd")
data(lung)
A <- lung
x <- biclust(A, method=BCssvd, K=1)

# Now with SciDB arrays:
library("s4vdp4")
X <- as.scidb(A)
x1 <- biclust(X, method=BCssvd, K=1)

# Compare the results:
sqrt( x@info$res[[1]]$u - x1@info$res[[1]]$u )
       [,1]
[1,] 5.202109e-16
```
SVD and principal components

S <- svd(A, nu=3, nv=3)
dim(S)
[1] 4 50000 50000

# Result is a 3-D array containing U, S (sparse), and V
Virtual machines and EC2 images ready to roll (including Rstudio) available from: www.scidb.org

R package on CRAN and development version at: github.com/Paradigm4