Quantessentials

R advice – data.table, the best package in the world?

Equities

Global

Quantitative

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Continuing Quantessentials

By popular demand we continue our Quantessentials series, aimed at educating clients to the technical aspects of our research and exploring real-world implementation issues.

The only data manipulation package you arguably need

In this report, we introduce arguably the most powerful general-purpose package for data analysis, "data.table". This simple tool provides a significant performance boost to many of the most popular quant problems we face daily; with a terse and simple syntax we find that it also significantly reduces programming time and the incidence of bugs.

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Why learn a new package?

data.table is arguably the most powerful package for doing data analysis in R; this package is essentially an extension to the native data.frame type, providing several extremely powerful enhancements:

- It provides a terse syntax that minimises coding time and errors
- Efficient joining of multiple tables, including fast timeseries joins
- Fast aggregations and lookups, leveraging an internal index structure

All's well that scales well

Equities data most often comes in a table format; dates and securities identifiers in the first columns, and various numerical and categorical factors in the subsequent columns. In R, this data format is traditionally represented by a *data.frame*; a native data type that provides a familiar interface to manipulate such data.

An approach that works well for small data may suffer as the data volume increases

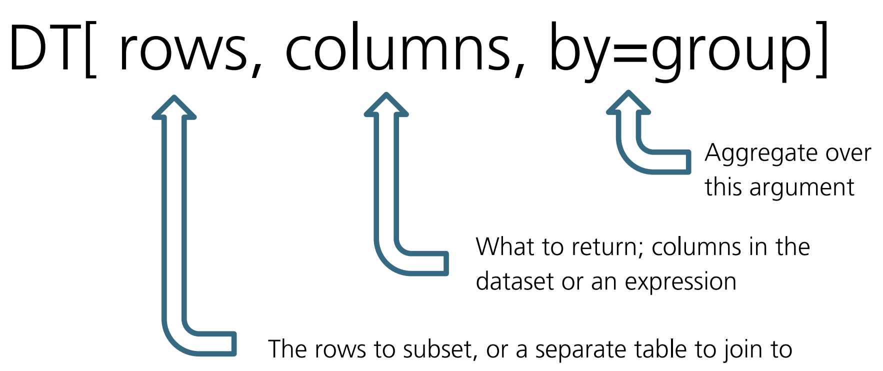
However a common pitfall in computing is how something can *scale*; an approach that works well with 100 data points might fail miserably at 100,000 data points—look no further than the ubiquitous spreadsheet to see this in action. *data.frame* suffers from such a weakness, and *data.table* provides an outstanding alternative to improve the capacity of many common tasks.

While the documentation on *data.table* is excellent and there is a strong support community on various technology sites, in this report we aim to address many of the common tasks that arise specifically in equity quant, and present our solutions to such problems using the *data.table* package.

Getting started

The package can be installed in the usual way: *install.packages('data.table').* Once loaded, a *data.table* can be created in the same way as a data.frame. The basic arguments to a data.table are shown below; it follows a similar notation to the traditional data.frame, but has significantly more functionality, as the examples in the subsequent section show.

Figure 1: The basic arguments to data.table



Source: UBS Quant

Simple examples

In the appendix we include the same data set from our previous Quantessentials report, which shows 40 of the largest companies globally. We now show how easily we can conduct data analysis using this package. Note *data.table* does not support row names; however these can be incorporated into a separate column as necessary.

Figure 2: Simple examples over the screen data set

```
require(data.table)
stop('refer to the appendix for the dataset used')

# average dividend yield
data[, mean(DivYield)]

# dividend yield for each sector
data[, mean(DivYield), by=Sector]

# P/E should be calculated by aggregating over E/P
data[, 1/mean(1/PE), by=Sector]

# calculate a market-cap weighted P/E per sector
data[, 1/weighted.mean(1/PE, MarketCap), by=Sector]

# write an aggregate right back to the table. Note you use := for assignment
data[, SectorPE:=1/weighted.mean(1/PE, MarketCap), by=Sector]

# or impute missing data, e.g. fill in missing PBR's with the sector median
data[, PBR:=ifelse(is.na(PBR), median(PBR, na.rm=T), PBR), by=Sector]

# write multiple columns at once with this shorthand notation
data[, `:=`(PayoutRatio=DivYield*PE, LogMarketCap=log(MarketCap)/log(10))]

# subset the returned columns, using the .() operator, an alias to list()
data[, .(Ticker, PE, SectorRelPE=PE/SectorPE)]

# you can write spaces/slashes in the column names if needed
data[, .(Ticker, `P/E`=PE, `Sector Relative P/E`=PE/SectorPE)]

# you can aggregate over any expression, e.g. aggregate over a date to get a timeseries
data[, .(ROE=mean(ROE, na.rm=T)), by=.(Sector, Momentum=ifelse(Return12m > 0, 'Positive', 'Negative'))]
```

Source: UBS Quant

Of course, these solutions are not unique; there are many different ways to accomplish the same task in R. Here the value of *data.table* is not necessarily the functionality that it offers; rather that it can accomplish in a single line what might take several lines with an alternative approach, or even a loop.

Calculating this in a timeseries, or over different categories is a trivial change to the code

For example, if this data contained multiple dates, a time series can be calculated by simply including the date field in the group argument. The examples above made use of the entire dataset at once, e.g. with no "irows" argument as shown in Figure 1.

More advanced examples

Below we show perhaps some more interesting examples of common *data.table* tasks; these illustrate some of the "special symbols" that *data.table* provides as a convenience. We find the most commonly used are the *.N* symbol which contains the number of rows in the group, and the *.SD* symbol, which contains the subset *data.table* corresponding to the group argument (i.e. *.N* = nrow(*.SD*)). For further details, type *help('special-symbols')*.

There are a number of convenience variables that make light work of complex problems

Figure 3: More advanced examples over the screen

```
# the .N symbol simply returns the row count in each group
data[, .N, by=Sector]

# get the tickers with the highest ROE per sector
data[, Ticker[which.max(ROE)], by=Sector]

# or return their entire row using the .SD subset reference
# this is like a "mini data.table" which you can access, per group
data[, .SD[which.max(ROE)], by=Sector]

# all of these queries can be run after subsetting the rows
data[Return12m < 0, .SD[which.max(ROE)], by=Sector]

# alternatively, you can "chain" subsequent data.table calls together
data[Return12m < 0][, .SD[which.max(ROE)], by=Sector]

# the sector average P/E, excluding each stock (the variable .N is the number of rows in the group)
data[!is.na(PE), .(Ticker, PE, SectorPEx=(.N-1)/(sum(1/PE)-1/PE)), by=Sector]

# the same thing, but with a market-cap weighted P/E
data[!is.na(PE), .(Ticker, PE, (sum(MarketCap)-MarketCap)/(sum(MarketCap/PE)-MarketCap/PE)), by=Sector]

# excluding each stock from the median sector P/E is less efficient, but it's possible
data[, .(Ticker, PE, SectorPEx=sapply(seq_along(PE), function(i) median(PE[-i], na.rm=T))), by=Sector]

# estimate the stock return component not explained by common risk factors
data[, ReturnResid:=resid(lm(FwdReturn~log(MarketCap) + Beta + 1/PBR, data=.SD, na.action='na.exclude'))]

# if you want to refer to columns programmatically, use with=F
value.cols <- c('PE', 'PBR', 'DivYield')
data[, value.cols, with=F]

# assign to several columns using this pattern - the .SDcols argument specifies the columns in .SD
data[, (paste0(value.cols, '/Vol')):=lapply(.SD, function(i) i/Vol), .SDcols=value.cols]

# to run a formula across these columns, e.g. to calculate the rank IC
data[, lapply(.SD, cor, FwdReturn, method='spearman', use='pairwise'), .SDcols=value.cols]

# but a better approach is to convert the table to a long format first
datalong <- melt(data, id.vars=c('Ticker', 'FwdReturn'), measure.vars=value.cols)
datalong[, cor(FwdReturn, value, method='spearman', use='pairwise'), by=variable]
```

Source: UBS Quant

Note the *data.table* package implements its own *melt()* and *dcast()* functions for converting data from a wide to long, and long to wide format respectively; these are significantly faster than the standard implementations. It is often possible to keep data in a wide format; however the more flexible approach is to convert it to long first.

Keys and joins

Similar to a database, *data.table* has the functionality to index into the data, which can yield huge performance benefits if strategically applied. The application of the index (referred to as keying the data) incurs a one-off computational cost, but then enables one table to be joined to another table, and more efficient aggregations.

Judicious application of indices can yield performance gains of several orders of magnitude

Figure 4: Key and join basics

```
# if we have another data.table that we want to join to our screen
data2 <- data.table(SomeTicker=c('AAPL UW', 'GOOG UW', 'IBM UN'), SomeData=runif(3))

# first create the key to access the data by Ticker
setkey(data2, SomeTicker)

# now we can join the tables. note the inner table 'queries' the outer table
# this is not by column name but by column order (or key order if present)
# to only keep matched rows, use data2[data, nomatch=0]
data2[data]

# only the table getting 'queried' needs a key. querying a table without a key gives an error
data[data2]

# data2[data] is very different to data[data2]
setkey(data, Ticker)
data[data2]

# to find which rows in data are being matched, you can use the argument which=T
data[data2, which=T]
```

Source: UBS Quant

Keys can be composited over multiple columns; if the last part of the key is ordinal then ordered joins (most often this refers to a timeseries join) are available. This is perhaps the most compelling feature in *data.table*, being significantly faster and simpler than any other approach.

This task often arises to join data captured at different frequencies (e.g. matching quarterly holdings to monthly data); matching irregular data with regular data (e.g. matching events data to market prices); or accounting for non-trading days.

Figure 5: Ordered joins

```
daily <- data.table(Ticker=c('AAPL UW', 'GOOG UW'), Date=as.Date('1999-12-30') + rep(1:20, each=2),
                    Blah=rep(1:20, each=2) + runif(40))

# you can also create a key in the data.table call like data.table(..., key='Ticker,Date')
setkey(daily, Ticker, Date)

weekly <- daily[format(Date, '%A')=='Friday', .(Ticker, Date, Blah2=sample(LETTERS, .N))]

# while the regular join will only match on exact dates
weekly[daily]

# the rolling join will pad the low frequency data to the high frequency
weekly[daily, roll=T]

# to limit the amount of roll, you can provide a maximum
# note this is not the number of rows to pad instead it refers to Date+3
weekly[daily, roll=3]

# you can pad backwards with negative rolls
weekly[daily, roll=-3]
```

Source: UBS Quant

It is perhaps not apparent from the above example how much faster this approach is compared to others. The next section briefly touches on the performance gains you can expect from implementing such tasks using this package.

Mo data, mo problems

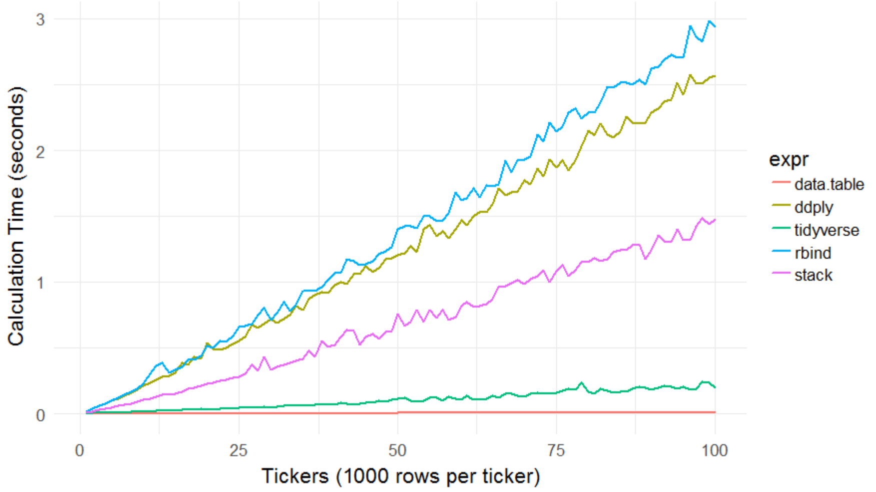
Naturally we cannot include a huge data set in this report for to demonstrate the effectiveness of this package, so we create a large random data set for illustrative purposes. Figure 6 demonstrates how to create such a data set, and then tests several different approaches to the very common task of Figure 5 above.

If we consider a daily timeseries containing 1,000 dates per ticker, then calculate the time taken to join this to a weekly time series and pad the low frequency data forward, it quickly becomes obvious how poorly the alternatives scale; and how a simple task in *data.table* entails a messy coding effort otherwise.

Note this example takes a long time to run. Use fewer rows if computationally prohibitive

Figure 6: Joining datasets with different frequencies

```
lapply(c('plyr', 'dplyr', 'tidyr', 'zoo', 'tidyverse', 'data.table', 'microbenchmark', 'ggplot2'), require,
  character.only=T)

res <- rbindlist(lapply(seq(100), function(n) {

  # create some random daily data for "n" tickers
  dailyDT <- data.table(Ticker=unique(stringi::stri_rand_strings(n, 6, pattern='[A-Z]')),
                        Date=as.Date('1999-12-31') + rep(1:1000, each=n), Blah=rep(1:1000, each=n) + runif(1000*n))
  setkey(dailyDT, Ticker, Date)

  # now suppose the "Blah2" data is only available on a weekly frequency
  weeklyDT <- dailyDT[format(Date, '%A')=='Friday', .(Ticker, Date, Blah2=sample(LETTERS, .N, replace=T))]
  dailyDF <- data.frame(dailyDT)
  weeklyDF <- data.frame(weeklyDT)

  bm <- microbenchmark(
    data.table = weeklyDT[dailyDT, roll=T],
    ddply = ddply(merge(dailyDF, weeklyDF, by=c('Ticker', 'Date'), all.x=T), .(Ticker), na.locf),
    tidyverse = left_join(dailyDF, weeklyDF, by = c('Ticker', 'Date')) %>%
                dplyr::group_by(Ticker) %>% tidyr::fill(Blah2),
    rbind = do.call(rbind, by(merge(dailyDF, weeklyDF, by=c('Ticker','Date'), all.x=T), dailyDF$Ticker,
            na.locf, na.rm=T)),
    stack = cbind(dailyDF, stack(lapply(unstack(merge(dailyDF, weeklyDF, by=c('Ticker', 'Date'),
            all.x=T), Blah2~Ticker), na.locf, na.rm=F))),
    times=10, unit='s')
  data.table(summary(bm))[, N:=n]
}))

ggplot(res) + geom_line(aes(N, median, colour=expr), size=1) + theme_minimal(base_size=16) +
  xlab('Tickers (1000 rows per ticker)') + ylab('Calculation Time (seconds)')
```



Source: UBS Quant

Extrapolating this trend, if this simple code were run over a comprehensive stock list of say 10,000 names, the *data.table* method would take **0.6 seconds** while the worst performing method (rbind) takes **5 minutes**. The above timings exclude the one-off performance cost of creating the key; however has negligible performance impact and the sorting cost is common to all approaches.

Appendix

In Figure 7 below we show the data set used in this report. Copy and paste this directly into R before working through the examples. This includes 40 of the largest companies globally and a handful of common factors used in quantitative analysis. The factors are as of 31st July 2016 and the forward return includes up to 31st August 2016.

Figure 7: The data set used in the report

```
data <- data.table(read.csv(
text="Ticker,Sector,MarketCap,Beta,GrossMargin,PEG,PE,PBR,DivYield,ROE,ROIC,Vol,FwdReturn,Return1m,Return12m,NetDE
AAPL UW,Information Technology,562022,1.38,38.80,2.12,11.84,4.38,2.00,39.06,27.47,21.97,2.36,11.49,-13.70,0.19
MSFT UW,Information Technology,442557,1.23,62.66,NA,19.39,5.96,2.36,12.34,8.72,22.65,2.01,13.69,27.42,-0.79
XOM UN,Energy,368876,0.82,21.54,NA,24.26,2.14,3.28,7.58,6.63,13.99,-1.18,-0.78,13.34,0.22
JNJ UN,Health Care,344596,0.75,69.43,0.20,18.06,4.74,2.40,21.89,17.51,9.79,-4.07,5.27,29.44,-0.23
AMZN UW,Consumer Discretionary,359676,1.34,33.48,0.00,91.71,24.27,0.00,9.10,4.35,27.04,1.36,6.31,43.07,0.10
GE UN,Industrials,279053,1.02,34.08,0.03,19.02,3.14,2.95,8.33,2.72,17.84,0.32,4.38,23.61,1.22
FB UW,Information Technology,355708,1.17,83.88,0.47,27.29,7.52,0.00,11.02,11.01,17.89,1.76,10.91,31.18,-0.44
NESN VX,Consumer Staples,250209,0.78,49.62,NA,22.10,3.84,2.90,13.69,11.59,13.88,0.77,5.11,10.82,0.24
T UN,Telecommunication Services,266320,0.46,38.60,NA,14.68,2.16,4.39,13.19,6.59,11.39,-5.57,2.46,30.59,0.98
JPM UN,Financials,231060,1.25,NA,0.51,10.71,1.04,2.75,9.69,4.09,24.89,5.52,8.54,-3.00,2.27
WFC UN,Financials,242176,1.07,NA,0.94,11.59,1.40,3.13,11.75,5.69,20.34,6.75,4.40,-13.69,1.82
GOOG UW,Information Technology,527988,1.21,61.78,0.40,20.29,4.27,0.00,14.24,13.93,16.61,-0.23,9.69,18.78,-0.57
PG UN,Consumer Staples,228360,0.60,50.23,NA,21.47,3.92,3.11,14.03,10.80,11.36,2.01,3.66,9.32,0.33
PFE UN,Health Care,223762,0.61,72.03,0.09,14.45,3.55,3.09,11.65,8.10,12.78,-4.86,6.48,7.43,0.32
VZ UN,Telecommunication Services,225851,0.60,47.56,2.26,13.93,12.12,4.05,128.45,14.94,12.93,-5.56,1.08,25.13,5.58
CVX UN,Energy,193144,1.23,8.07,NA,30.39,1.28,4.18,0.85,0.70,16.28,-0.83,0.16,15.52,0.22
NOVN VX,Health Care,197850,1.09,64.35,NA,16.84,2.78,3.36,9.13,7.54,18.76,-3.61,3.68,-15.70,0.32
BRK/B UN,Financials,355729,0.88,24.96,1.22,18.60,1.38,0.00,9.80,7.20,15.94,4.31,2.95,0.84,0.17
KO UN,Consumer Staples,188263,0.57,59.90,NA,22.08,7.59,3.07,27.08,13.62,13.52,-0.46,-1.20,11.11,0.99
MRK UN,Health Care,162462,0.82,62.81,0.71,15.67,3.71,3.10,10.08,6.56,16.40,7.04,5.13,5.11,0.29
ROG VX,Health Care,218243,1.04,69.34,0.02,15.97,10.05,3.27,43.70,23.02,20.07,-3.11,-0.28,-8.42,0.66
HD UN,Consumer Discretionary,170865,1.06,32.27,0.91,20.51,27.17,1.78,93.09,28.78,15.99,-2.48,8.18,22.59,2.79
INTC UW,Information Technology,164400,1.41,62.20,0.12,13.30,2.69,2.81,19.46,15.12,21.46,3.74,11.48,24.05,0.17
BAC UN,Financials,148041,1.46,NA,NA,10.19,0.63,1.38,6.18,3.22,33.22,11.90,15.59,-16.82,1.12
7203 JT,Consumer Discretionary,173183,0.94,20.05,5.23,10.57,1.07,3.56,13.60,8.60,33.75,5.84,17.77,-25.12,0.76
CMCSA UW,Consumer Discretionary,162195,0.69,58.39,0.99,17.97,3.10,1.52,15.72,8.27,13.67,-2.96,8.05,10.63,0.95
CSCO UW,Information Technology,153688,1.37,62.51,0.63,12.52,2.46,2.92,16.91,12.63,19.58,2.98,10.83,11.97,-0.56
V UN,Information Technology,184419,0.93,78.23,0.91,24.14,5.81,0.67,23.85,18.68,21.15,3.83,5.36,6.71,-0.17
PM UN,Consumer Staples,155536,0.72,64.38,0.03,21.19,NA,4.05,NA,50.88,16.76,-0.33,0.57,21.11,-2.11
PEP UN,Consumer Staples,156954,0.62,54.91,NA,21.84,13.99,2.58,38.27,12.83,12.88,-1.30,5.86,15.84,2.04
005930 KP,Information Technology,194464,0.99,37.45,0.54,9.58,1.28,1.36,11.65,11.54,21.70,5.26,7.80,24.56,-0.36
700 HK,Information Technology,226081,0.96,58.39,0.62,31.22,11.53,0.25,28.87,19.78,23.56,8.20,10.85,29.39,-0.83
DIS UN,Consumer Discretionary,163115,1.06,41.35,1.08,15.75,3.70,1.43,20.22,15.49,15.01,-1.55,0.57,-17.93,0.37
HSBA LN,Financials,130240,1.19,NA,NA,11.19,0.73,6.91,6.44,3.34,19.57,15.59,10.66,-7.94,0.22
IBM UN,Information Technology,153528,0.96,48.76,0.18,11.59,10.33,3.24,95.80,25.52,18.82,-0.23,10.75,4.66,2.06
C UN,Financials,127286,1.62,NA,1.22,8.83,0.61,0.46,7.16,3.81,34.88,8.97,9.40,-23.90,1.24
2330 TT,Information Technology,130621,0.97,45.46,0.80,13.34,3.49,3.48,24.33,20.89,20.60,2.03,12.42,36.80,-0.31
ORCL UN,Information Technology,169536,1.10,74.74,0.30,14.61,3.72,1.46,18.82,10.76,19.97,0.44,5.65,6.50,-0.23
MO UN,Consumer Staples,132286,0.46,62.41,0.31,21.00,48.25,3.27,205.76,35.00,11.90,-2.38,-1.18,26.19,3.29
UNH UN,Health Care,136613,0.83,NA,0.34,16.68,3.88,1.40,17.93,10.94,13.06,-4.99,2.92,19.52,0.66"))
```

Source: UBS Quant

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Rollin' Rollin' Rollin'	Oct-16	Speeding up R / Plotting correlation matrices	Jun-16
Getting started with random forests	Sep-16		

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1:Percentage of companies under coverage globally within the 12-month rating category.
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