

Introduction to the **data.table** Package in R

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Introduction

This vignette is aimed at those who are already familiar with R, in particular creating and using objects of class `data.frame`. We aim for this quick introduction to be readable in **10 minutes**, covering the main features in brief. The main features are the 3 numbered section titles: 1.Keys, 2.Fast Grouping, 3.Fast Merging/Joining. For the context that this document sits please briefly check the last section, Further Resources.

`data.table` is not *automatically* better or faster. The user has to climb a short learning curve, experiment, and then use the features well. For example this document explains the difference between a *vector scan* and a *binary search*. Both extract methods are available. If a user continues to use vector scans though, as they are used to in a `data.frame`, it will work, but they will miss out on the benefits that the package provides.

Creation

Recall that we create a `data.frame` using the function `data.frame()`.

```
> df = data.frame(x=c("b", "b", "b", "a", "a"), v=rnorm(5))
> df
```

	x	v
1	b	-0.9040867
2	b	-0.1059699
3	b	-0.4321208
4	a	1.3120513
5	a	0.9773132

We create a `data.table` in exactly the same way.

```
> dt = data.table(x=c("b", "b", "b", "a", "a"), v=rnorm(5))
> dt
```

	x	v
[1,]	b	1.1293724
[2,]	b	0.6865761
[3,]	b	-0.4599603
[4,]	a	0.9658598
[5,]	a	1.2424037

Observe that a `data.table` prints the row numbers slightly differently. There is nothing significant about that. We can also convert existing `data.frame` objects to `data.table`.

```
> cars = data.table(cars)
> head(cars)
```

```

      speed dist
[1,]     4    2
[2,]     4   10
[3,]     7    4
[4,]     7   22
[5,]     8   16
[6,]     9   10

```

We have just created two `data.tables`: `dt` and `cars`. It is often useful to see a list of all our `data.tables` in memory.

```
> tables()
```

```

      NAME NROW MB COLS      KEY
[1,] cars   50 1  speed,dist
[2,] dt     5 1  x,v
Total: 2MB

```

The MB column is useful to quickly assess memory use and to spot if any redundant tables can be removed to free up memory. Just like `data.frame`'s, `data.table`'s must fit inside RAM.

Some users regularly work with 20 or more tables in memory, rather like a database. The result of `tables()` is itself a `data.table`, returned silently, so that `tables()` can be used in programs. `tables()` is unrelated to the base function `table()`.

Also note that `data.table()` automatically converts character vectors to factor.

```
> sapply(dt,class)
```

```

      x      v
"factor" "numeric"

```

As the user you should vary rarely need know that this has occurred. See `?factor` if you are unfamiliar with factors. Factors will appear to you as though they are character columns. You can refer to them just as though they are character.

You may have noticed the empty column KEY from `tables()` above. This is the subject of the next section, the first of the 3 main features of the package.

1. Keys

Lets start by considering `data.frame`, specifically `rownames`. Or in English *row names*. That is, the multiple names belonging to the single row. The multiple names belonging to the single row? That is not what we are used to in a `data.frame`. We know that each row has at most one name. A person has at least two names, a first name and a second name. That is useful to organise a telephone directory for example which is sorted by surname then first name. But each row in a `data.frame` can only have one name.

A *key* is one or more columns of `rownames`. These columns may be integer, factor or other classes, not just character. Furthermore, the rows are sorted by the key. Therefore a `data.table` can have at most one key, because it cannot be sorted in more than one way.

Uniqueness is not enforced i.e. duplicate key values are allowed. Since the rows are sorted by the key, any duplicates in the key will appear consecutively.

Lets remind ourselves of our tables.

```
> tables()
```

```

      NAME NROW MB COLS      KEY
[1,] cars   50 1  speed,dist
[2,] dt     5 1  x,v
Total: 2MB

```

```
> dt
```

```
      x      v
[1,] b  1.1293724
[2,] b  0.6865761
[3,] b -0.4599603
[4,] a  0.9658598
[5,] a  1.2424037
```

No keys have been set yet. We can use `data.frame` syntax in a `data.table` too.

```
> dt[2,]
```

```
      x      v
[1,] b 0.6865761
```

```
> dt[ dt$x == "b", ]
```

```
      x      v
[1,] b  1.1293724
[2,] b  0.6865761
[3,] b -0.4599603
```

But since there are no rownames the following does not work.

```
> cat(try(dt["b",]))
```

```
Error in `[.data.table`](dt, "b", ) :
```

```
The data.table has no key but i is character. Call setkey first, see ?setkey.
```

The error message tells us we need to use `setkey()`.

```
> setkey(dt,x)
```

```
> dt
```

```
      x      v
[1,] a  0.9658598
[2,] a  1.2424037
[3,] b  1.1293724
[4,] b  0.6865761
[5,] b -0.4599603
```

Notice that the rows in `dt` have been re-ordered by `x`. The two "a" rows have moved to the top. We can confirm that `dt` does indeed have a key using `haskey()`, `key()`, `attributes()`, or just running `tables()`.

```
> tables()
```

```
      NAME NROW MB COLS      KEY
[1,] cars   50 1  speed,dist
[2,] dt      5 1  x,v         x
Total: 2MB
```

Now we are sure that `dt` has a key, lets try again.

```
> dt["b",]
```

```
      x      v
[1,] b 1.129372
```

Since there are duplicates in this key (i.e. repeated values of "b") the subset returns the first row in that group, by default. The `mult` argument (short for *multiple*) controls this.

```
> dt["b",mult="first"]
```

```
      x      v
[1,] b 1.129372
```

```
> dt["b",mult="last"]
```

```
      x      v
[1,] b -0.4599603
```

```
> dt["b",mult="all"]
```

```
      x      v
[1,] b 1.1293724
[2,] b 0.6865761
[3,] b -0.4599603
```

Lets now create a new `data.frame`. We will make it large enough to demonstrate the difference between a *vector scan* and a *binary search*.

```
> grpsize = ceiling(1e7/26^2) # 10 million rows, 676 groups
```

```
[1] 14793
```

```
> tt=system.time( DF <- data.frame(
+   x=rep(factor(LETTERS),each=26*grpsize),
+   y=rep(factor(letters),each=grpsize),
+   v=runif(grpsize*26^2))
+ )
```

```
      user  system elapsed
4.312    1.956    6.874
```

```
> head(DF,3)
```

```
      x y      v
1 A a 0.76942968
2 A a 0.09188673
3 A a 0.12746939
```

```
> tail(DF,3)
```

```
      x y      v
10000066 Z z 0.3403961
10000067 Z z 0.4706203
10000068 Z z 0.5345332
```

```
> dim(DF)
```

```
[1] 10000068      3
```

We might say that R has created a 3 column table and *inserted* 10,000,068 rows. It took 6.874 secs, so it inserted 1,454,766 rows per second. That is normal in base R.

Lets extract an arbitrary group from the data.frame DF.

```
> tt=system.time(ans1 <- DF[DF$x=="R" & DF$y=="h",]) # 'vector scan'
```

```

      user  system elapsed
4.389    0.944    5.334

```

```
> head(ans1,3)
```

```

      x y      v
6642058 R h 0.985217669
6642059 R h 0.001228116
6642060 R h 0.405414585

```

```
> dim(ans1)
```

```
[1] 14793      3
```

Now we convert to a data.table and extract the same group.

```
> DT = data.table(DF)
```

```
> setkey(DT,x,y)
```

```
> ss=system.time(ans2 <- DT[J("R","h"),mult="all"]) # 'binary search'
```

```

      user  system elapsed
0.008    0.004    0.029

```

```
> mapply(identical,ans1,ans2)
```

```

      x y      v
TRUE TRUE TRUE

```

At 0.029 seconds, this was **183** times faster than 5.334 seconds, and produced precisely the same result. If you are thinking that a few seconds is not much to save, its the relative speedup thats important. The vector scan is linear, but the binary search is $O(\log n)$. It scales. If a task taking 10 hours is sped up by 100 times to 6 minutes, that is significant¹.

What does the J() do?

Was it really this, or was it something slow about using data.frame syntax in a data.table? Its exactly the same :

We can do vector scans in data.table too.

```
> system.time(ans1 <- DF[DF$x=="R" & DF$y=="h",])
```

```

      user  system elapsed
4.192    0.972    5.788

```

```
> system.time(ans2 <- DT[DT$x=="R" & DT$y=="h",])
```

```

      user  system elapsed
4.240    1.084    5.326

```

```
> mapply(identical,ans1,ans2)
```

```

      x y      v
TRUE TRUE TRUE

```

```
> system.time(ans3 <- DT[x=="R" & y=="h",])
```

```

      user  system elapsed
4.172    1.112    5.287

```

```
> identical(ans2,ans3)
```

¹We wonder how many people are deploying parallel techniques to code that is vector scanning

```
[1] TRUE
```

If the phone book analogy helped, then this should not be surprising. We use the key. We take advantage of the fact that the table is sorted and we use binary search to find the matching rows. We didn't vector scan; we didn't use `==`.

When we used `DT$x=="R"` we *scanned* the entire column `x`, testing each and every value to see it equalled "R". We did that again in the `y` column, testing for "h". Then `&` combined the two logical results to create a single logical vector which was passed to the `[]` method which searched it for `TRUE` and returned those rows. These were *vectorized* operations. They occurred internally in R and were very fast, but they were scans. We did those scans because *we* wrote that R code.

When `i` is itself a `data.table`, we say that we are *joining* the two `data.table`'s. In this case we are joining `DT` to the 1 row, 2 column table returned by `data.table("R","h")`. Since we do this a lot, there is an alias for `data.table` called `J()`, short for join.

```
> identical( DT[J("R","h"),mult="all"],
+           DT[data.table("R","h"),mult="all"] )
```

```
[1] TRUE
```

Both vector scanning, and binary search, are available in `data.table`, but one way of using `data.table` is much better than the other.

The join syntax is short, fast to write and easy to maintain. Passing a `data.table` into a `data.table` subset, is similar to base R which allows a matrix to be passed into a matrix subset.² There are other types of join and further arguments which are beyond the scope of this quick introduction.

This first section has been about the first argument to the `[]`, namely `i`. The next section is do with the 2nd argument.

2. Fast grouping

The second argument to `[]` is `j` and may be one or more expressions of column names, as if the column names were variables.

```
> dt[,sum(v)]
```

```
[1] 3.564252
```

When we supply a `j` expression and a 'by' list of expressions, the `j` expression is repeated for each group defined by the 'by'.

```
> dt[,sum(v),by=x]
```

```
      x      V1
[1,] a 2.208264
[2,] b 1.355988
```

The 'by' in `data.table` is fast. Lets compare to `tapply`.

```
> ttt=system.time(tt <- tapply(DT$v,DT$x,sum)); ttt
```

```
      user  system elapsed
9.557    1.032   10.831
```

```
> sss=system.time(ss <- DT[,sum(v),by=x]); sss
```

```
      user  system elapsed
0.576    0.296    1.055
```

²Subsetting a key'd `data.table` by an `n`-column `data.table` is consistent with subsetting a `n`-dimension array by an `n`-column matrix

```

> head(tt)

      A      B      C      D      E      F
192398.6 192099.5 192228.3 192080.0 192485.9 192353.3

> head(ss)

      x      V1
[1,] A 192398.6
[2,] B 192099.5
[3,] C 192228.3
[4,] D 192080.0
[5,] E 192485.9
[6,] F 192353.3

> identical(as.vector(tt), ss$V1)

[1] TRUE

At 1.055sec, this was 10 times faster than 10.831sec, and produced precisely the same result.
Lets group by two columns.

> ttt=system.time(tt <- tapply(DT$v,list(DT$x,DT$y),sum)); ttt

      user  system elapsed
11.121    1.328   15.066

> sss=system.time(ss <- DT[,sum(v),by="x,y"]); sss

      user  system elapsed
0.564    0.424    1.290

> tt[1:5,1:5]

      a      b      c      d      e
A 7436.617 7389.337 7393.115 7383.246 7413.246
B 7389.727 7386.222 7423.414 7362.127 7397.497
C 7413.287 7387.008 7377.754 7388.208 7476.493
D 7393.459 7363.521 7445.955 7348.573 7396.076
E 7388.735 7482.426 7415.139 7396.800 7441.141

> head(ss)

      x y      V1
[1,] A a 7436.617
[2,] A b 7389.337
[3,] A c 7393.115
[4,] A d 7383.246
[5,] A e 7413.246
[6,] A f 7384.949

> identical(as.vector(t(tt)), ss$V1)

[1] TRUE

```

This was **11** times faster, and the syntax a little simpler and easier to read.

To return several expressions, pass a list() to j. TO DO - Example

The list is auto-recycled within each group. Do a condition on that. To DO - Example.

You can pass expressions to by too. And for this its cleaner to pass a list() to by, instead of character. TO DO - Example.

There is a super-charge option for advanced users. Use the dropfactor. To DO - Example.

3. Fast joining/merging of irregularly spaced ordered observation

Recap : `x[i]` is a join between `x` and `data.table i x[,j,by=list()]` is grouping

This section now combines together `i`, `j` and `by` together in one query. We also introduce `roll`.

`merge(x,y)` is the same but contains the union of columns. When `merge` is passed `data.table`'s, it operates much faster than base `merge` on `data.frame`'s. TO DO - example.

Grouping without setting a key : 1. Fast temporary key creation due to fast radix. 2. Using key without `'by'`.

Fast roll join. TO DO - example.

Other resources

This was a quick start guide. Further resources include :

- The help page describes each and every argument `?["data.table"]`
- The FAQs deal with distinct topics in an easy to digest manner
- The performance tests are more complex real world examples
- `test.data.table` contains over 100 low level tests of the features.
- Presentations
- YouTube Demo
- R-Forge commit logs: <http://lists.r-forge.r-project.org/pipermail/datatable-commits/>
- Website: <http://datatable.r-forge.r-project.org/>
- Mailing list : datatable-help@lists.r-forge.r-project.org