## Three hour tutorial

# data.table

**30 June 2014**

**Matt Dowle**

## Overview

|  |  |
|---|---|
| data.table in a nutshell | 20 mins |
| Client server recorded demo | 20 mins |
| Main features in more detail | 2 hours |
| Q&A | 20 mins |

## What is data.table?

- Think `data.frame`, inherits from it
- `data.table()` and `?data.table`

**Goals:**

- Reduce programming time

  fewer function calls, less variable name repetition
- Reduce compute time

  fast aggregation, update by reference
- In-memory only, 64bit and 100GB routine
- Useful in finance but wider use in mind, too

  e.g. genomics

# Reducing programming time

```
trades[
   filledShares < orderedShares,
   sum( (orderedShares-filledShares)
        * orderPrice / fx ),
   by = "date,region,algo"
]
```

---

| | | | |
|---|---|---|---|
| R : | i | j | by |
| SQL : | WHERE | SELECT | GROUP BY |

## Reducing compute time

e.g. 10 million rows  x  3 columns x,y,v     230MB

```
DF[DF$x=="R" & DF$y==123,]   # 8     s
DT[.("R",123)]               # 0.008s

tapply(DF$v,DF$x,sum)        # 22    s
DT[,sum(v),by=x]             #  0.83s
```

See above in timings vignette (copy and paste)

## Fast and friendly file reading

e.g. 50MB .csv, 1 million rows x 6 columns

```
read.csv("test.csv")                   # 30-60s

read.csv("test.csv", colClasses=,
              nrows=, etc...)          #    10s

fread("test.csv")                      #     3s
```

e.g. 20GB .csv, 200 million rows x 16 columns

```
read.csv("big.csv", ...)               #  hours

fread("big.csv")                       #     8m
```

## Update by reference using `:=`

Add new column ”sectorMCAP” by group :

```
DT[,sectorMCAP:=sum(MCAP),by=Sector]
```

Delete a column (0.00s even on 20GB table) :

```
DT[,colToDelete:=NULL]
```

Be explicit to really copy entire 20GB :

```
DT2 = copy(DT)
```

## Why R?

1) R's lazy evaluation enables the syntax :
   - `DT[ filledShares < orderedShares ]`
   - query optimization before evaluation
2) Pass `DT` to any package taking `DF`. It works.

   `is.data.frame(DT) == TRUE`
3) CRAN (cross platform release, quality control)
4) Thousands of statistical packages to use with data.table

## Client/server recorded demo

http://www.youtube.com/watch?v=rvT8XThGA8o

## Main features in more detail ...

## Essential!

- Given a 10,000 x 10,000 matrix in any language
- Sum the rows
- Sum the columns
- Is one way faster, and <u>why</u>?

## setkey(DT, colA, colB)

- Sorts the table by colA then colB.  That's all.
- Like a telephone number directory: last name then first name
- X[Y] is just binary search to X's key
- You **DO** need a key for joins X[Y]
- You **DO NOT** need a key for by=  (but many examples online include it)

## Joins: X[Y]

- Vector search vs binary search
- One column == is ok,  but not 2+ due to temporary logicals (e.g. slide 5 earlier)
- J(), .(), list(), data.table()
- CJ()
- SJ()
- nomatch
- mult

## ”Cold” by (i.e. without setkey)

Consecutive calls unrelated to key are fine and common practice :

```
> DT[, sum(v), by="x,y"]
> DT[, sum(v), by="z"]
> DT[, sum(v), by=colA%%5]
```

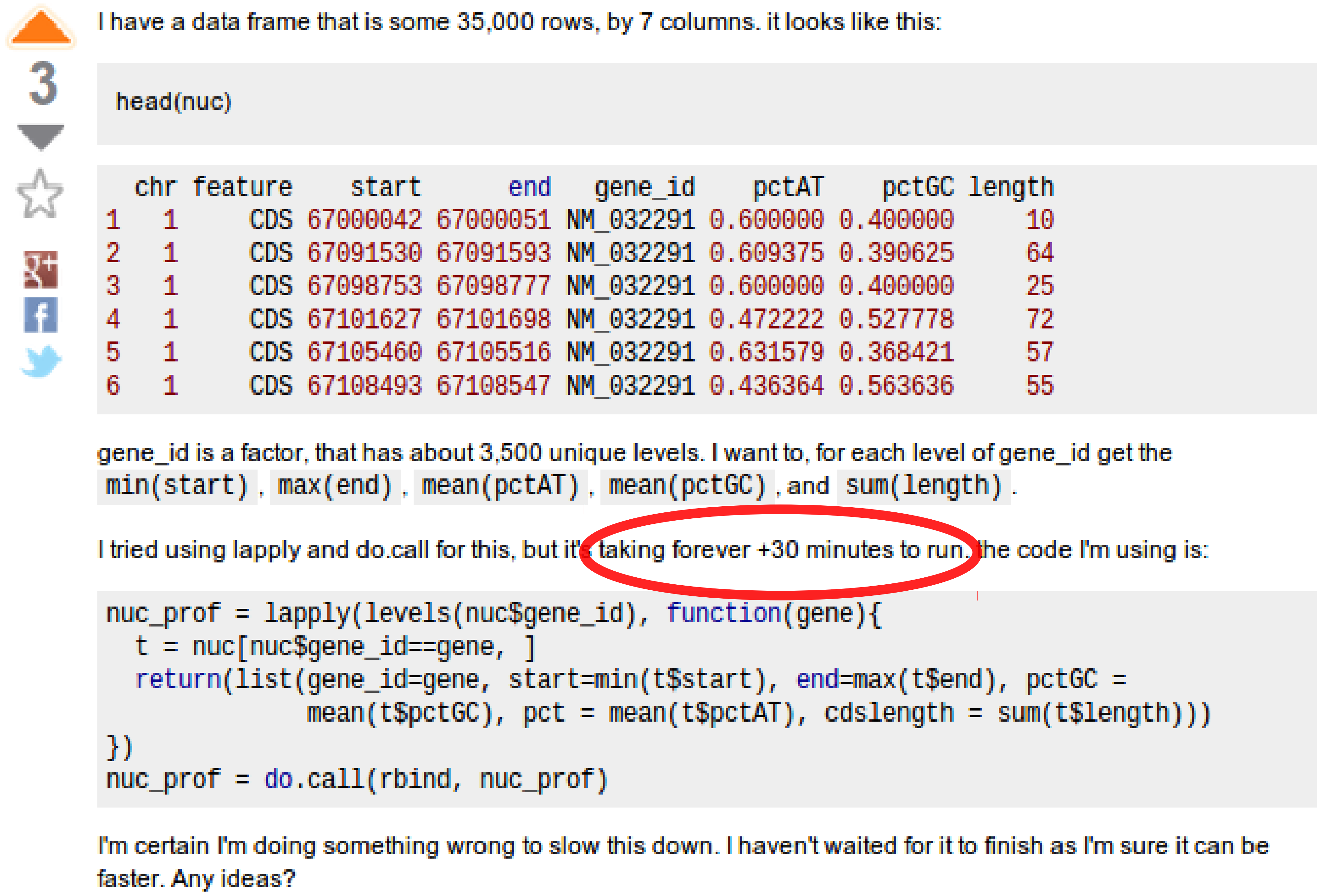
Also known as "ad hoc by"

## DT[i, j, by]

- Out loud: ”Take `DT`, subset rows using `i`, then calculate `j` grouped by `by`”
- Once you grok the above reading, you don't need to memorize any other functions as all operations follow the same intuition as base.

# lapply and do.call running very slowly?

June 2012



3

I have a data frame that is some 35,000 rows, by 7 columns. it looks like this:

```
head(nuc)
```

```
  chr feature     start       end    gene_id     pctAT     pctGC length
1   1     CDS 67000042 67000051 NM_032291 0.600000 0.400000     10
2   1     CDS 67091530 67091593 NM_032291 0.609375 0.390625     64
3   1     CDS 67098753 67098777 NM_032291 0.600000 0.400000     25
4   1     CDS 67101627 67101698 NM_032291 0.472222 0.527778     72
5   1     CDS 67105460 67105516 NM_032291 0.631579 0.368421     57
6   1     CDS 67108493 67108547 NM_032291 0.436364 0.563636     55
```

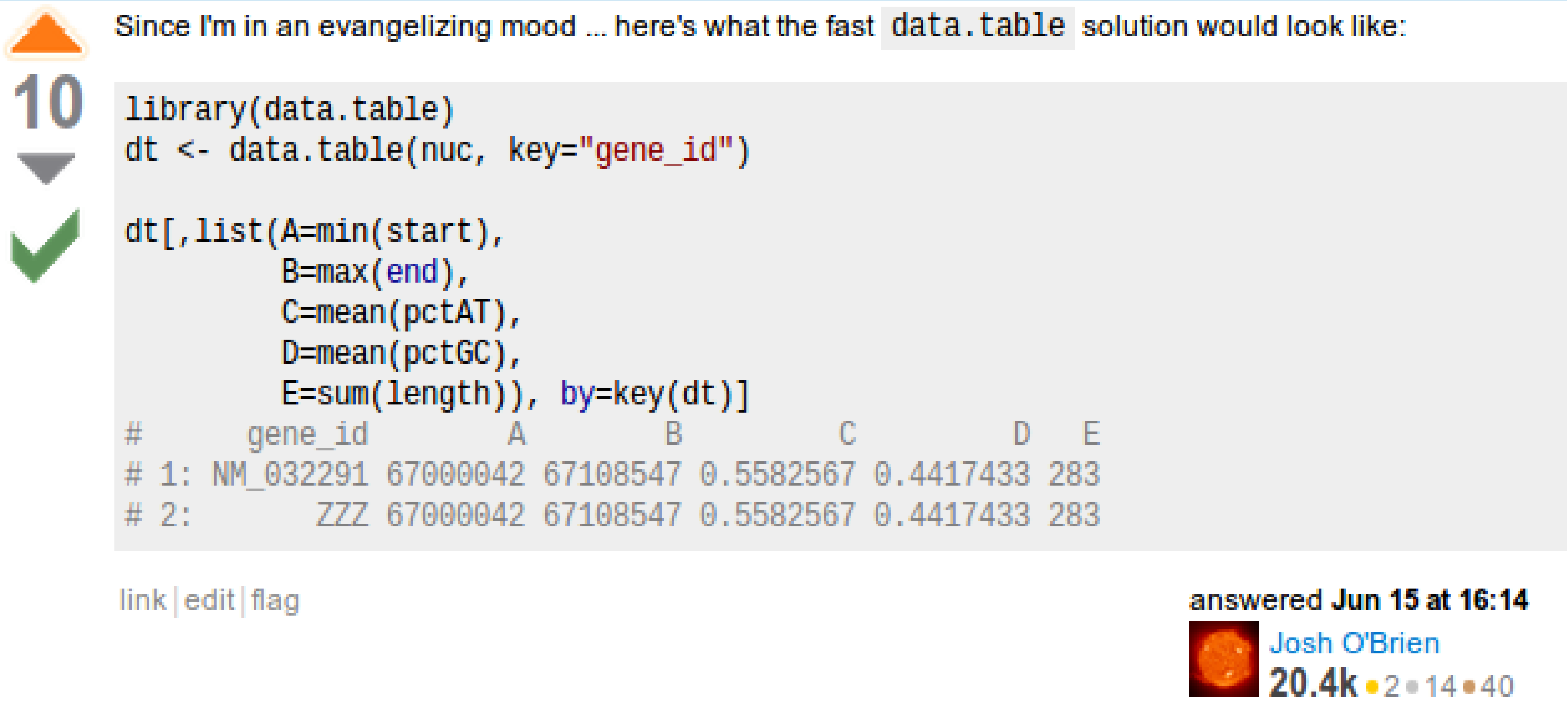
gene_id is a factor, that has about 3,500 unique levels. I want to, for each level of gene_id get the `min(start)`, `max(end)`, `mean(pctAT)`, `mean(pctGC)`, and `sum(length)`.

I tried using lapply and do.call for this, but it's taking forever +30 minutes to run. the code I'm using is:

```
nuc_prof = lapply(levels(nuc$gene_id), function(gene){
  t = nuc[nuc$gene_id==gene, ]
  return(list(gene_id=gene, start=min(t$start), end=max(t$end), pctGC =
              mean(t$pctGC), pct = mean(t$pctAT), cdslength = sum(t$length)))
})
nuc_prof = do.call(rbind, nuc_prof)
```

I'm certain I'm doing something wrong to slow this down. I haven't waited for it to finish as I'm sure it can be faster. Any ideas?

# data.table answer



Since I'm in an evangelizing mood ... here's what the fast `data.table` solution would look like:

```
library(data.table)
dt <- data.table(nuc, key="gene_id")

dt[,list(A=min(start),
         B=max(end),
         C=mean(pctAT),
         D=mean(pctGC),
         E=sum(length)), by=key(dt)]
#      gene_id        A        B         C         D   E
# 1: NM_032291 67000042 67108547 0.5582567 0.4417433 283
# 2:       ZZZ 67000042 67108547 0.5582567 0.4417433 283
```

NB: It isn't just the speed, but the simplicity. It's easy to write and easy to read.

## User's reaction

**”data.table is awesome! That took about 3 seconds for the whole thing!!!”**

**Davy Kavanagh, 15 Jun 2012**

## but ...

- Example had `by=key(dt)` ?
- Yes, but it didn't need to.
- If the data is very large (1GB+) and the groups are big too then getting the groups together in memory can speed up a bit (cache efficiency).

# DT[,,by=] -vs- DT[,,keyby=]

- **`by`** preserves order of groups (by order of first appearance)
- Both preserve order of rows within groups (important!) and unlike SQL
- **`keyby`** is a **`by`** as usual, followed by **`setkeyv(DT,by)`**

# Prevailing joins (roll=TRUE)

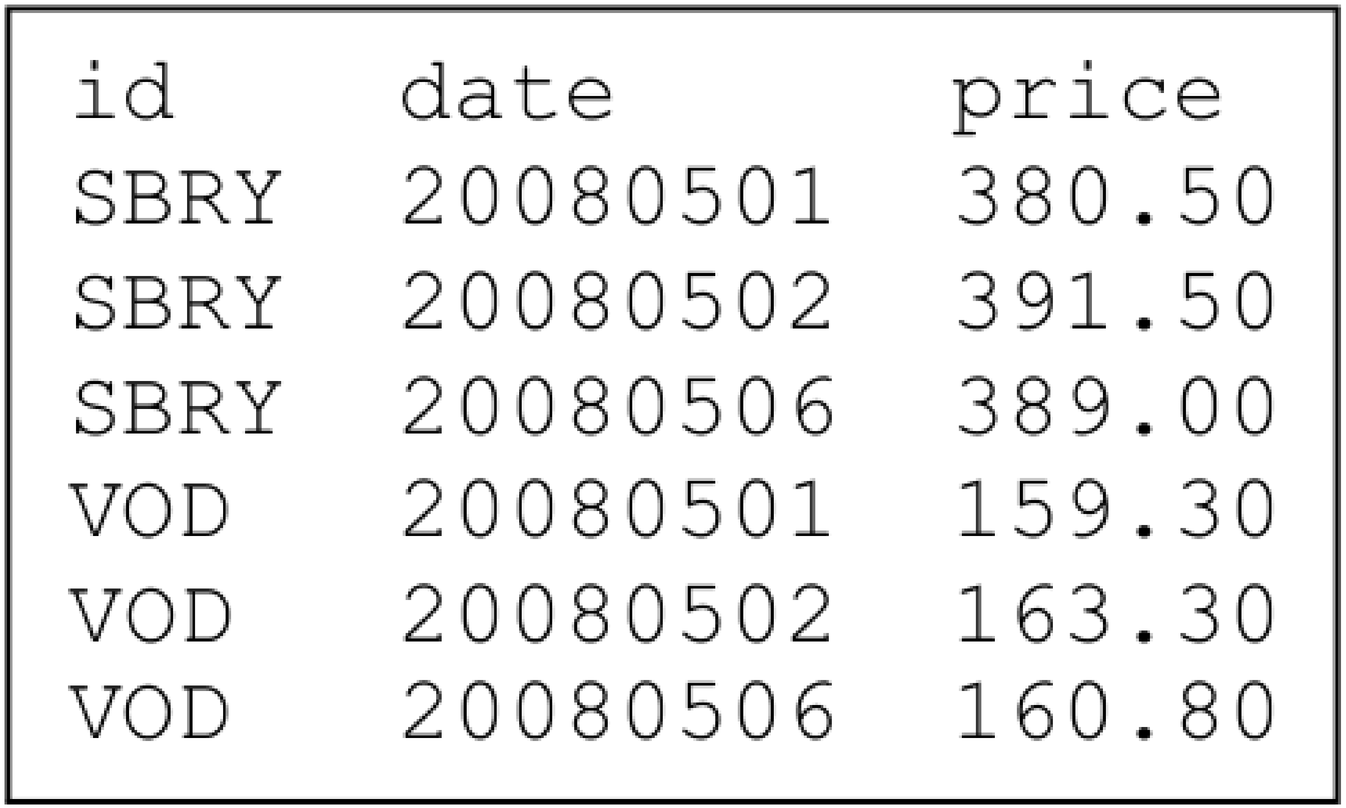
- One reason for setkey's design.
- Last Observation (the prevailing one) Carried Forward (LOCF), efficiently
- Roll forwards or backward
- Roll the last observation forwards, or not
- Roll the first observation backwards, or not
- Limit the roll; e.g. 30 days (roll = 30)
- Join to nearest value (roll = ”nearest”)
- i.e. ***ordered joins***

## ... continued

- `roll = [-Inf,+Inf] |`
  ```
         TRUE | FALSE |
         ”nearest”
  ```

- `rollends = c(FALSE,TRUE)`

- By example ...



| id | date | price |
|---|---|---|
| SBRY | 20080501 | 380.50 |
| SBRY | 20080502 | 391.50 |
| SBRY | 20080506 | 389.00 |
| VOD | 20080501 | 159.30 |
| VOD | 20080502 | 163.30 |
| VOD | 20080506 | 160.80 |

```
1. PRC[J(“SBRY”)]                                        # all 3 rows
2. PRC[J(“SBRY”,20080502),price]                         # 391.50
3. PRC[J(“SBRY”,20080505),price]                         # NA
4. PRC[J(“SBRY”,20080505),price,roll=TRUE]               # 391.50
5. PRC[J(“SBRY”,20080601),price,roll=TRUE]               # 389.00
6. PRC[J(“SBRY”,20080601),price,roll=TRUE,rollends=FALSE]      # NA
7. PRC[J(“SBRY”,20080601),price,roll=20]                 # NA
8. PRC[J(“SBRY”,20080601),price,roll=40]                 # 389.00
```

## Performance

All daily prices 1986-2008 for all non-US equities
• 183,000,000 rows (id, date, price)
• 2.7 GB

```
system.time(PRICES[id==”VOD”])   # vector scan
user     system     elapsed
66.431   15.395     81.831
```

```
system.time(PRICES[J(“VOD”)])    # binary search
user     system     elapsed
0.003    0.000      0.002
```

setkey(PRICES, id, date) needed first (one-off apx 20 secs)

## Variable name repetition

- The 3rd highest voted [R] question (of 43k)

  How to sort a dataframe by column(s) in R (*)

- DF[with(DF, order(-z, b)), ]
  - vs -
  DT[ order(-z, b) ]

- quarterlyreport[with(lastquarterlyreport,order(-z,b)),]
  - vs -
  quarterlyreport[ order(-z, b) ]

Silent incorrect results due to using a similar variable by mistake. Easily done when this appears on a page of code.

(*) Click link for more information

## but ...

- Yes order() is slow when used in i because that's base R's order().
- That's where ”optimization before evaluation” comes in.  We now auto convert order() to the internal forder() so you don't have to know.
- Available in v1.9.3 on GitHub, soon on CRAN

## split-apply-combine

Why ”split” 10GB into many small groups???

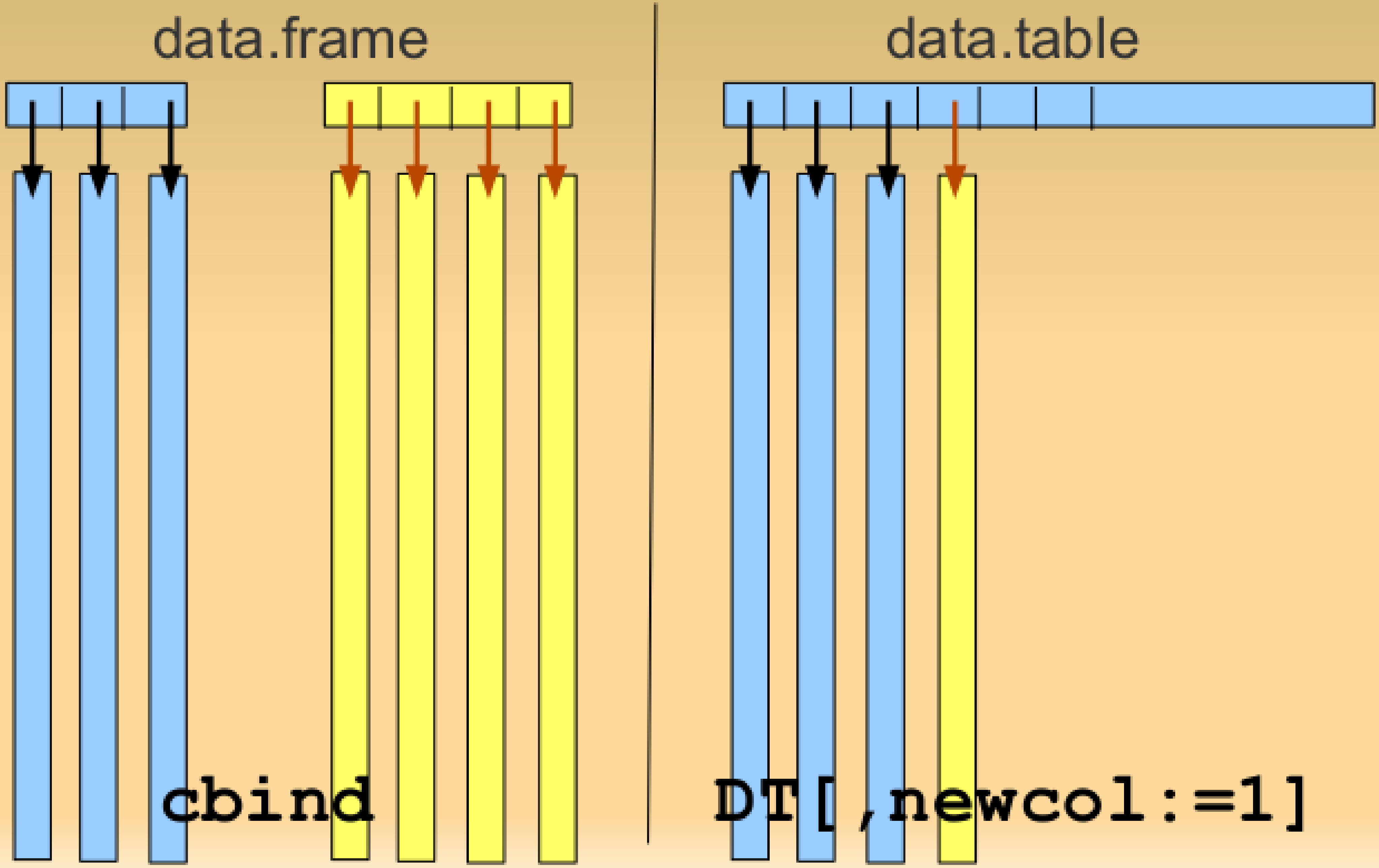
Since 2010, data.table :

- Allocates memory for largest group
- Reuses that same memory for all groups
- Allocates result data.table up front
- Implemented in C
- eval() of j within each group

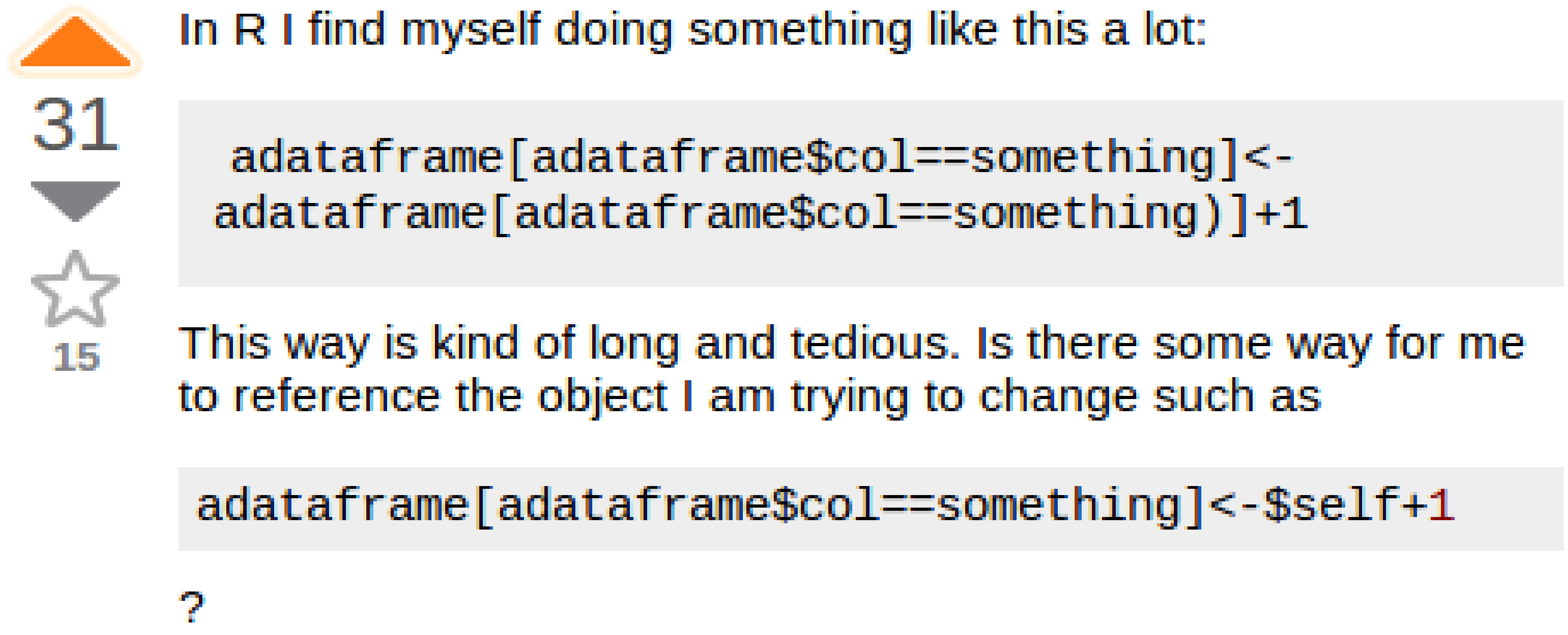
## Recent innovations

- Instead of the eval(j) from C, dplyr converts to an Rcpp function and calls that from C. Skipping the R eval step.
- In response, data.table now has **GForce**: one function call that computes the aggregate across groups. Called once only so no need to speed up many calls!
- Both approaches limited to simple aggregates: sum, mean, sd, etc. But often that's all that's needed.

# data.table over-allocates



# Assigning to a subset



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In R I find myself doing something like this a lot:

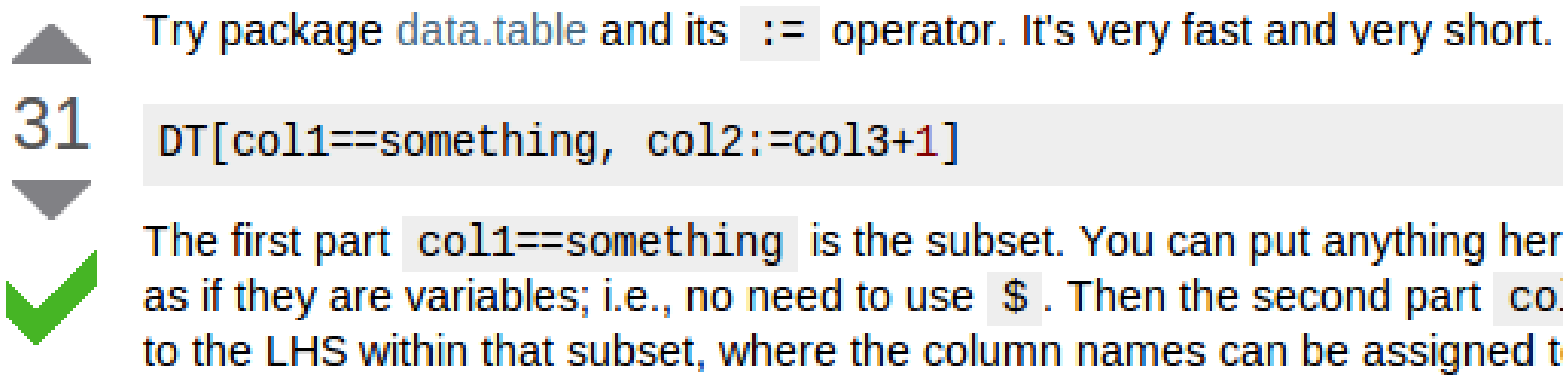
```
adataframe[adataframe$col==something]<-
adataframe[adataframe$col==something)]+1
```

This way is kind of long and tedious. Is there some way for me to reference the object I am trying to change such as

```
adataframe[adataframe$col==something]<-$self+1
```

?

# continued



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Try package data.table and its `:=` operator. It's very fast and very short.

```
DT[col1==something, col2:=col3+1]
```

The first part `col1==something` is the subset. You can put anything her
as if they are variables; i.e., no need to use `$`. Then the second part `co`
to the LHS within that subset, where the column names can be assigned t

Easy to write, easy to read

## Multiple `:=`

```
DT[, `:=`(newCol1=mean(colA),
          newCol2=sd(colA)),
      by=sector]
```

Can include a subset in i as well

## `set*` functions

- `set()`
- `setattr()`
- `setnames()`
- `setcolorder()`
- `setkey()`
- `setkeyv()`

## copy()

- data.table **IS** copied-on-change by `<-` and `=` as usual in R.  Those ops aren't changed.
- No copy by `:=` or `set*`
- You have to use those, so it's clear to readers of your code
- When you need a copy, call `copy(DT)`
- Why copy a 20GB data.table, even once.
- Why copy a whole column, even once.

# list columns

- Each <u>cell</u> can be a different type
- Each <u>cell</u> can be vector
- Each <u>cell</u> can itself be a data.table
- Combine list columns with i and by

# list column example

```
data.table(
  x = letters[1:3],
  y = list( 1:10,
            letters[1:4],
            data.table(a=1:3,b=4:6)
))
    x   y
1:  a   1,2,3,4,5,6,
2:  b   a,b,c,d
3:  c   <data.table>
```

## All options

| | |
|---|---|
| `datatable.verbose` | `FALSE` |
| `datatable.nomatch` | `NA_integer_` |
| `datatable.optimize` | `Inf` |
| `datatable.print.nrows` | `100L` |
| `datatable.print.topn` | `5L` |
| `datatable.allow.cartesian` | `FALSE` |
| `datatable.alloccol` | `quote(max(100L,ncol(DT)+64L))` |
| `datatable.integer64` | `"integer64"` |

## All symbols

- `.N`
- `.SD`
- `.I`
- `.BY`
- `.GRP`

## .SD

```
stocks[, head(.SD,2), by=sector]
```

```
stocks[, lapply(.SD, sum), by=sector]
```

```
stocks[, lapply(.SD, sum), by=sector,
.SDcols=c("mcap",paste0(revenueFQ",1:8))]
```

# .I

```
if (length(err <- allocation[,
                 if(length(unique(Price))>1) .I,
                 by=stock ]$V1 )) {

  warning("Fills allocated to different
accounts at different prices! Investigate.")

  print(allocation[err])

} else {

  cat("Ok   All fills allocated to each
account at same price\n")

}
```

## Analogous to SQL

```
DT[ where,
    select | update,
    group by ]
  [ having ]
  [ order by ]
  [ i, j, by ] ... [ i, j, by ]
```

# New in v1.9.2 on CRAN

- 37 new features and 43 bug fixes
- set() can now add columns just like :=
- .SDcols “de-select” columns by name or position; e.g.,

  ```
  DT[,lapply(.SD,mean),by=colA,.SDcols=-c(3,4)]
  ```
- fread() a subset of columns
- fread() commands; e.g.,

  ```
  fread("grep blah file.txt")
  ```
- Speed gains

## Radix sort for integer

- R's method=”radix” is not actually a radix sort … it's a counting sort. See ?setkey/Notes.
- data.table liked and used it, though.
- A true radix sort caters for range > 100,000
- ( Negatives was a one line change to R we suggested and was accepted in R 3.1 )
- Adapted to integer from Terdiman and Herf's code for float …

# Radix sort for numeric

- R reminder: numeric == floating point numbers
- Radix Sort Revisited, Pierre Terdiman, 2000

  http://codercorner.com/RadixSortRevisited.htm
- Radix Tricks, Michael Herf, 2001

  http://stereopsis.com/radix.html
- Their C code now in data.table with minor changes; e.g., NA/NaN and 6-pass for double

## Faster for those cases

20 million rows x 4 columns,  539MB

a & b (numeric), c (integer), d (character)

| | v1.8.10 | v1.8.11 |
|---|---|---|
| setkey(DT, a) | 54.9s | 7.2s |
| setkey(DT, c) | 48.0s | 7.0s |
| setkey(DT, a, b) | 102.3s | 16.9s |
| ”Cold” grouping (no setkey first) : | | |
| DT[, mean(b), by=c] | 47.0s | 8.7s |

https://gist.github.com/arunsrinivasan/7997273

# New feature: melt/cast

i.e. reshape2 for data.table

| | |
|---|---|
| 20 million rows x 6 columns (a:f) | 768MB |
| melt(**DF**, id=”d”, measure=1:2) | 191 sec |
| melt(**DT**, id=“d”, measure=1:2) | 3 sec |
| dcast(**DF**, d~e, ..., fun=sum) | 184 sec |
| dcast(**DT**, d~e, ..., fun=sum) | 28 sec |

https://gist.github.com/arunsrinivasan/7839891

Similar to melt_ in Kmisc by Kevin Ushey

## … melt/cast continued

Q: Why not submit a pull request to reshape2 ?

A: This C implementation calls data.table internals at C-level (e.g. fastorder, grouping, and joins). It makes sense for this code to be together.

## Miscellaneous 1

`DT[, (myvar):=NULL]`

Spaces and specials; e.g., `by="a, b, c"`

`DT[4:7,newCol:=8][]`

- extra `[]` to print at prompt
- auto fills rows 1:3 with NA

`rbindlist(lapply(fileNames, fread))`

fread's drop and select

# Miscellaneous 2

Dates and times

Errors & warnings are deliberately very long

Not joins `X[!Y]`

Column plonk & non-coercion on assign

by-without-by  =>  `by=.EACHI`

Secondary keys / merge

R3, singleton logicals, reference counting

bit64::integer64

## Miscellaneous 3

Print method vs typing DF,  copy fixed in R-devel

How to benchmark

mult = ”all” | ”first” | ”last”   (may expand)

with=FALSE

which=TRUE

nomatch 0 (inner join) or NA (outer join)

Chained queries:  DT[...][...][...]

Dynamic and flexible queries (eval text and quote)

fread sep2

## Not (that) much to learn

- Main manual page: `?data.table`
- Run `example(data.table)` at the prompt (53 examples)
- No methods, no functions, just use what you're used to in R

# Thank you

https://github.com/Rdatatable/datatable/

http://stackoverflow.com/questions/tagged/data.table

```
> install.packages(”data.table”)
> require(data.table)
> ?data.table
> ?fread
```

Learn by example :

```
> example(data.table)
```