Fast, stable and scalable true radix sorting

useR!, Aalborg

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Machine Intelligence

Overview

- Released in data.table v1.9.2 (Feb 2014)
- Propose to move to base so R community can benefit with no code changes
- Find sponsor from core team with time
- Your feedback and suggestions please

2009 : Tom Short

Tom: I like data.table! But setkey is slow and I have issues with dates. Any ideas?

Matt: Sorry, not really. I can have a think. You're welcome to join the project?

Tom: Ok thanks, I will. What about using **sort.list(x, method="radix")**?

Matt: What's sort.list(x,method="radix")?

```
> sort(c(4,2,8,7))
[1] 2 4 7 8
> order(c(4,2,8,7))
[1] 2 1 4 3
> sort.list(c(4,2,8,7))
[1] 2 1 4 3
> ?sort.list
```

“ sort.list is the same [as order], using only one argument. “

“ x is an atomic vector “

sort.list(x)

would be better named

order.vector(x)

but we love it anyway ...

2009-2015 : base R

```
> x = sample(1:100000, 1e8, replace=TRUE)   #380MB
> system.time(o1 <- order(x))
   user  system elapsed
 79.444   0.056  79.402
> system.time(o2 <-  sort.list(x, method="radix"))
   user  system elapsed
  1.572   0.028   1.597
> identical(o1,o2)
[1] TRUE
```

Tom used sort.list(x,method="radix")

nrow(DT) = 10 million v1.2 => v1.3

setkey(DT, a, b) **37s** **5s**

Column by column in reverse :

1. o = 1:nrow
2. order o by column b [1st call to sort.list]
3. order o by column a [2nd call to sort.list]

Hard to beat, even today.

R's C code for method=”radix” step 1 / 4

```
// find range(x) = max(x) - min(x)
for(i=0; i<n; i++) {
    if(ISNA(x[i])) continue;
    if(x[i] > xmax) xmax = x[i];
    if(x[i] < xmin) xmin = x[i];
}
range = xmax – xmin + 1;
```

NB: essence of code presented in these slides

R's C code for method=”radix” steps 2-4 / 4

```
if(range > 100000) error("too large a range of values in 'x'");

long counts[ range+1 ];   // allocate

for(i=0; i<n; i++) counts[x[i] – xmin]++;                    #2

for(i=1; i<=range; i++) counts[i] += counts[i-1];            #3

for(i=n-1; i>=0; i--) ans[--counts[x[i] - xmin]] = i;        #4
```

method = “radix”

would be better named

method = “counting”

but we love it anyway

because it is so fast

R 3.0.0

“ sort(), sort.int() and sort.list() now use radix sorting for factors of less than 100,000 levels when method is not supplied. So does order() if called with a single factor, unless na.last = NA. “

Default changed only for factors. For integers with range < 100,000 you still have to call sort.list(x, method=”radix”) manually.

[Aside] R 3.1.0

“ sort.list(method = "radix") now allows negative integers (wish of PR#15644). “

PR#15644 by Matt Dowle

In step 1 (finding the range), remove one line :

if(tmp < 0) error("negative value in 'x'");

Current R 3.2.1

```
> x = sample(1:100001, 1e8, replace=TRUE)  #380MB
> system.time(o1 <- order(x))
   user  system elapsed
 79.444   0.056  79.402
> system.time(o2 <-  sort.list(x, method="radix"))
   user  system elapsed
  1.572   0.028   1.597
> identical(o1,o2)
[1] TRUE
```

Current R 3.2.1

```
> x = sample(1:100002, 1e8, replace=TRUE)
> system.time(o1 <- order(x))
   user  system elapsed
 79.416   0.044  79.361
> system.time(o2 <-  sort.list(x, method="radix"))
Error in sort.list(x, method = "radix") :
    too large a range of values in 'x'
```

data.table:::forderv(x)

```
> x = sample(1:100002, 1e8, replace=TRUE)
> system.time(o1 <- order(x))
   user  system elapsed
 79.416   0.044  79.361
> system.time(o2 <- data.table:::forderv(x))
   user  system elapsed
  1.664   0.060   1.722
> identical(o1,o2)
[1] TRUE
```

Scaling up now possible

```
> x = sample(1:1e6, 1e9, replace=TRUE)
> system.time(o2 <- data.table:::forderv(x))
   user  system elapsed
 18.716   0.288  18.982
> system.time(o1 <- order(v))
```

Over 20 mins then I stopped it

true radix sorting

To illustrate, consider these 2 numbers as 4 *columns* of bytes, each with range 256 :

705788748

25

00101010	00010001	01111011	01001100
00000000	00000000	00000000	00010111
42	17	123	76
0	0	0	25

Proceed just like Tom did on columns in reverse order, but on bytes within the integer

numeric

Terdiman, 2000

http://codercorner.com/RadixSortRevisited.htm

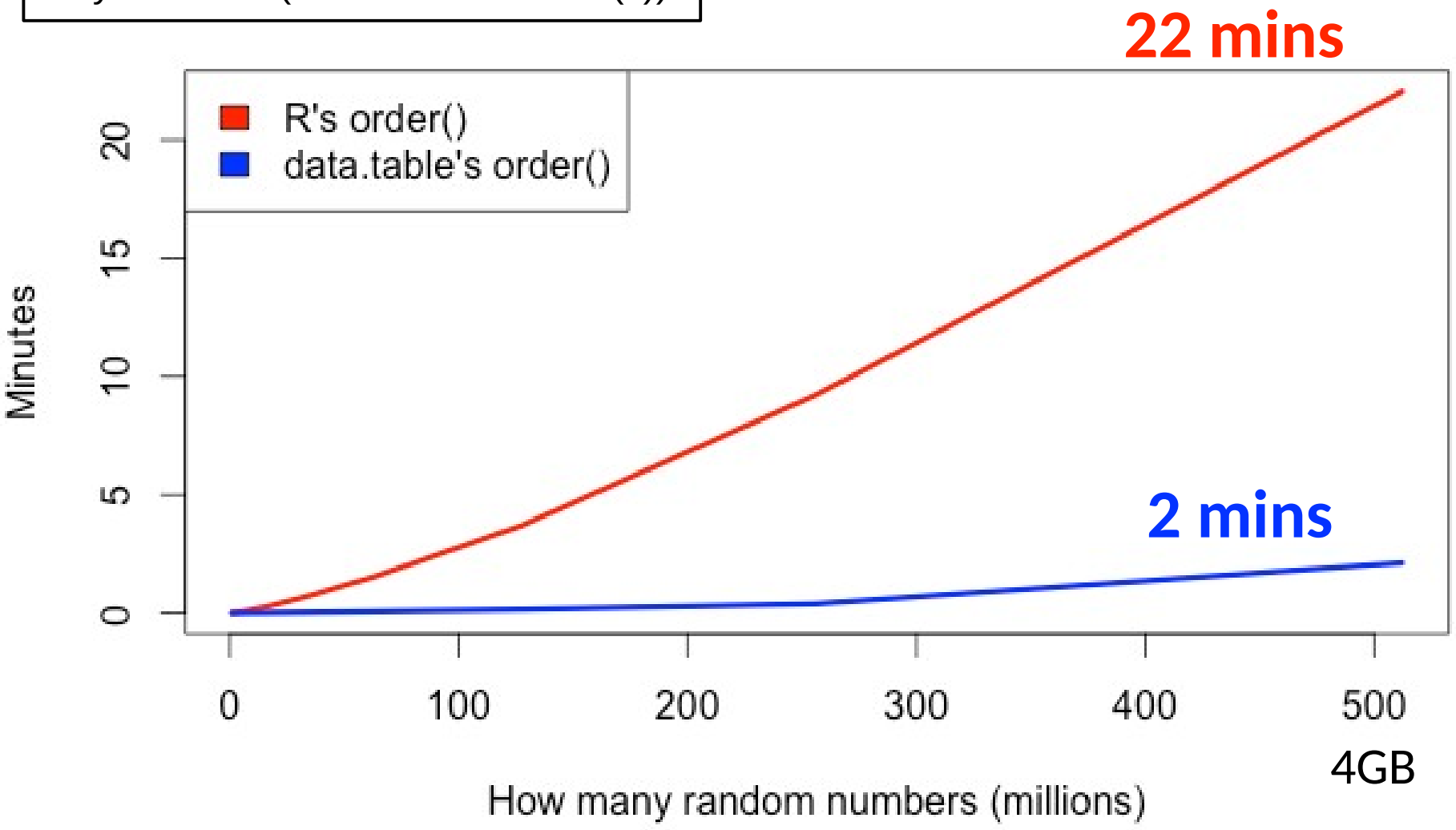
Herf, 2001

http://stereopsis.com/radix.html

Arun Srinivasan implemented forder() in data.table entirely in C for integer, character and double

Matt Dowle changed from LSD (backwards) to MSD (forwards) for cache efficiency and to benefit from (partially) sorted data inputs

```
> x = runif(500e6)   # unique this time
> system.time(data.table:::forderv(x))
```



MacBook Pro 2.8GHz Intel Core i7 16GB
R 3.1.3 data.table 1.9.4

Miscellaneous

- setNumericRounding(2|1|0)
- CHARSXP are sorted by pointer value to get uniques, then uniques are sorted by forwards radix on the character string
- Endian dependent hence QEMU emulation of PowerPC before release to CRAN
- We appreciate CRAN's Solaris Sparc – it's proxy for other big endian machines
- Partial sorting, median, quantiles
- MSD radix sort is parallelizable

Thank you

Please try out data.table:::forderv()

Questions / suggestions?