DISCLOSED

Coordinating package 'ff' for large objects with R base

Oehlschlägel, Adler

Munich, Göttingen

July 2009

Context of discussion

Package 'ff' 2.1.0

- provides large, fast disk-based vectors and arrays
- NEW: dataframes with up to 2.14 billion rows
- NEW: lean datatypes on CRAN under GPL, e.g. 2bit factors
- NEW: fixed width characters (fffc)
- NEW: fast length()<- increase for ff vectors

Package 'bit' 1.1.0

- Class 'bit': lean in-memory boolean vectors + fast operators
- NEW: class 'ri' (range-index) for chunked-processing
- NEW: class 'bitwhich': alternative for very skewed filters
- NEW: close integration with ff objects and chunked processing

Package 'R.ff'

- GOAL: convert standard R into a system, that provides the most commonly used methods for ff as well as for standard RAM objects (math, operators, data manipulation etc.) and do this PURELY in R.
- QUESTION: is this possible with a separate package, or do we need to more closely integrate R base with large object capabilities?
- ANSWER: seems somewhat possible but is not clever to do this!

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

EXAMPLE I – preparation

```
library(ff)                   # loads library(bit)
N <- 8e7; n <- 1e6
countries <- factor(c('FR','ES','PT','IT','DE','GB','NL','SE','DK','FI'))
years <- 2000:2009; genders <- factor(c("male","female"))

country <- ff(countries, vmode='ubyte', length=N, update=FALSE, filename="d:/tmp/country.ff", finalizer="close")
for (i in chunk(1,N,n)) country[i] <- sample(countries, sum(i), TRUE)  # 9 sec

year <- ff(years, vmode='ushort', length=N, update=FALSE, filename="d:/tmp/year.ff", finalizer="close")
for (i in chunk(1,N,n)) year[i] <- sample(years, sum(i), TRUE)         # 9 sec

gender <- ff(genders, vmode='quad', length=N, update=FALSE, filename="d:/tmp/gender.ff", finalizer="close")
for (i in chunk(1,N,n)) gender[i] <- sample(genders, sum(i), TRUE)     # 9 sec

age <- ff(0, vmode='ubyte', length=N, update=FALSE, filename="d:/tmp/age.ff", finalizer="close")
for (i in chunk(1,N,n)) age[i] <- ifelse(gender[i]=="male", rnorm(sum(i), 40, 10), rnorm(sum(i), 50, 12))  # 90 sec

income <- ff(0, vmode='single', length=N, update=FALSE, filename="d:/tmp/income.ff", finalizer="close")
for (i in chunk(1,N,n)) income[i] <- ifelse(gender[i]=="male", rnorm(sum(i), 34000, 5000), rnorm(sum(i), 30000, 6000))  # 90 sec

x <- ffdf(country=country, year=year, gender=gender, age=age, income=income)

fcountry <- bit(N)
fyear <- bit(N)
for (i in chunk(1,N,n)) fcountry[i] <- x$country[i] == 'FR'       # 20 sec
for (i in chunk(1,N,n)) fyear[i] <- x$year[i] %in% c(2008,2009)   # 20 sec

close(x)
save.image(file="d:/tmp/ffbit.RData")
```

Short demo of 'ff' with 'bit'

```
library(ff)                             # loads library(bit)
load(file="d:/tmp/ffbit.RData")         # load some ff and bit objects
open(x)                                 # open ffdf (all embedded vectors)

x[1:10,]                                # subscripting returns data.frame
sum(.rambytes[vmode(x)]) * 8e7 / 1024^2  # instead of 1.8 GB in RAM
sum(.ffbytes[vmode(x)]) * 8e7 / 1024^2   # only 630 MB disk/fs-cache
object.size(physical(x))                 # and 9k in R's RAM

fcountry
filter <- fcountry & fyear
summary(filter)                         # check filter summary, then use
summary(filter, range=c(1, 1000)) # dito for chunk
summary(x[filter & ri(1,8e6, N),], maxsum = 12)
# filter combined with range index and used as subscript to ffdf

nrow(x)
nrow(x) <- 1e8
x[c(1,1e8),]
```

NOTE the following peculiarities

```
library(ff)                                  # lo
load(file="d:/tmp/ffbit.RData")              # lo                    it objects
open(x)                                      # op                    edded vectors)

x[1:10,]                                     # subscripting returns data.frame
sum(.rambytes[vmode(x)]) * 8e7 / 1024^2      # instead of 1.8 GB in RAM
sum(.ffbytes[vmode(x)]) * 8e7 / 1024^2       # only 630 MB disk/fs-cache
object.size(physical(x))                     # and 9k in R's RAM

fcountry
filter <- fcountry & fyear
summary(filter)                              # check filter summary, then use
summary(filter, range=c(1, 1000))            #
summary(x[filter & ri(1,8e6, N),],           #
# filter combined with range index                                  to ffdf

nrow(x)
nrow(x) <- 1e8
x[c(1,1e8),]
```

subscripting ffdf did return something very usefull … but a different class

'bit' subscripts are unknown to standard R

assignment to local variable did not create a local copy but changed the global original through a reference

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Is R too functional a language? Sometimes there is too much copying!

```
> n <- 1e8
> y <- double(n)
> gctorture(on = TRUE)
> attr(y, "a") <- 1
> gctorture(on = TRUE)
> attr(y, "b") <- 2
Fehler: kann Vektor der Größe 762.9 MB nicht allozieren
Zusätzlich: Warnmeldungen:
1: In attr(y, "b") <- 2 :
  Reached total allocation of 1535Mb: see help(memory.size)
2: In attr(y, "b") <- 2 :
  Reached total allocation of 1535Mb: see help(memory.size)
3: In attr(y, "b") <- 2 :
  Reached total allocation of 1535Mb: see help(memory.size)
4: In attr(y, "b") <- 2 :
  Reached total allocation of 1535Mb: see help(memory.size)
```

Can a functional language hande large data with all its copying?

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Is R a functional programming language at all?

```
> f<- function(x){
        x[] <- x[]  + 1L
        return(x)
}

> y <- matrix(1L, nrow=1, ncol=2)
> z <- f(y)
> y[]
     [,1] [,2]
[1,]    1    1
> z[]
     [,1] [,2]
[1,]    2    2


> library(bigmemory)
> y <- big.matrix(1, 2, type = "integer", init=1L)
> z <- f(y)
> y[]
[1] 2 2
> z[]
[1] 2 2
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Don't blame "bigmemory" or "ff"!

```
> f<- function(x){
+ x$a <- x$a  + 1L
+ return(x)
+ }
>
> y <- data.frame(a=1)
> z <- f(x)
> y$a
[1] 1
> z$a
[1] 2
```

```
> y <- new.env()
> y$a <- 1
> z <- f(y)
> y$a
[1] 2
> z$a
[1] 2
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

ff can do both – but it reads a bit clumsy …

```
> library(ff)
> fref <- function(x){x[1] <- x[1]+1; x}
> fval <- function(x){x <- clone(x); x[1] <- x[1]+1; x}
> y <- ff(1)
> fref(y)
ff (open) double length=1 (1)
[1]
  2
> y
ff (open) double length=1 (1)
[1]
  2
> fval(y)
ff (open) double length=1 (1)
[1]
  3
> y
ff (open) double length=1 (1)
[1]
  2
```

… and ask for explicit cloning of RAM objects would destroy R as a functinal programming language

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

What about an easy to read and explicit syntax?

```
ff[i]
# dispatches to "[.ff"

ff[i] <- value
# dispatches to "[<-.ff" and clones ff before assigning value

value -> ff[i]
# dispatches to "->[.ff" and assigns value by reference
```

How to pass a return object into a function or expression for reuse?

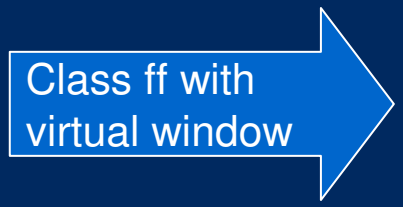
```
# currently R.ff does
newff <- aff + bff
oldff <- "+"(aff, bff, FF_RETURN=oldff)

# then R.ff could read
newff <- aff + bff
aff + bff -> oldff
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

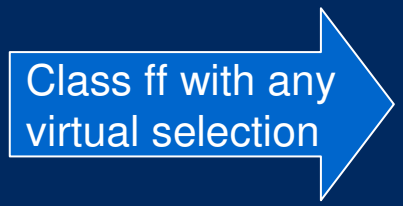
What should `ff[i]` return?

+ returns consistent class
- kills performance because we need to copy from larger to smaller ff on disk and then coerce to standard RAM object: `as.ram(ff[i])`

Current implementation
+ returns much faster
- returns inconsistent class



+ returns much faster (but still needs coercion)
- returns relatively consistent class (still ff, just with different vw)
- vw complicates virtual-to-physical subscript translation
- vw does not allow for arbitrary subscripts



+ fully consistent
- more indirect subscript processing costing performance, e.g. by attaching a 'bit' vector storing the virtual selection, translating each new subscript to 'bit' and return '&' of both

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

[.AsIs

```
# Currently R has:

> get("[.AsIs")
function (x, i, ...)
structure(NextMethod("["), class = class(x))

# assuning that [.class always returns the same class


# ff fixes this by

assignInNamespace(
    "[.AsIs"
  , function (x, i, ...){
      ret <- NextMethod("[")
      oldClass(ret) <- c("AsIs", oldClass(ret))
      ret
    }
  , "base"
  )

# Should go into Base R
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Double inheritance and triple method dispatch

```
> class(x$gender)
[1] "ff_vector" "ff"
> class(x$gender[1:10])
[1] "factor"
# x$gender inherits from both - 'ff' and 'factor'
# i.e. we have a two-dimensional class inheritance
# currently:
# when subscripting, we restore class attributes of the vector
# however, second dimension is invisible in first class call
# and adding an S3 class fails

# in
x$gender[filter]
# "[" needs to be dispatched
# on classes of the object 'ff' and 'factor'
# and on class 'bit' of the subscript
# i.e. we have dispatch on three classes
# currently:
# we coerce the subscript to class 'hi', ff's hybrid index class
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Are we done by simply using S4 classes? 6-dimensional dispatch

Matrix has
3-dimensional dispatch

- storage.type
- dense vs. sparse
- type of matrix

R.ff could add yet another
3-dimensions

- RAM vs. disk based
- whole vs. chunked processing
- type of subscripts

let's look at subscripts

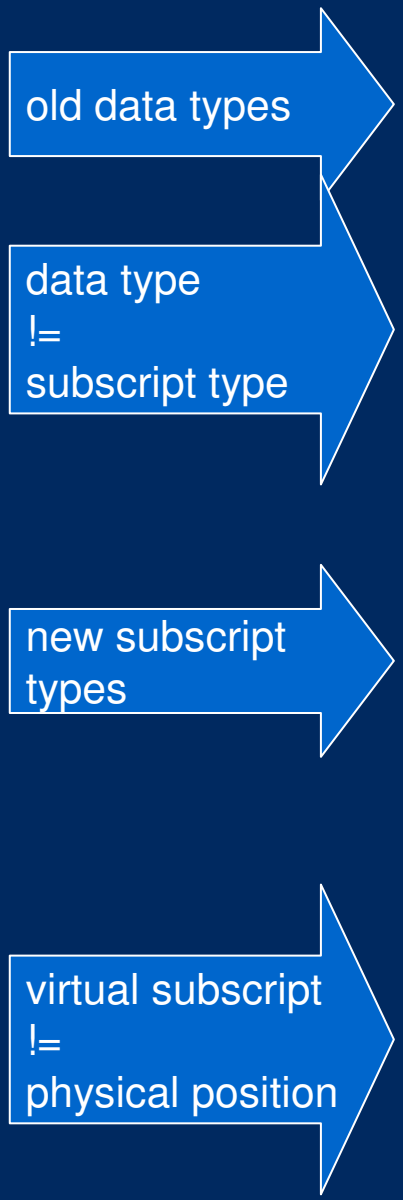
What about the speed of the S4 class system?

Does S4 really solves all issues that arise in context of large objects?

- E.g. chunked iterating over all data
- Upper limit of chunk size to reduce RAM-need
- Lower limit on chunk size to avoid costly disk access
- Distributed calculation on multiple cores / cluster nodes
- Partitioned physical storage

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

We need more data-types and subscript-types



- logical
- integer (positive, negative)
- character (names)

- as.integer(logical)
- which(logical) => make generic either `which` or `as.which`

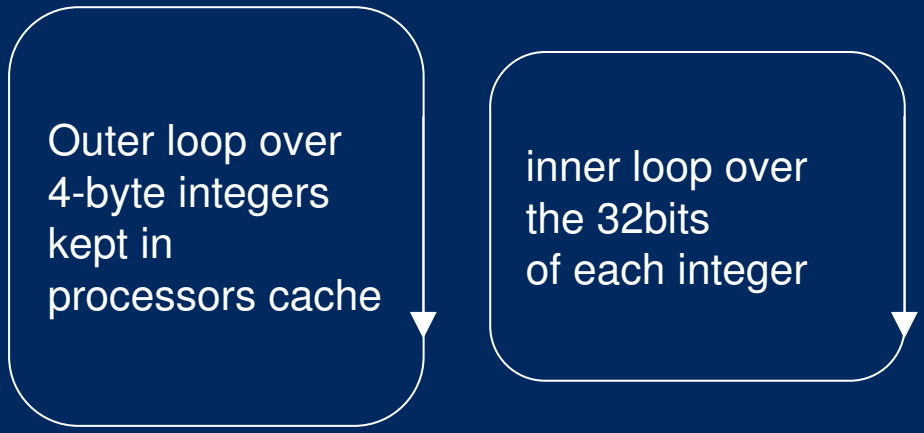
- 64bit integer for *virtual* addressing
  (not necessarily 64bit pointers for *physical* addressing)
- which (need generic 'which' or 'as.which' for stricly positive)
- bit
- whichbit (FALSE or negint or posint or TRUE)
- ri (range index identifying a virtual chunk)
- hi (hybrid index storing the sorted, compressed physical access positions)
- … ?

Is a consequence of
- virtual windows (vw)
- Different mappings from virtual structure to physical storage (e.g. non-standard dimorder, block cyclic layout for PBLAS)

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Remember that subscripting is implicit looping

```
# take
ff2[bit] <- ff1[bit]
```




```
# what we want is a
# possibly compiled, chunked and parallelized iteration aka
foreach (i in bit) %dopar% {ff2[i] <- ff1[i]}

# and what we want to avoid is evaluation of i1:i2 in
foreach (i in i1:i2) %dopar% {ff2[i] <- ff1[i]}
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Thesis: speed optimization with C-code is evil: let's kill .Call()

- An old rule in S says: do use the appropriate access function, do not rely on the internal structure of an object
- .Call is a severe violation of this – sensible – rule
- Calling C-code to obtain a faster looping of an operation over the elements of a vector assumes the vector is in-RAM and kills compatibility because it bypasses necessary method dispatches (e.g. if a 'vector' is 'ff' instead of standard RAM
- Doing method dispatches during the loop would clearly kill performance
- Can't we have the dispatches in a looped expression BEFORE the loop and then do a compiled iteration with callbacks to the resolved functions?
- In order to do this, we would need to know that the dispatch would never change during the loop, i.e. that the classes of the involved objects do not change during the loop.
- Such a context information could be provided to the interpreter using ***expression attributes***
- This would allow to write algorithms for untyped – but stable – objects

- Daniel Adler and Philipp Tassilo have proven with their revolutionary Rdyncall that a static foreign language interface like .Call is not needed to call binary code

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Challenge: efficient processing might need physical iteration sequence different from virtual iteration sequence

```
# take
cumsum(vector[sample(length(vector))])

# or
cumsum(vt(matrix))  # virtually transposed matrix

# naively iterated would crazily jump between file positions

# the latter can be indirectly chunked
# by using block cyclic design of the matrix

# the former requires chunking of the loop itself
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Example for chunked looping

```
y <- ff(vmode="integer", length=100)
chunk(1, 100, 30)
for (i in chunk(1, 100, 30)) y[i] <- i[1]:i[2]
b <- bit(100)
for (i in chunk(1, 100, 30)) b[i] <- y[i] > 50
summary(b)
```

What is the best chunk size – given available RAM, physical partition and number of cores?

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Candidates for expression attributes

```
# require strict sequential processing
# does not exist in SQL - R is more flexible
{expr1, expr2, .sequential=TRUE}

# allow parallelization
{expr1, expr2, .sequential=FALSE}

# how to parallelize
{expr1, expr2, .parallel="multicore"}
{expr1, expr2, .parallel="MPI"}

# when to dispatch
{expr1, expr2, .dispatch="static"}
{expr1, expr2, .dispatch="dynamic"}

# when to parse
{expr1, expr2, .parse="compile"}
{expr1, expr2, .parse="interpret"}
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Candidates for function attributes

```
runif(n=4, min=c(1, 10, 100), max=c(2, 20, 200))
```

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

Other topics

- efficient and identical ordering: quicksort vs. merge sort
- indexing (b-tree, quad-tree, r-trees, …)
- summary is too dynamic in its return structure
- factor treatment is inconsistent, compare c() and rbind.data.frame()
- ffapply: expressions or function calls?
- transparent partitioning of ff into smaller files could help performance, could this be synchronized with with pblas?

Source: Oehlschlägel, Adler (2009) Coordinating package 'ff' for large objects with R base.

SOME DETAILS
NOT PRESENTED
IN THE SESSION

Atomic data types supported by ff

implemented
not implemented

vmode(x)		
boolean	1 bit logical	no NA
logical	2 bit logical	with NA
quad	2 bit unsigned integer	no NA
nibble	4 bit unsigned integer	no NA
byte	8 bit signed integer	with NA
ubyte	8 bit unsigned integer	no NA
short	16 bit signed integer	with NA
ushort	16 bit unsigned integer	no NA
integer	32 bit signed integer	with NA
single	32 bit float	
double	64 bit float	
complex	2x64 bit float	
raw	8 bit unsigned char	
character	fixed widths, tbd.	

Compounds

- factor
- ordered
- custom compounds
  - Date
  - POSIXct
  - POSIXlt (not atomic)

Supported data structures

soon on CRAN

prototype available

not yet implemented

	example	class(x)
vector	`ff(1:12)`	`c("ff_vector","ff")`
array	`ff(1:12, dim=c(2,2,3))`	`c("ff_array","ff")`
matrix	`ff(1:12, dim=c(3,4))`	`c("ff_matrix","ff_array","ff")`
data.frame	`ffdf(sex=a, age=b)`	`c("ffdf","ff")`
symmetric matrix with free diag	`ff(1:6, dim=c(3,3), symm=TRUE, fixdiag=NULL)`	
symmetric matrix with fixed diag	`ff(1:3, dim=c(3,3), symm=TRUE, fixdiag=0)`	
distance matrix		`c("ff_dist","ff_symm","ff")`
mixed type arrays instead of data.frames		`c("ff_mixed", "ff")`

Supported index expressions

implemeneted

not implemented

```
x <- ff(1:12, dim=c(3,4), dimnames=list(letters[1:3], NULL))
i <- as.bit(c(TRUE, FALSE, FALSE))
```

expression	Example
(which) positive integers	`x[ 1, 1]`
negative integers	`x[ -(2:12) ]`
logical	`x[ c(TRUE, FALSE, FALSE), 1]`
character	`x[ "a", 1]`
integer matrices	`x[ rbind(c(1,1)) ]`
bit	`x[ i & i, 1]`
bitwhich	`x[ as.bitwhich(i), 1]`
range index	`x[ ri(1,1), 1]`
hybrid index	`x[ as.hi(1) ,1]`
zeros	`x[ 0 ]`
NAs	`x[ NA ]`

ff's internal index

Source: Oehlschlägel (2010) Managing large datasets in R – ff examples and concepts