# The ff package: Handling Large Data Sets in R with Memory Mapped Pages of Binary Flat Files

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# Overview

- Introduction
- The `ff` package
- Selected examples
- Architecture
- Summary and conclusion

# 1. Introduction

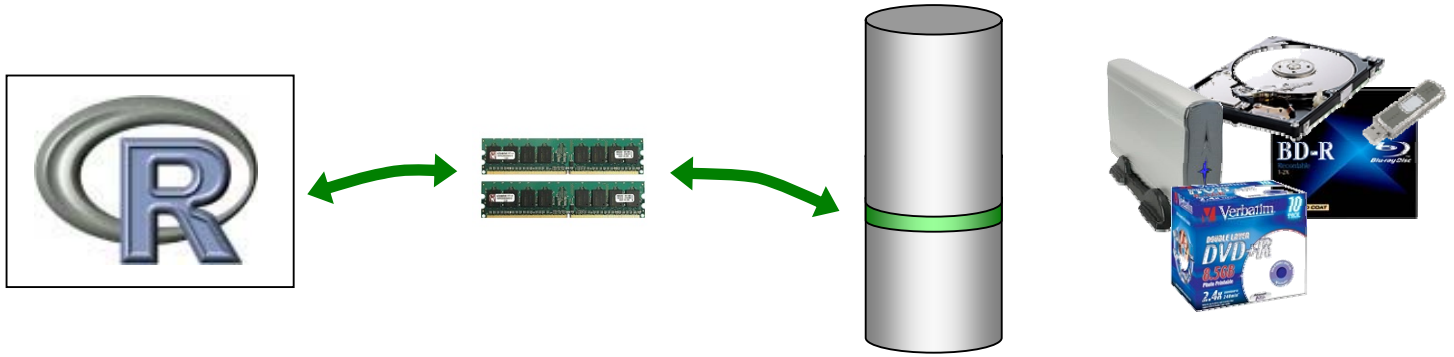
- **Two issues when dealing with large data sets in R:**
  - Memory limitations

    On most computer systems it is not possible to use more than 2 GB of memory, i.e. it is not possible to use the data (in the "usual" way)
  - Addressing limitations

    The range of indexes that can be used is limited, i.e. computers don't understand arbitrary large numbers

- **Memory limitations**
  - On 32-bit OSes the maximum amount of memory (virtual memory space) is limited to 2-4 GB; one cannot store larger data into memory
  - In general, it is impracticable to handle data that is larger than the available RAM (resorting to virtual memory drastically slows down things)
  - Another issue is given by the question whether all data need to be present in memory at the same time (e.g. when only a random sample of a large data set is considered)

- **Memory limitations, cont.**
  - A solution to the memory limitation problem is given by considering only parts of the data at a time, i.e. instead of loading the entire data set into memory only chunks thereof are loaded upon request

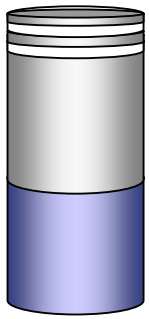



R Memory Data on persistant storage

  - The `ff` package was designed to provide convenient access to large data from persistant storage
  - Only one small section of the data (typically 4 - 64KB) is mirrored into main memory at a time

- Addressing limitations
  - Specific issue for 32-bit machines:

    The maximum addressable range goes up to $2^{31}$-1 ; this is the biggest representable (signed) integer



further entries
not accessable

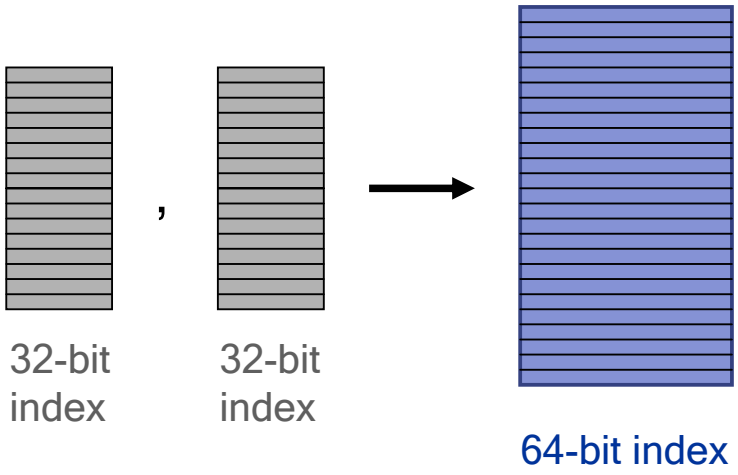
$2^{31}$-1 entries

```
> as.integer(2^31-1)
[1] 2147483647
> as.integer(2^31)
[1] NA
Warning message:
NAs introduced by coercion
```

  - In other words, the addressing issue limits the size of the data that can be analyzed to 16 GB (for double)
  - The memory limitation usually kicks in before the addressing limitation

```
> x <- rep(0, 2^31-1)
Error: cannot allocate vector of length 2147483647
```

- **Addressing limitations, cont.**
  - On 32-bit R systems things get complicated: R uses 32-bit integer arithmetics, while the hard disk is addressed with 64 bits (on most filing systems). Also, C++ provides 64-bit integer arithmetics on 32-bit systems.
  - A simple “trick” to extend the addressable range on 32-bit machines is to introduce “multi-indices”




  - On the R side multiple 32-bit indices are used; these are converted into one 64-bit index on the C++ side

## An overview of the ff package

- The **ff** package introduces a new R object type acting as a container.
  It operates on large binary flat files (double numeric vector).
  Changes to the R object are immediately written on the file.

- The **ff** package comprises the following two parts
  - a "low-level" layer written in C++
  - a "high-level" layer in R

- The package was designed for convenient access to large data sets:
  - large data sets (i.e. **ff** objects) are accessed in the same way as ordinary R objects

- The R Programming Interface ("high-level" layer)
  - The R layer comprises the following sections:
    - Opening / Creating flat files
      Controlled by the two core functions **ff** and **ffm**. When a **length** or **dim** argument is specified, a new file is created, otherwise an existing file is opened
    - I/O operations
      These are controlled by the "**[**" operator (for reading) and the "**[<-**" operator for writing
    - Generic functions and methods for **ff** and **ffm** objects
      Methods for **dim** and **length** are provided and the function **sample** is converted to a generic function
  - Auxillary functions include e.g. **seqpack** for optimization purposes

- Selected examples of usage
  - Creating a (one-dimensional) flat file:

```
> library("ff")
> foo1 <- ff("foo1", length = 10)
> foo1
$ff.attributes
   class    file pagesize readonly
    "ff"  "foo1"  "65536"  "FALSE"
$first.values
[1] 0 0 0 0 0 0 0 0 0 0
> foo1[1:10]
[1] 0 0 0 0 0 0 0 0 0 0
```

  - Modifying data:

```
> data("rivers")
> foo1[1:10] <- rivers[1:10]
> foo1[1:10]
[1]  735  320  325  392  524  450 1459  135  465  600
```

- Selected examples of usage, cont.

  - Creating a (multi-dimensional) flat file:

```
> m <- ffm("foom", dim = c(31, 3))
> data("trees")
> m[1:31, 1:3] <- trees[1:31, 1:3]
```

  - In order to interact with the **`biglm`** package the wrapper function **`ffm.data.frame`** is provided:

```
> require(biglm)
> ffmdf <- ffm.data.frame(m, c("Girth", "Height", "Volume"))
```

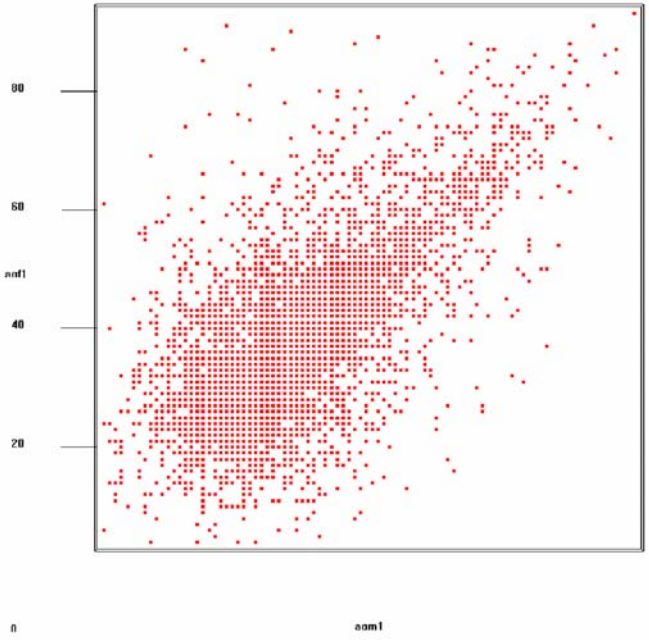
- Selected examples of usage, cont.

  - Using **`biglm`** with **`ffm`** objects:

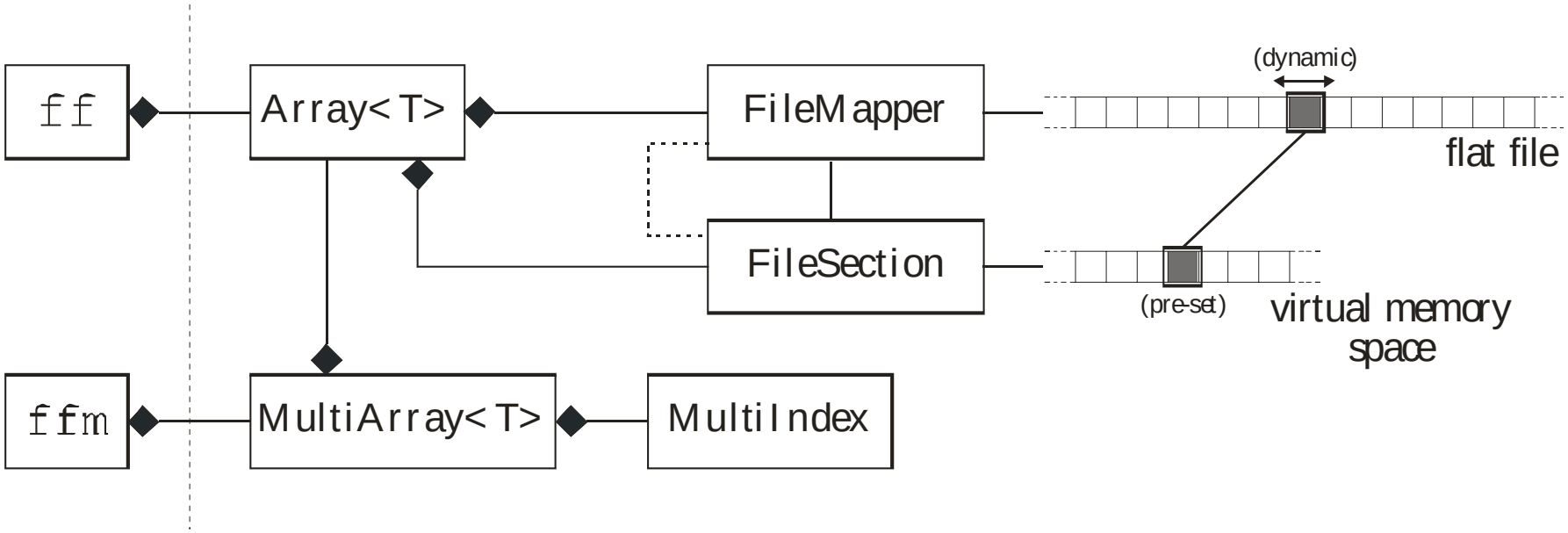
```
> fg <- log(Volume) ~ log(Girth) + log(Height)
> m0 <- bigglm(fg, data = ffmdf, chunksize = 10,
+                 sandwich = TRUE)
> summary(m0)
Large data regression model: bigglm(formula = formula, data =
datafun, ...)
Sample size = 31
              Coef    (95%    CI)     SE p
(Intercept) -6.632 -8.087 -5.176 0.728 0
log(Girth)   1.983  1.871  2.094 0.056 0
log(Height)  1.117  0.733  1.501 0.192 0
Sandwich (model-robust) standard errors
```

- Selected examples of usage, cont.
  - Loading a 14 GB flat file (US Census data from 2000 for Texas), taking a random sample of selected variables and plotting the sample:

```
> # loading the flat file:
> txdata <- ffm("G:/texas_p")

> # drawing a sample of indices
> set.seed(1337)
> ind <- runique(10000, total = 750624)
> agm <- txdata[ind, 394]
> agf <- txdata[ind, 395]

> # removing missing values (coded as '0')
> in.c1 <- agm != 0 & agf != 0
> agm1 <- agm[in.c1]
> agf1 <- agf[in.c1]

> require(rgl)
> plot3d(agm1, agf1, 0, size = 2, col = "red")
> view3d(0, 0, fov = 1, zoom = 0.7)
```



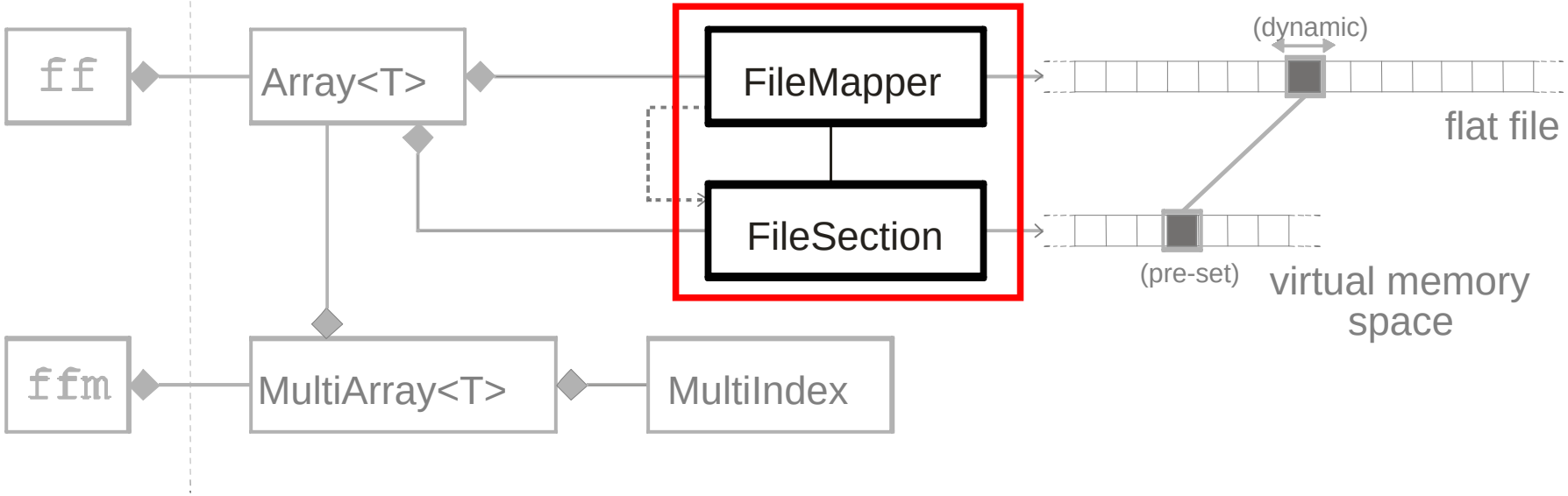
- The “low-level” layer
  - Structure of the “low-level” C++ layer




  - The C++ layer consists of two parts:

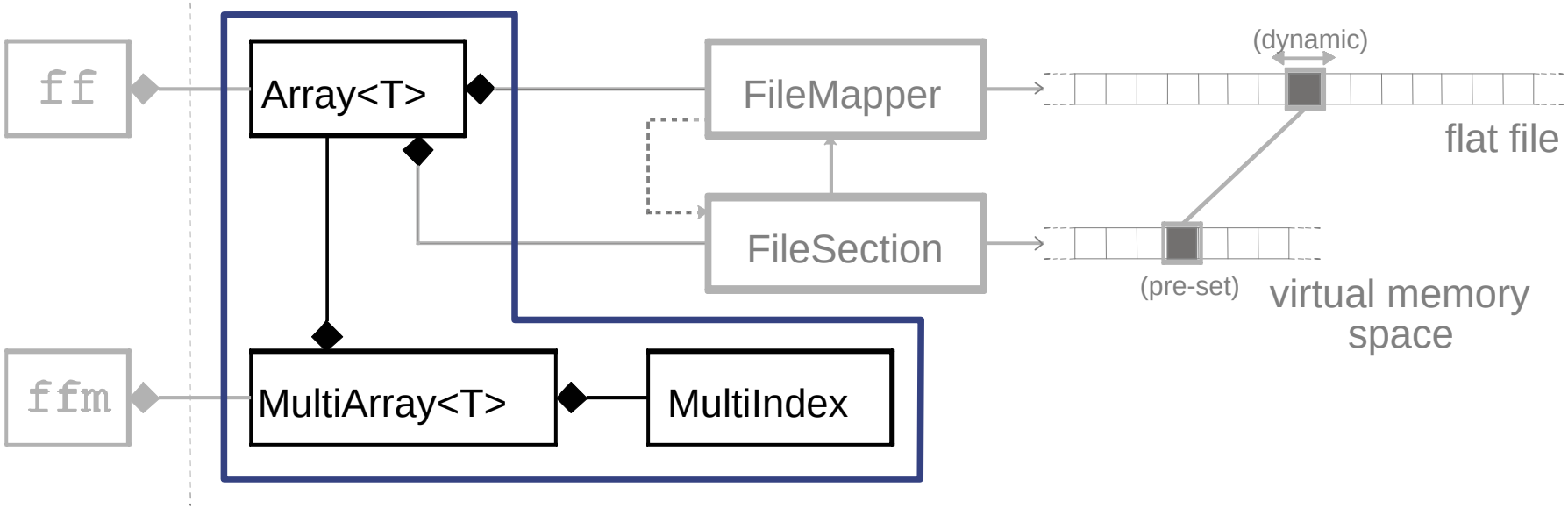
    - abstractions to platform-specific services and
    - a collection of template container classes

- The “low-level” layer
  - *Abstractions to platform-specific system services* contain a FileMapping and a FileSection class (both are platform specific)




  - *FileMapping* class: Implementation of memory mapped file facilities; exposes a factory method to create FileSection objects
  - *FileSection* class: Implementation of memory mapped file *regions* that exposes the pointer to the corresponding file region that is mapped to main memory

- The “low-level” layer
  - The *template container classes* implement a caching strategy on top of memory mapped pages of large files




  - *Array<T>* template class manages one FileSection object at a time
  - *Multiarray<T>* template class implements a multi-dimensional array using a multiple integer index
  - *MultiIndex* utility class translates between multiple integer indices an 64-bit indices

# 5. Summary and conclusion

- We have presented the **ff** package for handling large data sets in R; it was developed for the *UseR! 2007* programming competition
- The package comprises two components, a low-level layer written in C++ and a high-level layer in R
- The package uses platform-specific features and has been ported to Windows, Linux, Mac OS X and FreeBSD
- With this approach it is possible to work on multiple large data sets simultaneously
- 64-bit systems also benefit from this approach
- The package is available from

  http://wsopuppenkiste.wiso.uni-goettingen.de/ff

# 5. Summary and conclusion

- **Future work**
  - Support for further data types - besides doubles - is in progress
  - The architecture of the package is modular - various storage and caching policies can be evaluated in the future
  - Further I/O optimizations (performance gains)
  - Re-implementing algorithms based on chunks (like the **`biglm`** package)
  - Feedback and suggestions for improvement are welcome