

Code Profiling in R: A Review of Existing Methods and an Introduction to Package **GUIProfiler**

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Abstract Code analysis tools are crucial to understand program behavior. Profile tools use the results of time measurements in the execution of a program to gain this understanding and thus help in the optimization of the code. In this paper, we review the different available packages to profile R code and show the advantages and disadvantages of each of them. In addition, we present **GUIProfiler**, a package that fulfills some unmet needs.

Package **GUIProfiler** generates an HTML report with the timing for each code line and the relationships between different functions. This package mimics the behavior of the MATLAB profiler. The HTML report includes information on the time spent on each of the lines of the profiled code (the slowest code is highlighted). If the package is used within the RStudio environment, the user can navigate across the bottlenecks in the code and open the editor to modify the lines of code where more time is spent. It is also possible to edit the code using Notepad++ (a free editor for Windows) by simply clicking on the corresponding line. The graphical user interface makes it easy to identify the specific lines which slow down the code.

The integration in RStudio and the generation of an HTML report makes **GUIProfiler** a very convenient tool to perform code optimization.

Introduction

Software profiling is the analysis of a computer program performed by measuring the time spent on each line of code, code coverage or memory usage during its execution. Profiling is the first step towards efficient programming. The development of efficient software depends on identification of key bottlenecks. Focusing the optimization only on the bottlenecks is known to maximize efficiency in both development time and program runtime (Wilson et al., 2014). In interpreted languages (including R) a few lines can form major bottlenecks. See for example Visser et al. (2015).

With the advent of data mining, data analytics and big data analysis, code profiling is gaining prominence. In these fields, one potential limitation to scientific advance is inefficient code. Since the factors that affect the execution time are difficult to foresee beforehand, and the bottlenecks (if the code is large) are especially difficult to identify, the need of a profiling tool is apparent. In addition to that, inefficient code is also prone to have bugs. Our experience is that profiling is also an indirect way to fix errors in software.

The base distribution of R includes a profiling tool that consists of the functions `Rprof` to start and stop the profiling and `summaryRprof` as a parser of the output. The description of `Rprof` given in the help file is: “Profiling works by writing out the call stack every interval seconds (...)”. This means that R uses the operating system interrupts to sample and write the call-stack (by default every 20 msecs). Therefore, lines that take more than 20 msecs appear at least once in the file written by the internal R profiler. On the other hand, a “fast” line of code where the execution time is strictly less than 20 msecs may or may not appear in the output file (with the probability of being included proportional to its execution time). Therefore, the output of profiling the same code is not identical for different runs. Overall it can be noted that statistical profiling (i.e., the one implemented in R) intrudes very little on the executed code (i.e., it almost does not affect its execution time) and is considered to be an efficient way to achieve proper profiling.

In previous versions of R (prior to 3.0), `Rprof` only worked at the function level (i.e., the profiler only provided information on the functions in the stack). Since version 3.0, it is possible to perform line profiling. If the `line.profiling` option is selected, the file generated by `Rprof` also includes information on the specific *line* of code in the stack (not only the *function*). This extension made it possible to identify the specific lines that slow down the code.

The output of `Rprof` is quite simple: a file that shows the name and some other characteristics of a function every time it is found to be in the stack. Despite this simplicity, it is necessary to parse this file to understand the content and R provides the “`summaryRprof` function (...)” that can be used to process the output file to produce a summary of the usage” (from its help file).

The functionality of `summaryRprof` falls short in some aspects. If a function is called several times, `summaryRprof` fails to identify the specific function call that is slowing down the computation. As

functions can be nested in other functions, finding the true bottleneck is not obvious. In `summaryRprof`, it is not possible to track the hierarchy among the functions. `summaryRprof` was developed prior to the `line.profil` option and does not take full advantage of this information. This fact will be shown in detail in the analysis of the different profile tools below.

These limitations have fostered the development of other command line functions and packages such as `proftable`, `aprof`, `proftools`, `profr`, and `lineprof`. `proftable` (Klevtsov, 2014) is a convenient command line function that parses the output of `Rprof` and shows the output in a reasonable and intuitive way. `aprof` (Visser et al., 2015) displays graphically the time spent on each line of code and provides an estimate on how optimizing a single line of code will affect the overall performance. It also shows the output of memory profiling. `proftools` (Tierney and Jarjour, 2013) includes useful command line tools to perform the profiling. Among other functionalities, it shows a graph of the different hierarchical relationships between the called functions. `lineprof` (Wickham, 2014a) can be considered an evolution of `profr` (Wickham, 2014b) and is developed by the same author. It is a profiling package that provides output integrated in the RStudio environment. It shows a nice graphical output and also includes memory profiling capabilities. In addition to these tools, the `pbDPAPI` package (Schmidt et al., 2015) offers access to low-level hardware counter information and is mainly used for advanced profiling. On the other hand, the most convenient package to test the performance of a single line of code is `microbenchmark` (Mersmann, 2014). It cannot be applied, though, to profile complex code. To our knowledge, these are all the available tools to aid in R profiling.

All these packages are, as most R packages, command line tools. Although they represent an important advance if compared with the `summaryRprof` function, none of them are especially user-friendly. In comparison, MATLAB™ (The MathWorks Inc., 2015) provides a profiler that includes a convenient user interface by means of an HTML report. Profiling MATLAB code is easy and straightforward with the aid of its profile tool. An R profiler with this convenient front-end that includes GUI capabilities would be highly desirable.

Fortunately, the development of this tool is not such a challenging task. Several packages such as `Nozzle.R1` (Gehlenborg, 2013) or `knitr` (Xie, 2014) are available on CRAN that automatically generate HTML reports based on an easy syntax. `GUIProfiler` (de Villar and Rubio, 2015) is an R package that automatically generates an HTML report that summarizes the profiling results. These reports are generated with the aid of `Nozzle.R1`. Its integration in the RStudio environment makes it especially user friendly.

The following sections show how to use package `GUIProfiler` as well as provide a review on the profiling capabilities of the aforementioned tools using the same sample code for all of them.

Case study using GUIProfiler

The first lines of code are required for the installation of the package. As `GUIProfiler` is hosted on CRAN, the installation is straightforward:

```
install.packages("GUIProfiler")
library("GUIProfiler")
```

If the package is properly installed, no errors should appear after calling the `library` command. `GUIProfiler` has a practical limitation that must be taken into account: The profiled code must be stored on an accessible file. It is therefore better to run a source command instead of writing the lines directly in the command line. The reason of this limitation is that the report is based on the output from `Rprof` and that it only includes information on the functions stored at files, not from the script that calls them. In addition to that, it only accepts one function per file. R does allow to include several functions in a single file. We are currently working to circumvent this limitation.

Here we present some sample code (included also in the `GUIProfiler` documentation) that will be used with all the profiling tools. The HTML report generated by package `GUIProfiler` is shown in Figure 1 and the code is,

```
temp <- tempdir()
# Definition of two functions
normal.solve <- function(A, b) {
  Output <- solve(crossprod(A), t(A) %*% b)
}
chol.solve <- function(A, b) {
  L <- chol(crossprod(A))
  Output1 <- backsolve(L, t(A) %*% b, transpose = TRUE)
  Output2 <- backsolve(L, Output1)
}
```

```

compareMethods <- function() {
  library(MASS)
  # Call the functions
  source(paste(temp, "/normal.solve.R", sep = ""))
  source(paste(temp, "/chol.solve.R", sep = ""))
  # Solving a big system of equations
  nrows <- 1000
  ncols <- 500
  A <- matrix(rnorm(nrows * ncols), nrows, ncols)
  b <- rnorm(nrows)
  # Testing different possibilities
  Sol1 <- qr.solve(A, b)
  # Using QR factorization
  Sol2 <- coefficients(lm.fit(A, b))
  # lm.fit, based on QR but with some overhead
  Sol3 <- ginv(A) %*% b
  # Using the pseudoinverse based on SVD
  Sol4 <- normal.solve(A, b)
  # Using a function based on the normal equations.
  Sol5 <- chol.solve(A, b)
  # Using Choleski factorization.
}
# Dump these functions to three different files
dump("normal.solve", file = paste(temp, "/normal.solve.R", sep = ""))
dump("chol.solve", file = paste(temp, "/chol.solve.R", sep = ""))
dump("compareMethods", file = paste(temp, "/compareMethods.R", sep = ""))
source(paste(temp, "/compareMethods.R", sep = ""))

```

This code implements the minimum squares solution of a linear system of equations using different methods: QR factorization, the `lm.fit` function (that internally also uses the QR factorization), computation of a generalized pseudoinverse (that internally uses the SVD factorization), using the normal equations and, finally, using the Choleski factorization. The solutions using either of them are identical, i.e., the vectors `Sol1`, `Sol2`, `Sol3`, `Sol4` and `Sol5` are identical up to computer precision.

The lines to profile the code are only the last ones in the example code of the `RRprofReport` function. Specifically,

```

# Profile the code
RRprofStart()
compareMethods()
RRprofStop()
RRprofReport()

```

Each of these lines are self-explanatory. In the first line we activate and start the **GUIProfiler**. The following line executes the function that is being profiled. Once this line finishes, the profiling is stopped and the last line generates the report based on the output of the R profiler. In the RStudio environment, this report is shown in the viewer pane. In addition, the markers pane indicates the lines of code where more time was spent. It is possible to navigate through the source code by simply clicking on the corresponding markers.

If the program is not executed in the RStudio environment, `RRprofReport()` opens a new browser window. Figure 1 shows a snapshot of the generated report. The report consists of two groups of tables: a summary of the called functions with the time spent on each of them and a group of tables with the time spent on each line of code for each function. A convenient feature, if the browser is the Internet Explorer and Notepad++ is installed, is that the line numbers of the functions are clickable: Once a line number is clicked, the corresponding file is opened with the cursor on the selected line (as shown in Figure 2). On the right panel of Figure 2, the layout of **GUIProfiler** is shown in the RStudio environment. Note that RStudio version ≥ 0.99 is required. We tested **GUIProfiler** on RStudio 0.99.467. The navigation across the different functions can be done using the markers tab.

Comparison between different profiling tools

Using the same example, we compare the functionalities of the different profiling tools in their ability to provide insight on the profiled code. All the profiling tools (including **GUIProfiler**) manipulate the file generated by `Rprof` to provide a more readable and useful output. Therefore, most of the code to profile a function is shared by the different packages: First of all there is a call to `Rprof` to start

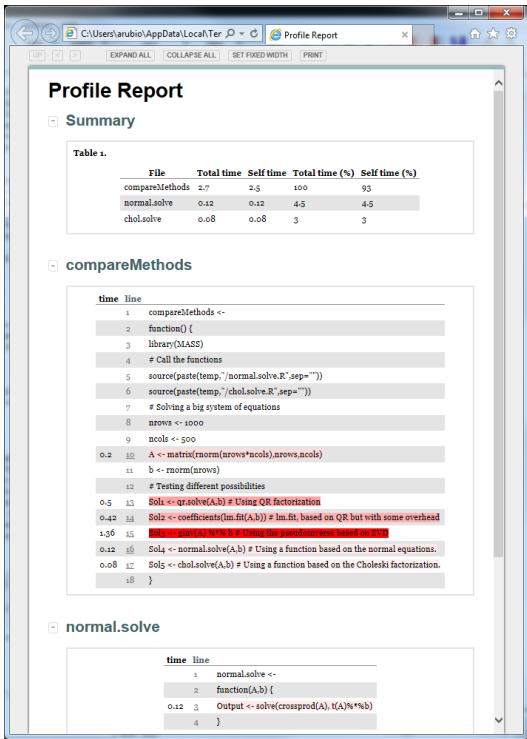


Figure 1: HTML report generated by GUIProfiler.

	HTML report	Graphical output	Function nesting	Line profiling	Memory profiling	Connection with editors
GUIProfiler	✓	✓	✓	✓	✗	✓(*)
summaryRprof	✗	✗	✗	✓	minimal	✗
proftable	✗	✗	✓	✓	✗	✗
aprof	✗	✓	✓	✓	✓	✗
proftools	✗	✓	✓	✗	✗	✗
profr	✗	✓	✓	✗	✗	✗
lineprof	✓	✓	✓	✓	✓	✗
MATLAB	✓	✓	✓	✓	✓(**)	✓

Table 1: Comparison of different profile tools for R. (*) GUIProfiler connects the results with RStudio and with the Notepad++ editor. (**) Non-documented characteristic.

profiling, the code itself to be profiled and a second call to Rprof to stop profiling. The differences between them are the way the output of Rprof is summarized and displayed.

Table 1 shows a comparison between the functionalities of Rprof parsers used to profile R code. The first column indicates if the package generates an HTML report. The second column indicates if the package generates some visual graphical output to show the results. The “Function nesting” column shows whether the package is able to display the hierarchy across the function calls. The “Line profiling” column states whether the package provides information related with each of the lines in the code, not only the functions (i.e., whether it takes advantage of the line.profiles option). The “Memory profiling” column states whether the package shows results of profiling memory usage and finally, the “Connection with editors” column states whether the package has a direct link with an editor to fix the potential bottlenecks.

We also included the features of the MATLAB profiler. As can be seen, it offers all these functionalities. One anecdotal note of the MATLAB profiler is that, even though it implements memory profiling (in a very effective and user friendly manner), this feature is non-documented. **summaryRprof**, **lineprof** and **aprof** implement memory profiling in R. **lineprof** and **GUIProfiler** provide an HTML report. **GUIProfiler** is the only one that provides a connection with editors.

We include Table 2 to show the dependencies for each of the packages. As a general rule, packages with few dependencies are easier to install and to run in different conditions (i.e. on a server

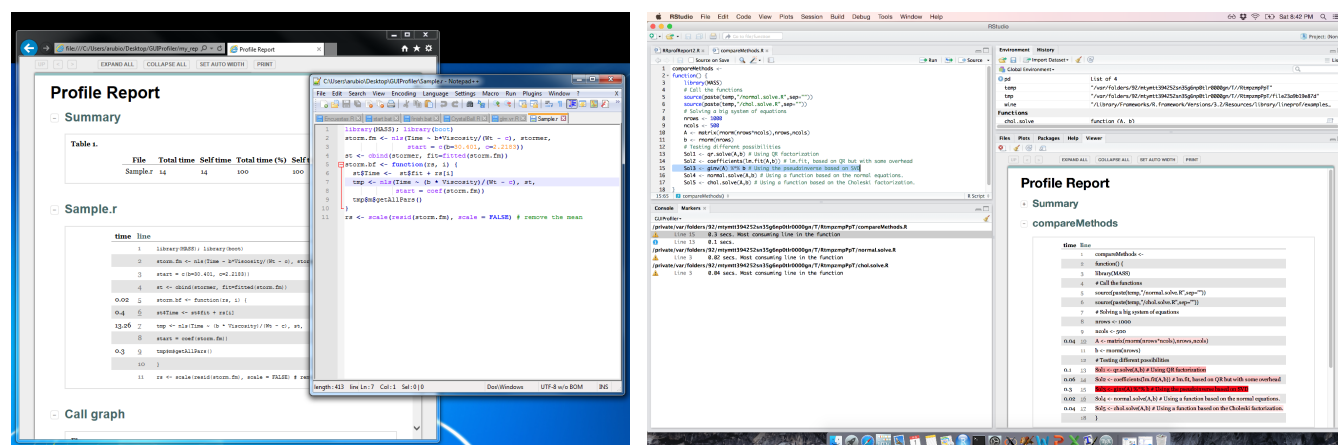


Figure 2: Layout of GUIProfiler. Left: Internet Explorer and Notepad++. Right: RStudio environment. The report is shown in the viewer tab on the right, and the markers tab on the left can be used to navigate across the code.

Tool	Dependencies
GUIProfiler	Nozzle.R1 , Rgraphviz (Hansen et al., 2015), graph (Gentleman et al., 2015), proftools
summaryRprof	None
proftable	None
aprof	grDevices
proftools	Rgraphviz , graph
profr	stringr (Wickham, 2015), plyr (Wickham, 2011)
lineprof	devtools (installation; Wickham and Chang, 2015), environment (C compiler), shiny (Chang et al., 2015, and its dependencies)

Table 2: Dependencies of the packages analyzed. Only packages not included in the standard distribution are mentioned.

environment). The following sections describe how to profile the example using the tools shown in Table 1.

summaryRprof

The code to perform the profiling of the example using **summaryRprof** is:

```
Rprof(tmp <- tempfile(), line.profiling = TRUE)
compareMethods()
Rprof(append = FALSE)
summaryRprof(tmp)
unlink(tmp)
```

and the output,

```
$by.self
self.time self.pct total.time total.pct
"La.svd"      0.80    40.82      0.80    40.82
".Call"       0.40    20.41      0.40    20.41
".Fortran"    0.38    19.39      0.38    19.39
"crossprod"   0.12     6.12      0.12     6.12
".External"   0.10     5.10      0.10     5.10
"%*%"        0.08     4.08      0.08     4.08
...More lines not included...
```

```
$by.total
```

```
total.time total.pct self.time self.pct
"compareMethods"      1.96   100.00    0.00    0.00
"ginv"                 0.90    45.92    0.00    0.00
"svd"                  0.82    41.84    0.02    1.02
"La.svd"               0.80    40.82    0.80   40.82
".Call"                0.40    20.41    0.40   20.41
"coefficients"         0.40    20.41    0.00    0.00
"lm.fit"               0.40    20.41    0.00    0.00
".Fortran"             0.38    19.39    0.38   19.39
"qr"                   0.38    19.39    0.00    0.00
...More lines not included...
```

```
$sample.interval
[1] 0.02
```

```
$sampling.time
[1] 1.96
```

If we focus on the "by.self" part, the information is not too useful: the .Call or .Fortran functions can be used anywhere and depending on their argument, their behavior is completely different. On the other hand, the crossprod function is used many times in the code and the table only shows the overall time spent on it. Although the line.profiling option was set, line information does not appear anywhere in the output. The latest version of R (by setting `summaryRprof(tmp, lines = "show")`) provides basic information on line profiling.

The "by.total" part states that the most costly functions are `ginv`, `svd` and `La.svd`. However, these functions are in fact all the same: `ginv` calls `svd` that, in turn, calls `La.svd`. The output does not show this hierarchy in the calls to the function. In addition, the `summaryRprof` output does not show locations of the calls to the corresponding functions within the code. The output presents therefore serious limitations for its practical use that can be solved with other tools described below.

proftable

`proftable` is a convenient function that solves some of the aforementioned problems of **summaryRprof**: Each line of code is clearly identified and can be easily tracked. The function can be accessed from GitHub. The code to run the example is:

```
Rprof(tmp <- tempfile(), line.profiling = TRUE)
compareMethods()
Rprof(append = FALSE)
source("https://raw.githubusercontent.com/noamross/noamtools/master/R/proftable.R")
proftable(tmp)
```

And the output,

```
PctTime Call
36.364 compareMethods > 1#15 > ginv > svd > La.svd
20.000 compareMethods > 1#14 > coefficients > lm.fit > .Call
19.091 compareMethods > 1#13 > qr.solve > qr > qr.default > .Fortran
4.545 compareMethods > 1#15 > ginv > %*%
3.636 compareMethods > 1#10 > matrix > rnorm > .External
2.727 compareMethods > 1#15 > ginv > svd > La.svd > matrix
2.727 compareMethods > 1#16 > normal.solve > 2#3 > solve > crossprod
2.727 compareMethods > 1#16 > normal.solve > 2#3 > solve > solve.default
1.818 compareMethods > 1#17 > chol.solve > 3#3 > chol > crossprod
0.909 C:\\Some directories...\\chol.solve.R > 3: > #File

#File 1: C:\\Users\\arubio\\AppData\\Local\\Temp\\RtmpEH6ki0\\compareMethods.R
#File 2: C:\\Users\\arubio\\AppData\\Local\\Temp\\RtmpEH6ki0\\normal.solve.R
#File 3: C:\\Users\\arubio\\AppData\\Local\\Temp\\RtmpEH6ki0\\chol.solve.R
```

Parent Call: None

```
Total Time: 2.2 seconds
Percent of run time represented: 94.5 %
```

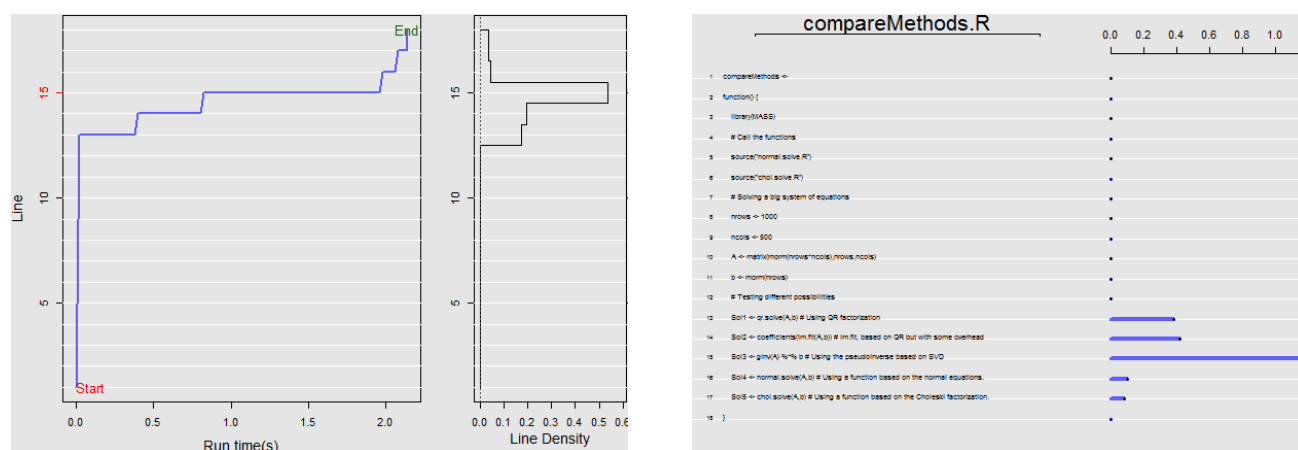


Figure 3: Output generated by profileplot of an 'aprof' object. Left panel: accumulated time and time spent on each line of code. Right: content for each line of code and the spent on each of them.

In this case the hierarchical relationships between `ginv`, `svd` and `La.svd` (as well as other ones) are clearly stated. Each line of code may appear several times. This "excess" of information can be useful to identify within each line of code which is the most costly part. However, it is also confusing. For example, line 15 of the first archive appears several times in the list since `svd` and matrix multiplication (both inside the `ginv` function) are costly operations.

`proftable` includes the location of each line in each file, making their analysis within a context easier. `proftable` is a simple, yet very useful tool.

aprof

aprof also works with the output of `Rprof` and provides visual aids based on line profiling. It helps to identify the most promising sections of code to optimize. One interesting unique functionality is that **aprof** also projects the potential gains. The last version has also memory profiling included. The code to run **aprof** is:

```
library(aprof)
Rprof(tmp <- tempfile(), line.profiling = TRUE)
compareMethods()
Rprof(append = FALSE)
fooaprof <- aprof(paste(tmp, "/compareMethods.R", sep = ""), tmp)
plot(fooaprof)
profileplot(fooaprof)
summary(fooaprof)
```

Running the provided code in **aprof** generates nice plots that describe the time spent on each line of code (and the code itself). Figure 3 shows the **aprof** output. The summary function estimates the speed-up by optimizing a single line of code (or all the lines of code). The output to the console is:

Largest attainable speed-up factor for the entire program

when 1 line is sped-up with factor (S):

```
Speed up factor (S) of a line
      1      2      4      8     16    S -> Inf**
Line*: 15 :  1.00  1.40  1.75  2.00  2.15  2.33
Line*: 13 :  1.00  1.06  1.10  1.12  1.13  1.14
Line*: 14 :  1.00  1.06  1.10  1.12  1.13  1.14
Line*: 16 :  1.00  1.03  1.05  1.06  1.06  1.07
Line*: 17 :  1.00  1.03  1.05  1.06  1.06  1.07
Line*: 10 :  1.00  1.01  1.02  1.02  1.02  1.02
```

Lowest attainable execution time for the entire program when

lines are sped-up with factor (S):

	Speed up factor (S) of a line				
	1	2	4	8	16
All lines	2.840	1.420	0.710	0.355	0.178
Line*: 15 :	2.840	2.030	1.625	1.423	1.321
Line*: 13 :	2.840	2.670	2.585	2.543	2.521
Line*: 14 :	2.840	2.670	2.585	2.543	2.521
Line*: 16 :	2.840	2.750	2.705	2.683	2.671
Line*: 17 :	2.840	2.750	2.705	2.683	2.671
Line*: 10 :	2.840	2.810	2.795	2.788	2.784

Total sampling time: 2.84 seconds
 * Expected improvement at current scaling
 ** Asymtotic max. improvement at current scaling

The line of code 'fooaprof <- aprof("myfile.R...")' can be run for each of the files to get the profiling of all the executed functions. In this case it can be done by,

```
compareaprof <- aprof(paste(temp, "/compareMethods.R", sep = ""), tmp)
plot(compareaprof)
profileplot(compareaprof)
compareaprof <- aprof(paste(temp, "/normal.solve.R", sep = ""), tmp)
plot(compareaprof)
profileplot(compareaprof)
compareaprof <- aprof(paste(temp, "/chol.solve.R", sep = ""), tmp)
plot(compareaprof)
profileplot(compareaprof)
```

Alternatively, if the user wants to go into more detail for each of the functions, targetedSummary can be used to disentangle nested functions.

The information provided by **aprof** and **GUIProfiler** is very similar: **aprof** provides the output as an image and **GUIProfiler** as an HTML report.

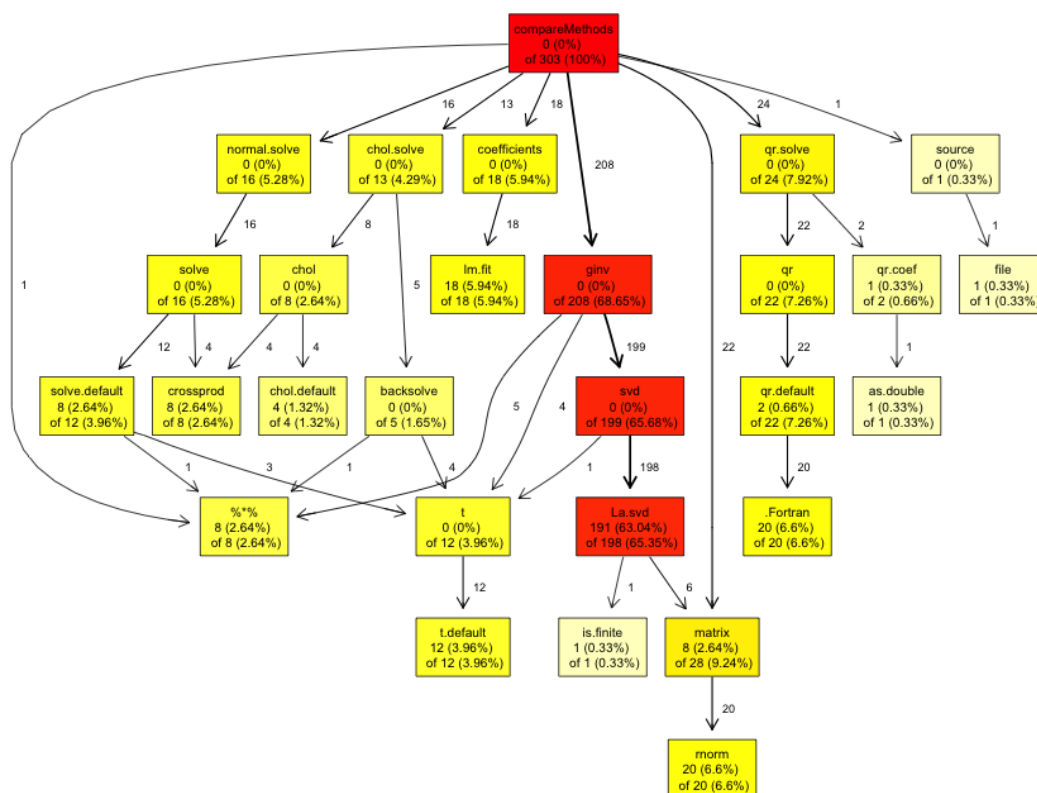
proftools

proftools provides tools for examining Rprof profile output. It shows graphically the dependencies among the different functions and the time spent on each of them. The code to profile the example is:

```
library(proftools)
Rprof(tmp <- tempfile(), line.profiling = TRUE)
compareMethods()
Rprof(append = FALSE)
pd <- readProfileData(tmp)
plotProfileCallGraph(pd, style = google.style, score = "total", nodeSizeScore = "none")
```

The user can get this information in the console by using the function printProfileCallGraph. The corresponding output is for this example:

```
Call graph
index   % time   % self   % children   name
[1]      100.00      0.00     100.00   compareMethods [1]
1.06      0.00      0.00      0.00      %*% [15]
0.00      2.13      0.00      0.00      chol.solve [19]
0.00     21.28      0.00      0.00      coefficients [8]
0.00     43.62      0.00      0.00      ginv [2]
0.00      6.38      0.00      0.00      matrix [13]
0.00      3.19      0.00      0.00      normal.solve [16]
0.00     22.34      0.00      0.00      qr.solve [6]
-----
0.00     43.62      0.00      0.00      compareMethods [1]
[2]     43.62      0.00     43.62      ginv [2]
4.26      0.00      0.00      0.00      %*% [15]
0.00     39.36      0.00      0.00      svd [4]
-----
39.36      0.00      0.00      0.00      svd [4]
[3]     39.36     39.36      0.00      La.svd [3]
```


Figure 4: Output of **proftools**.

```

-----
0.00      39.36      ginv [2]
[4]      39.36      0.00      39.36      svd [4]
39.36      0.00      La.svd [3]
-----
21.28      0.00      qr.default [11]
1.06      0.00      qr.coef [23]
[5]      22.34      22.34      0.00      .Fortran [5]
-----
0.00      22.34      compareMethods [1]
[6]      22.34      0.00      22.34      qr.solve [6]
0.00      21.28      qr [10]
0.00      1.06      qr.coef [23]
-----
21.28      0.00      lm.fit [9]
[7]      21.28      21.28      0.00      .Call [7]
-----
... Additional lines not shown here...

```

Figure 4 shows the dependencies between the different functions. Probably, this tool provides the most intuitive representation of the different relationships among the functions in the code. We have taken advantage of this in **GUIProfiler** and this graph is also included in the generated report.

proftools is, however, “function based” and the `line.profilng` option is not used at all. In fact, if `Rprof` is used without the `line.profilng` option, the result is identical.

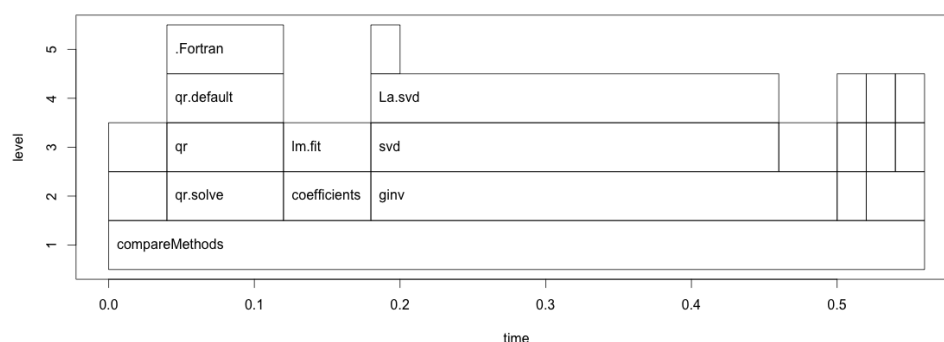
profr

profr is one of the oldest packages to parse the `Rprof` output. The first version appeared in May, 2008. Its usage, as for the other tools described here, is straightforward:

```

library(profr)
profcompareMethods <- profr(compareMethods())

```

Figure 5: Output of **prof**.

```
head(profcompareMethods)
plot(profcompareMethods)
```

The output provided by **prof** is the following:

	level	g_id	t_id	f	start	end	n	leaf	time	source
8	1	1	1	compareMethods	0.00	0.76	1	FALSE	0.76	.GlobalEnv
9	2	1	1	matrix	0.00	0.08	1	FALSE	0.08	base
10	2	2	1	qr.solve	0.08	0.20	1	FALSE	0.12	base
11	2	3	1	coefficients	0.20	0.26	1	FALSE	0.06	stats
12	2	4	1	ginv	0.26	0.66	1	FALSE	0.40	MASS
13	2	5	1	normal.solve	0.66	0.74	1	FALSE	0.08	.GlobalEnv

There is a useful plot command that shows the time spent on each function. In turn, the functions are grouped by levels. The output is shown in Figure 5.

prof was (with **summaryRprof**) the first attempt to display the result of profiling R code. It was developed before **line.profit** was available and does not make use of it. The graphical representation is much more informative than the text output. However, although the hierarchical tree of **proftools** and the graph shown in **prof** show basically the same information, in our opinion, the tree is more visually apparent and attracts attention directly to the bottlenecks of the code.

lineprof

lineprof can be considered as an evolution of **prof** (both have the same developer and maintainer). Although it is not yet on CRAN, the installation from GitHub is straightforward.

```
install.packages("devtools")
library(devtools)
devtools::install_github("hadley/lineprof")
```

lineprof presents some characteristics that make it unique: It is integrated in the RStudio environment using the **shiny** package, it provides memory profiling out of the box and finally, using the **shiny** environment it is possible to navigate across the different functions to find out the bottlenecks in the code. The application to the example is also straightforward:

```
library(lineprof)
x <- lineprof(compareMethods())
shine(x)
```

The resulting figure shows the output in the viewer pane in RStudio. The code for each function is shown there. The blue lines of code are hyperlinks to the corresponding functions. The last column represents the memory spent on each line of code. It can be seen that the creation of the 1000×500 matrix is the most expensive line of code in terms of memory use.

We experienced some minor issues when using **lineprof** that are worth mentioning. The representation in RStudio is a little bit buggy: The columns for each of the results (time spent, memory used, etc) are not properly shown. The navigation across the functions, although very intuitive, does not link directly to the RStudio editor to work on the code. Finally, when working on the **shiny** environment, the console appears to be busy and the user has to break it using Ctrl-C or Esc. We expect that most of these minor problems will be fixed in the stable release.

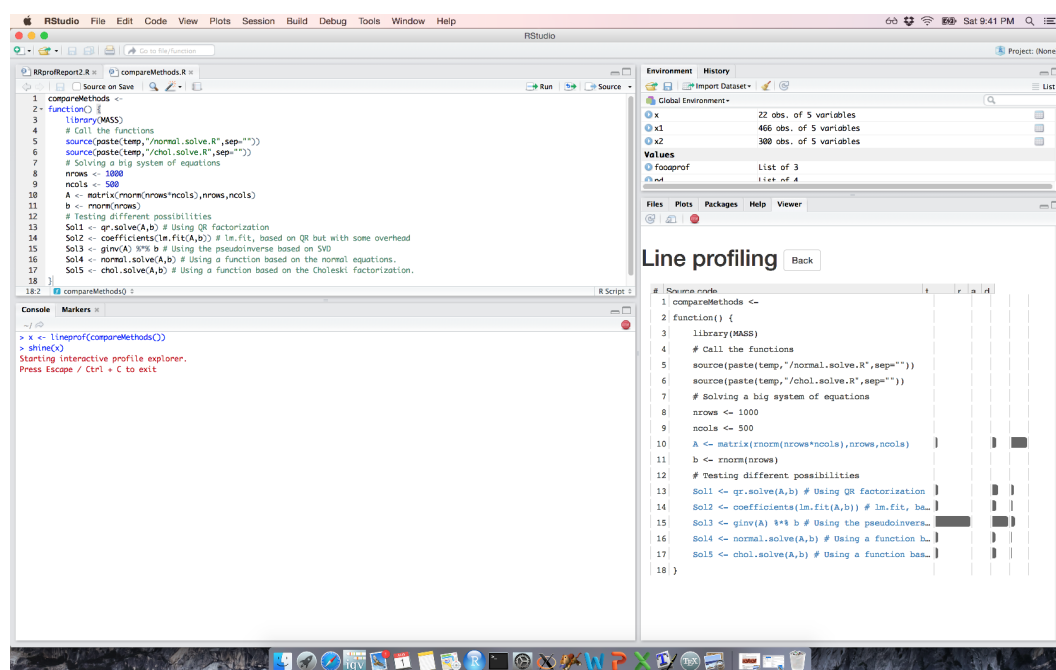


Figure 6: Output of lineprof.

Discussion and conclusion

This paper describes **GUIProfiler**, a graphical user interface to the line profiler provided by R and reviews, in relation to **GUIProfiler**, all other available profiling packages. Based on an example, we presented how to profile this code using the different packages and compared their advantages and disadvantages.

This review shows that, in spite of being far from the intuitiveness and user friendliness of the MATLAB profiler, the different developed tools are getting closer to it. For example, the graphical display of the relationship between functions in **proftools** is useful and intuitive and MATLAB does not provide anything like it. **lineprof** allows the navigation across the different functions very much like MATLAB's profiler does.

Regarding the described tools, **proftable**, **profr** and **proftools** are comparable. **proftable** provides an abstract on the time spent on each line of the code that is clearer and more useful than the one from **summaryRprof**. **profr** and **proftools** show graphically the relationships between the different profiled functions and the time spent on each of them. Unfortunately, neither of them provide profiling at the line level.

The other group is formed by **aprof**, **lineprof** and **GUIProfiler**. All of them provide similar information: time spent on each line of code stating the actual code of the line. There are also some differences among them. **aprof** shows these results using plots and provides estimates of the expected improvements when speeding up the most costly lines of code. **lineprof** displays these results using the **shiny** environment. Both **lineprof** and **aprof** provide memory profiling. **GUIProfiler**, on the other hand, builds an HTML report which is interactively linked with the program code. The preference between both tools may be a question of taste, but in our opinion, the HTML report is more advantageous.

We would like to note that there might be other characteristics which could be taken into account when evaluating a profiling tool such as those considered in this paper. For example, we assumed that graphical output is something desirable. However, this is not the case if the profiled code is run on a server with no graphical capabilities. In the case of **lineprof**, for example, a runtime environment is required to compile it as well as package **shiny** and several other dependencies. Although these dependencies are not of concern when R is run on a personal computer, they can be problematic if the software is running on a server.

GUIProfiler has a convenient characteristic that is missing in the other packages: It connects the profiling tool with an editor to fix the bottlenecks. In the RStudio environment the navigation across the markers pane directly opens the editor on the clicked line of code. If R is used outside of the RStudio environment, **GUIProfiler** opens Notepad++ when clicking on the number of the line. This functionality is browser dependent and, at present, it is only implemented for the Internet Explorer

(and thus the Windows OS) by using ActiveX controls. However, we assume that most of the users will use the RStudio environment where the connection with an external editor is not necessary. Finally we would like to emphasize that **GUIProfiler** is a useful tool that interactively and graphically helps the users in the difficult task of profiling.

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