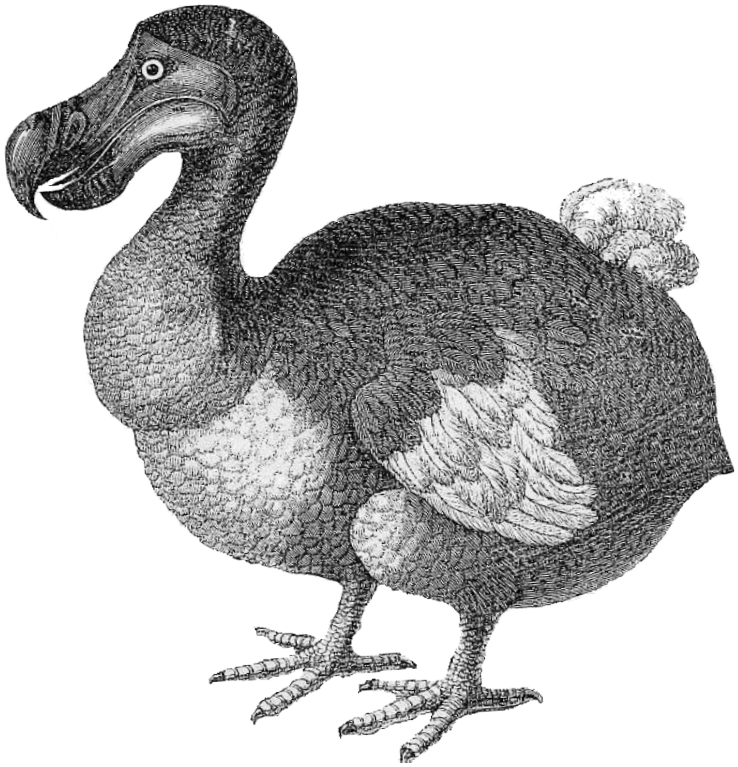
Version 1.1



Guide to the memuse Package

A Package for Estimating Memory Usage

Drew Schmidt

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Contents

1 Introduction

1.1 History

This package was born out of a ≈ 10 line function I wrote to estimate the memory usage of (non-allocated) in-core, dense R objects of numeric (double precision) data. I need this kind of thing for my work quite a bit, surprisingly, so it made sense to actually create this function instead of constantly doing ad hoc multiplications of $nrows \times ncols \times 8$ then dividing by powers of 1024 (or 1000 — more on this later).

But then I got the great idea to make this application ∼enterprise ready∼ by adding a lot of unnecessary and convoluted OOP. And so this stupid package was born. From this perspective, this intentional (unnecessary) over-engineering is a sort of a love letter to other needlessly complex programs, like the Enterprise Fizzbuzz[1].

1.2 Purpose

As hinted at in the above subsection, this package aids in the estimation of the memory usage of unallocated, dense, in-core, numeric objects; that's a very long-winded way of saying "matrices", but there you go. So why should you care about this package? Well, maybe you shouldn't; I'm not here to tell you what to do. But this is an impressively useful little package for my own work, and possibly yours too.

Aside from addressing uninteresting curiosities (e.g., *How much ram do I need to store a* $1,000,000 \times 1,000$ *matrix?* — answer: about 7.5GiB), it is very handy when benchmarking, especially if you are doing any kind of scaling study. To be a bit loose, *scalability* is the study of the performance of the implementation of a parallel algorithm. Most people are fairly familiar with the concept of *strong scalability*, even if they have never encountered the term before; this is where you try to capture how well your parallel algorithm is performing on a fixed total problem size, relative to the number of cores you throw at it. Good scaling makes a kind of $y = \frac{1}{x}$ kind of plot, but is usually converted into a speedup plot, which frankly I don't really want to get into. Look, I'm sorry I even brought it up, ok?

On the other hand, in a *weak scaling* study, you keep the *local* problem size (amount per processor) fixed and throw more cores at your method. This is a much less known way of measuring performance for the R community, but it is a very useful one, especially when you break $\approx 10,000$ cores; at that scale, strong scalability generally isn't possible for any remotely interesting task. The **memuse** package's methods `howbig()` and `howmany()` were designed with these two benchmarking tasks in mind.

In the remainder of the document, we will explore the **memuse** package, including how to install it, how to use it, and how it behaves with core R utilities. Additionally, in the oh-so-cleverly titled Section 3, we will talk more about storage units for memory sizes than is reasonable.

1.3 License

This package is libre software, or "free and open source", licensed under the GNU General Public License version ≥ 2 (see Figure 1 for full details). If you violate the terms of the GPL, Richard Stallman's beard will sue you in internet court.

[1] If you are unfamiliar with the fizzbuzz, see my posts "Honing your R skills for Job Interviews" and "The Fizzbuzz that Fortran Deserves".

Figure 1: The GNU GPL Explained

2 Installation

The package consists entirely of R code, so everything should install fine no matter which platform you use. You have several options for installation.

2.1 Installing from Source

The sourcecode for this package is available (and actively maintained) on GitHub. No binary is available from GitHub, only the source. To install this (or any other) package from source on Windows, you will need to first install the Rtools package. Rtools is not needed for Mac or Linux[2] platforms, and so **memuse** should install on them without problem.

The easiest way to install **memuse** from GitHub is via the **devtools** package by Hadley Wickham. With

[2]I'd just like to interject for a moment. What you're referring to as Linux, is in fact, GNU/Linux, or as I've recently taken to calling it, GNU plus Linux. Linux is not an operating system unto itself, but rather another free component of a fully functioning GNU system made useful by the GNU corelibs, shell utilities and vital system components comprising a full OS as defined by POSIX.

Many computer users run a modified version of the GNU system every day, without realizing it. Through a peculiar turn of events, the version of GNU which is widely used today is often called Linux, and many of its users are not aware that it is basically the GNU system, developed by the GNU Project.

There really is a Linux, and these people are using it, but it is just a part of the system they use. Linux is the kernel: the program in the system that allocates the machine's resources to the other programs that you run. The kernel is an essential part of an operating system, but useless by itself; it can only function in the context of a complete operating system. Linux is normally used in combination with the GNU operating system: the whole system is basically GNU with Linux added, or GNU/Linux. All the so-called Linux distributions are really distributions of GNU/Linux.

this package, you can effectively install packages from GitHub just as you would from the CRAN. To install **memuse** using **devtools**, simply issue the command:

```
library(devtools)
install_github(repo="memuse", username="wrathematics")
```

from R. Alternatively, you could download the sourcecode from github, unzip this archive, and issue the command:

```
R CMD INSTALL memuse-master
```

from your shell.

2.2 Installing from CRAN

I managed to trick the CRAN into letting this nonesense on their servers, so the installation amounts to issuing the command

```
install.packages("memuse")
```

from an R session. But you already knew that, didn't you? So why are you still reading this?

3 It Turns Out That Size Does Matter, and How You Are Using It Is Wrong

The core of the **memuse** package is the `memuse` class object. You can construct a `memuse` object via the `memuse()` or `mu()` constructor. The constructor has several options. You can pass the size of the object, the unit, the unit prefix (IEC or SI), and the unit names (short or long). The size is the number of bytes, scaled by some factor depending on the unit. The unit is an abstract rescaling unit, like percent, used for the sake of simple comprehension at larger scales; for example, kilobyte and kibibyte are the typical storage units to represent "roughly a thousand" bytes (more on this later). Finally, the unit names are for printing, i.e., controlling whether the long version (e.g., kilobyte) or short version (kB) is used. Table 1

IEC Prefix			SI Prefix		
Short	Long	Factor	Short	Long	Factor
B	byte	1	B	byte	1
KiB	kibibyte	2^{10}	kB	kilobyte	10^3
MiB	mebibyte	2^{20}	MB	megabyte	10^6
GiB	gibibyte	2^{30}	GB	gigabyte	10^9
TiB	tebibyte	2^{40}	TB	terabyte	10^{12}
PiB	pebibyte	2^{50}	PB	petabyte	10^{15}
EiB	exbibyte	2^{60}	EB	exabyte	10^{18}
ZiB	zebibyte	2^{70}	ZB	zettabyte	10^{21}
YiB	yobibyte	2^{80}	YB	yottabyte	10^{24}

Table 1: Units, Unit Prefices, and Scaling Factors for Byte Storage

gives a complete list of the different units for the different prefices.

So for example, 1 kilobyte (kB) is equal to 1000 bytes, but 1 kibibyte (KiB) is equal to 1024 bytes. And so 1 kB is roughly 0.977 KiB.

There is a great deal of ambiguity in the public regarding the meaning of these terms. People, even those who know the difference (myself included) almost overwhelmingly use, for example, gigabyte when they mean gibibyte. The reason for this is obvious; "gibibyte" sounds fucking stupid. This actually gets all the more confusing because in addition to many conflating — intentionally or otherwise — 1 megabyte (MB) with 1 mebibyte (MiB), internet service providers advertise their bandwidth speeds in terms of *bits*[3] instead of bytes *using the same goddamn symbols*. So for example, when an ISP reports "15 MB" bandwidth speeds, they are actually offering 5 megabit, or 1.875 megabytes (MB), which is 1.788 mebibytes (MiB). They do this because they're huge assholes.

Another example of this confusion is when people talk about ∼big data∼. Often I/O people will use the term "terabytes" or "exabytes" and mean it, even though many file-on-disk-size reporting utilities (such as `du`) use the IEC prefix. Rescaling reported SI units into IEC units — the ones people are generally more familiar with — is simple with the `memuse` package:

```
> swap.prefix(mu(size=1, unit="tb", unit.prefix="SI"))
0.909 TiB
> swap.prefix(mu(size=1, unit="pb", unit.prefix="SI"))
0.888 PiB
```

These sizes represent an impressive amount of data, but this ambiguity in naming conventions allows people to lie a bit. For all of these reasons, since the package is meant to be useful for understanding R object size, the default behavior is somewhat complicated, but can be summarized as trying to provide what most people meant in the first place. We achieve this by offering several default string objects which the user can easily control. These units are `.UNIT`, `.PREFIX`, and `.NAMES`.

In the sections to follow, we will further examine the above **memuse** functions, as well as the other utilities the package offers.

4 Using the memuse Package

The following sections demonstrate the ways in which the user is meant to interact with the **memuse** package. Hence the title.

4.1 Constructing memuse Objects

The `memuse` object is an S4 class object, which is a high-falootin way of saying it's a data structure with specialized interpreted context. Think of it like a list whose elements are always the same. The specification is:

$$\text{memuse} = \begin{cases} \text{size} \\ \text{unit} \\ \text{unit.prefix} \\ \text{unit.names} \end{cases}$$

[3] 1 byte is 8 bits

This object has a prototype, sanity checking, and all kinds of other boring crap no one cares about. What's important is how to use this thing.

To construct a `memuse` object, you can use the `memuse()` or `mu()` constructors. These functions behave identically; `memuse()` exists because I generally find it inappropriate to not have an object constructor of the same name as the object, and `mu()` exists because if I have to type more than 5 characters, I'm completely furious. I'm looking at you, `suppressPackageStartupMessages()`...

Precedence is given to `unit.prefix=` over `unit=` in the constructor. So for example, `mu(10, "mb", unit.prefix="IEC")` will return `10.000 MiB`. The assumption is that you either do not know or do not care about the distinction between IEC and SI unit prefices, but are probably more familiar with IEC.

4.2 Default Parameters

So as you might have guessed from Section 3, the `memuse` object's constructor is full of options you will never use. In the constructor, the argument `size=` is a required argument with no default. However, the constructors invoke the default parameters `.UNIT`, `.PREFIX`, and `.NAMES`. These are default data values loaded into the package. They are, respectively, `"best"`, `"IEC"`, and `"short"`. To change a package default, for example `"IEC"` to `"SI"`, simply execute:

```
.PREFIX <- "SI"
```

And from then on, the constructor will use SI units by default. This, and all other string values, are case insensitive, in the sense that the correct case will be determined for the user, regardless of the input. Similarly, the choices for `.NAMES` are `"short"` and `"long"`, and are again case insensitive.

On the other hand, `.UNIT` is slightly different. This defaults to `"best"` and like the weird guy at work, should probably just be left alone. Functions that need to know an input unit, such as the constructor `mu()`, have default argument `unit=.UNIT`. Realistically, you are probably better off modifying that argument as necessary than changing `.UNIT`. For example, you want to construct a 100 KiB `memuse` object, you probably just want to call

```
mu(100, "KiB")
```

This is equivalent to calling

```
mu(102400)
```

since the default `.UNIT=best` will make the choice to switch the units from b to KiB once you breach 1024 bytes. This sounds a lot more confusing than it really is.

4.3 Methods

Aside from the constructor, you have already seen one very useful method: `swap.prefix()`. In addition to these, we have several other obvious methods, such as `swap.unit()`, `swap.names()`, `print()`, `show()`, etc. But we also have some simple arithmetic, namely `'+'` (addition), `'*'` (multiplication), and `'^'` (exponentiation). So for example:

```
> mu(100) + mu(200)
300.000 B
> mu(100) * mu(200) # 100*200/1024
19.531 KiB
```

Other arithmetic of memuse objects is available, including division, as well as

Finally, we have the methods that inspired the creation of this entire dumb thing in the first place: `howbig()` and `howmany()`. The former takes in the dimensions of a matrix (`nrow` rows and `ncol` columns) and returns the memory usage (as the package namesake would imply) of the object. So for example, if you wanted to perform a principal components decomposition on a 100,000 by 100,000 matrix via SVD (as we have), then you would need:

```
> howbig(100000, 100000)
74.506 GiB
```

Of ram just to store the data. Another interesting anecdote about this sized matrix is that we were able to generate it in just over a tenth of a second. Pretty cool, eh?

As mentioned before, there is also the `howmany()` method which does somewhat the reverse of `howbig()`. Here you pass a `memuse` object and get a matrix size out. You can pass (exactly) one argument `nrow` or `ncol` in addition to the `memuse` object; the method will determine the maximum possible size of the outlying dimension in the obvious way. If no additional argument is passed, then the largest square matrix dimensions will be returned.

4.4 Package Demos

In addition to all of the above, the **memuse** package includes several demos. You can execute them via the command:

List of Demos

```
### (Use Rscript.exe for windows systems)

# Basic construction/use of memuse objects
Rscript -e "demo(demo, package='memuse', ask=F, echo=F)"
# Arithmetic
Rscript -e "demo(demo2, package='memuse', ask=F, echo=F)"
# howbig/howmany examples
Rscript -e "demo(demo3, package='memuse', ask=F, echo=F)"
```

5 Other

5.1 Comparison to `object.size()`

R contains a handy tool for telling you how big an already allocated object is, namely the `object.size()` function from the `utils` package. The functions in this package are essentially an extension of that function for unallocated, dense objects, provided your objects are numeric (more on this later).

So say we have the vector `x <- 1.0`. This should be using 8 bytes to store that `1.0` as a double, right? Well...

```
1 > object.size(1.0)
2 48 bytes
```

So where is all that extra space coming from? Simply put, R objects are more than just their data. They contain a great deal of very useful metadata, which is where all the nice abstraction comes from. Whenever you create a vector, R keeps track of, for example, its length. If you do not appreciate this convenience, go learn C and then get back to me.

For vectors, this overhead is 40 bytes, regardless of the type of data. Matrices, unsurprisingly cost more, clocking in at 200 bytes overhead. It is worth noting that this overhead does not scale; it is on a per-object basis. So we don't need 40 bytes for each element of a vector when just 8 would do (in the case of double precision values). We need 40 plus 8 per element:

```
> # 2 elements
> 40+8*2
[1] 56
> object.size(rnorm(2))
56 bytes
> # 100.000 elements
> 40+1e5*8
[1] 800040
‘> object.size(rnorm(1e5))
800040 bytes
```

The story is slightly more complicated for integer data (and a lot more complicated for strings; see the following section). On my machine (and probably yours, but not necessarily), `int`s costs 4 bytes. However, R does some aggressive allocation:

```
> object.size(1L:3L)
56 bytes
> object.size(1L:4L)
56 bytes
```

Here we see R allocating more bytes than it needs for integer vectors sometimes, choosing to allocate in 16 byte chunks rather than 8 byte chunks.

The **memuse** package does not adjust for this overhead, because it honestly just doesn't matter. This overhead is really paltry, and when you think about all the abstraction it buys you, it's a hell of a bargain. If you have a million R objects stored, you're wasting less than one MiB (1024^2 bytes); so you would need a billion objects to use just about a GiB (1024^3 bytes) on overhead. And if you're doing that kind of silly shit, my advice would be to learn how to properly use data structures.

All that said, the **memuse** package actually overwrites the default behavior of `object.size()`. By default, the return is an object of class `object_size`, which is a not-so-useful S3 class provided by core R. Once you load **memuse**, the return for the `object.size()` function will automatically be cast as a `memuse` object. So in reality, if you execute the code from the example above, you will actually get:

```
> object.size(rnorm(1e5))
781.289 KiB
```

The output at the top of this subsection is the output from `utils::object.size()`.

5.2 Strings

String objects have been avoided up until this point because they are much more difficult to describe in general, unless they have a great deal of regularity imposed on them. In R, strings by default are

allocated to use 56 bytes (not counting overhead), unless they need more. I'm not sure why this value was chosen, but 56 byte strings will allow for the storage of 7 chars (like `a` but not `aa`). Each char costs 1 byte, so there's some fat overhead for the strings here, and almost certainly an additional byte held out for the null terminator. So for example, recall that a vector allocates 40 bytes of overhead, so the vector string `letters` should use $56 \times 26 + 40$ bytes. We can easily verify that this is the case:

```
> 56*26+40
[1] 1496
> object.size(letters)
1496 bytes
```

If you have a string with more than 7 chars, R will allocate extra space in 8-16 byte blocks. After the initial 8 byte allocation (7 chars + null terminator), if you need more you get an additional 8 bytes (in reality this is probably a contiguous 16 byte allocation; I have not bothered to check). Beyond that, storage is allocate in 16 byte blocks for each string. For example:

```
>  object.size(c(paste(rep("a", 7), collapse=""), "a"))
152 bytes
>  object.size(c(paste(rep("a", 7+1), collapse=""), "a"))
160 bytes
>  object.size(c(paste(rep("a", 7+8+1), collapse=""), "a"))
176 bytes
>  object.size(c(paste(rep("a", 7+8+16+1), collapse=""), "a"))
192 bytes
```

If you have a vector of strings with them of varying lengths, the allocation of individual elements is handled on a case-by-case basis. Consider the following:

```
> object.size(c(paste(rep("a", 7+8+16+1), collapse=""), "a"))
192 bytes
```

This object (the vector of 2 elements with first element "aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa" and second element "a") is using 40 bytes for the vector, $56 + 8 + 16 + 16$ bytes for the first element, and 56 bytes for the second.

For all of these reasons, and given the fact that I almost never (ever) deal with character data, I have not bothered to make any attempt to extend, for example, `howmany()` or `howbig()`, to incorporate strings. Deal with it, nerd.