

A computational evaluation of some free mathematical software for scientific computing

^aThemistoklis Glavelis, ^aNikolaos Ploskas, ^{a*}Nikolaos Samaras

^a*Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece*

Abstract

The purpose of this paper is to present a computational comparison of some well-known free mathematical programs. Specifically, these programs are FreeMat, Mathnium, Octave, R and Scilab. All these programs are designed in order to be used either in the scientific community or the industry. Moreover, an additional aim of this paper is to propose open source alternative software which can replace commercial mathematical software. Several issues concerning available operating system platforms, data structures, languages' structure, matrix operations, program modularization, libraries, packages, profiling tools and online help facilities are addressed in this paper. Discussions on their weaknesses and strengths characteristics are presented. Finally, a speed comparison of some frequently used algorithms, procedures and operations within software is also presented.

Key words: Scientific Computing, Computational Comparison, Free Software, Mathematical Software.

* Corresponding Author. Address: 156 Egnatia Str., 54006 Thessaloniki, Greece, Tel: +302310891866, Fax: +302310891879.
Email addresses: (glavelis, ploskas, samaras)@uom.gr (Themistoklis Glavelis, Nikolaos Ploskas, Nikolaos Samaras).

1 Introduction

The aim of this paper is to carry out a computational comparison of some very popular free mathematical software. There exist several hundreds of such programs which are more or less related to mathematics and statistics. These programs are interactive and offer a vast range of mathematical and statistical functions and libraries. The main advantage of these scientific computing environments is their ability to manipulate simple or sophisticated mathematical expressions and to provide concise syntax for matrix operations. Apart from that, another significant issue is the fact that these software programs can be a great choice for beginner programmers because integrate numerical analysis, matrix computation, and specialized functions in an ease-to-use graphical environment.

All reviewed programs are free software and the users do not have to concern about the cost or their permission license. There is a subtle distinction between the definition of “free software” and “open source software”. Free software is a matter of the users’ freedom to run, copy change and distribute the software. Roughly speaking, open source software is a subset of free software. The software that is compared in this paper can be categorized in two groups. The first category is the open source software where the users are able to enhance and adapt the source code according to their demands. On the other hand, there is the freely available software which permits only the free usage of them and they do not permit the access to their source code. FreeMat [16], Octave [18] and R [15] belong to the first category, while Mathnium [19] and Scilab [17] belong to the second one.

During the last decade, the number of users of open source software increases every year. Open source software is a new attitude in computer science community. More and more scientists and software engineers prefer open source software because they are able to adjust it to their needs. Moreover, the last years a number of open source mathematical programming software have introduced. Consequently, the strengths and weaknesses of these mathematical programming languages are of great value for potential users. Furthermore, users of commercial mathematical languages are able to compare their abilities with those of open source and decide if they will choose an open source alternative solution.

Principles for modern software environments to computer algebra systems can be found in [2]. There have been some reviews of mathematical systems [5], [7] and [11] but they refer only to commercial programs, such as Matlab, Mathematica and Maple. In this paper we review the main features of the recent versions of FreeMat (version 3.6), Mathnium (version 1.051), Octave (version 3.0.3), R (version 2.8.0) and Scilab (version 5.0.2). Also, we have made computational experiments to compare the practical efficiency of these software programs.

This paper refers to amateur users but also to more experienced users. Consequently, the structure of the paper is chosen in order to introduce an amateur to mathematical programming at the same time of analyzing some more specific issues like parallel programming for experienced users. Furthermore, the sections of this paper include all the appropriate information that a scientist or a software engineer needs to dispose in order to decide which software is better for him.

An outline of the rest of the paper is as follows. In section 2, a general description of all the reviewed software is presented and in section 3, there are details about the data structures of these programs. Furthermore, in section 4 there is useful information referring to the programs modularization and in section 5 there is a general description of the programming style in these languages. Moreover, in section 6 there is a presentation of the libraries and packages of each software and in section 7, the functionality of the programming environments (debugging and profiling tools) is described. In section 8, there are information about the help-facilities and the available documentation. A speed comparison of some frequently used procedures within mathematical models is described in section 9. Finally, in section 10 the final conclusions are presented.

2 General Description

FreeMat is an interpreted, matrix-oriented development environment for engineering and scientific applications, similar to the commercial package Matlab. It provides visualization, solving numerical problems and image manipulation, as well as plotting.

Mathnium is a program for interactive numerical computations. In addition, Mathnium can be a great choice for beginner programmers. Due to its vast range of functions and libraries, Mathnium can be an ideal choice for solving numerical problems or manipulating complex arithmetic expressions without a great deal of programming effort. It is well known that Mathnium is written in Java. Consequently, it provides convenient language constructs which enable users to use their own existing Java classes without additional programming. As a result, very large number of existing libraries of Java classes can be very easily used within the Mathnium environment. Except for that, Mathnium offers another useful utility; within the Mathnium environment users are able to execute Matlab codes.

GNU Octave is a high-level language, mainly intended for numerical computations. It uses a language that is mostly compatible with Matlab. It may also be used as a batch-oriented language. Furthermore, Octave includes a large range of tools for manipulating problems referring to linear algebra, finding the roots of linear and nonlinear equations, integrating ordinary functions and ordinary differential equations. Another significant issue is the fact that Octave is easily extensible and customizable according to the demands of users.

R is an interpreted computer language and environment mainly for statistical computing, data analysis and graphics. It is a GNU project and is similar to the commercial Splus language. There are some important differences between these two software but almost every code written for Splus [22] runs unaltered under R language, because both they are based on S language. Moreover, R provides a wide variety of statistical utilities like linear and nonlinear modeling, classical statistical tests, time-series analysis, classification and many others. In addition R provides users with a large range of graphical techniques. Furthermore, R is highly extensible. The S language is often the vehicle of choice for research in statistical methodology, and R provides an Open Source route to participate in that activity.

Scilab is a software package providing a powerful computing environment for engineering and scientific applications. Scilab comes with a large range of functions, libraries and toolboxes. These libraries refer to 2-D and 3-D graphics, animation, linear algebra, sparse matrices, polynomials and rational functions, classic and robust control, differentiable and non-differentiable optimization, signal processing and statistics.

3. Data Structures

The matrix is a standard data type in FreeMat. The cell array is a fairly powerful array type that is available also in FreeMat. Roughly speaking, a cell array is a heterogeneous array type, meaning that different elements in the array can contain variables of different types (including other cell arrays). FreeMat supports a string array type that operates very much as user would expect. Strings are stored internally as 8-bit values, and are very similar to numerical arrays in all respects. FreeMat also supports global and persistent variables.

Numbers, numeric arrays, strings, structures, and cells are the basic data types in Mathnium. Mathnium strings are arrays of characters. Consequently, users are able to use all the matrix functions for strings as well. Mathnium also has a facility for the definition of derived data types as classes; this feature stems from the fact that Mathnium is implemented in Java.

The standard built-in data types in Octave are real and complex scalars and matrices, ranges, character strings, a data structure type, and cell arrays. Octave stores all numbers in IEEE floating point format to double (64-bit) precision. Matrix objects can be of any size, and can be dynamically reshaped and resized. Since a string is just a matrix, simple manipulations can be accomplished using standard matrix operators.

R software can support either homogeneous structures or structures with a mixture of data types. In homogeneous structures all data must be of the same type like vectors, factors, matrices and arrays. On the other hand, there are other structures with a mixture of modes like data frames, time series data and lists. In this category, several modes are allowed in

one object. For example, users are able to store numbers, characters, expressions and strings in a single object.

Scilab recognizes several data types. Scalar objects are constants, booleans, polynomials, strings and rational. Other basic objects are lists, typed-lists and functions. The list data type can be a collection of data objects not necessarily of the same type. Scilab considers a number of data objects as matrices like scalars and vectors. Furthermore, Scilab supports matrices of character strings which are constructed as ordinary matrices. Furthermore, symbolic manipulation of mathematical objects can be implemented by using matrices of character strings.

As it is shown in Table 1, all software supports the most common data types. Each software implements the sparse matrix data type, but FreeMat and Scilab support more functions for handling them. Only in Mathnium can be defined classes that extend Java classes.

4. Program Modularization

A script is a sequence of FreeMat commands contained in a file with extension .m. When the script is called the effect is the same as if the commands inside the script file were called one at a time from the keyboard. Unlike function files (which have the same extension, but have a function declaration), script files share the same environment as their callers. Hence, assignments made inside a script are visible to the caller which is not the case for functions. Unlike many other programming languages, FreeMat allows users to define functions that can take a variable number of input arguments. It is also possible to return a variable number of output arguments. Mathnium allows the user to define functions to organize their work with a variable number of inputs and output arguments. Moreover, inline functions can be declared in Mathnium that is convenient for defining simple functions, especially for calling functions that require a function as an argument. Furthermore, methods of Java classes in the class path can be easily imported as functions.

Complicated Octave programs can often be simplified by defining functions. Functions can be defined directly on the command line during interactive Octave sessions, or in external files (script files), and can be called just like built-in functions. A script file is a file containing (almost) any sequence of Octave commands. Octave like FreeMat can handle functions that take or return variable input or output arguments.

The R language allows the user to create objects of mode function. These are true R functions that are stored in a special internal form and may be used in further expressions and so on. In the process, the language gains enormously in power, convenience and elegance, and learning to write useful functions is one of the main ways to make your use of R comfortable and productive. R also can handle external script files. Functions are Scilab procedures ("macro", "function" and "procedure"

have the same meaning). Usually, they are defined in files with Scilab's editor and loaded into Scilab.

5. Programming Language Constructs

In this section, a general review of the programming capabilities is presented. The issues that this section will focus on are: object oriented programming, dynamic allocation of memory, sparse matrices and parallel computations.

Object-oriented programming is a style of programming that has become very popular in recent years. Much of the popularity comes from the fact that it is easier to write and maintain complicated systems with object-oriented programming. All reviewed software, except Octave, support object-oriented programming. Mathnium is written in Java and provides very simple mechanisms for using and extending existing Java classes, and implementing Java interfaces. R possesses a simple generic function mechanism which can be used for an object-oriented style of programming. FreeMat and Scilab also offer functions to write object oriented programs without demanding much programming effort.

FreeMat also supports fully the model of dynamic programming. FreeMat is able to handle pointers with the same way as the C language does. The only thing that users should be careful is to avoid problems with memory allocation; functions are not allowed to return pointers. As a general operating mechanism, the FreeMat code must allocate the proper arrays, and then pass them by reference to the functions. Like other languages, R allows the use of pointers in order to gain some extra bytes of memory. In order to be available the utilities and functions about dynamical allocation of memory, users must load an extra library to R software, named *Rindex*. Similar to FreeMat, Scilab is able to create and manipulate pointers and indices in order to constrain the waste of memory. Moreover, Scilab supports pointers to any kind of type, from integers and strings to data structures.

There are many classes of mathematical problems which give rise to matrices, where a large number of the elements are zero. In this case it makes sense to have a special matrix type to handle this class of problems where only the non-zero elements of the matrix are stored. Not only does this reduce the amount of memory to store the matrix, but it also means that operations on this type of matrix can take advantage of the a-priori knowledge of the positions of the non-zero elements to accelerate their calculations. A matrix type that stores only the non-zero elements is generally called sparse. All the above languages support creation and handling of sparse matrices with a selected density.

Nowadays, there are cases where the effectiveness of classical programming languages is not satisfactory with regard to the execution time. A growing number of real-world problems demand parallel computing capabilities. It is well-known that parallelization can lead to important reduction in total computational time. All reviewed software,

except Mathnium, support parallel programming. FreeMat implements parallel processing with MPI (Message Passing Interface). FreeMat is able to take full advantage of the benefits of MPI. Nowadays, multicore machines are everywhere. In this case, FreeMat offers an alternative, the OpenMP technique. Octave like FreeMat is able of running parallel its codes. Octave users in a cluster with several PCs can use the MPI toolbox in order to call MPI library routines.

Although R software is a programming tool which is used mainly by statisticians and econometricians, users have the possibility to execute their codes in parallel. In many cases, for example in time series, the amount of data is prohibitive for a single processor. R uses an MPI library in order to support this service. Consequently, users should load two extra packages, “Rmpi” and “taskPR” libraries. With these two packages users will be able to exploit all the advantages of parallel programming through R software. Like the other software, Scilab provides users with the opportunity to execute their programs in parallel. Similar to the previous cases, Scilab demands an MPI library. In contrast to other software, Scilab supports a generic interface to Grid computing. Through this interface users can execute and monitor their codes during the execution phase. Moreover, they are able to extract very useful information about the execution time like which processor has the biggest delay and which part of the code is executed in each computer. Moreover, if something goes wrong users can be aware very fast and easy of which machine has crashed.

As it is presented in Table 2, Freemat, R and Scilab are the most powerful tools referring to the language constructs that discussed in this section. Mathnium has a facility for the definition of derived data types as classes, but it doesn’t support dynamic allocation of memory and parallel programming. Octave has powerful tools for parallel programming, but it doesn’t allocate memory dynamic.

6. Libraries

This section covers one of the most significant issues in this paper. All reviewed programs have a big range of built-in mathematical functions. Their use is not constrained only to mathematics but it is spread into many scientific fields, like statistics and econometrics. In this section, we will review the strengths and weaknesses of these five programming languages in terms of their available functions and libraries.

FreeMat is designed to implement numerical algorithms for a wide range of applications. It supports functions of a wide variety of fields, like mathematics and statistics. It provides visualization and image manipulation. Furthermore, it supports many options for plotting. Moreover, FreeMat has functions for import / export utilities, like reading from XML or HTML files, but doesn’t include database connectivity. One other capability of FreeMat, that underlines its’ compatibility with Matlab, is the manipulation of heterogeneous array types and dynamic structure

arrays. Finally, FreeMat provides codeless interface to external C / C++ / FORTRAN code.

Mathnium is a program for interactive numerical computations. It has a comprehensive library of functions for a variety of problems in applied mathematics. Mathnium allows users to solve numerical problems without a great deal of programming effort. Although it is not a general purpose language, users can also extend the capabilities of Mathnium by using it as a programming language. The current version of Mathnium contains about four hundred functions for various tasks, but still, comparing to other reviewed software, requires more features to be implemented in the future.

Octave's primary scope is to be full compatible with Matlab. Octave has extensive tools for solving common numerical linear algebra problems, finding the roots of nonlinear equations, integrating ordinary functions, manipulating polynomials, and integrating ordinary differential and differential-algebraic equations. It is easily extensible and customizable via user-defined functions written in Octave's own language, or using dynamically loaded modules written in C++, C, Fortran, or other languages.

R is a language and environment for statistical computing and graphics. R provides a wide variety of statistical (linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering, etc.) and graphical techniques, and is highly extensible. Also provides database connectivity and a variety of functions for import / export utilities, like import from other commercial statistical packages (SPSS, S-PLUS, etc.). The capabilities of R are extended through user-submitted packages, which allow specialized statistical techniques as well as graphical devices.

Scilab supports a large amount of functions in the fields of standard mathematics, Linear Algebra and Numerical Analysis. Moreover, Scilab supports a large number of functions referring to statistics, stochastic statistics and distributions, although that this is not its strong feature. Scilab has built-in support for linear algebra (customized LAPACK), linear programming, constrained quadratic and non-linear programming, data exchange with Matlab, optimal control and signal processing. In addition to the built-in functions there are a few packages, written by Scilab users, that are available free of charge from the Internet. Furthermore, Scilab supports many functions for import / export utilities. Graphs are also very impressive. A number of readily available tools allow the users to take full advantage of their work, including copying of graphs to clipboard or printing to postscript.

7. Functionality of the programming environment (debugging and profilers)

This section covers some special features of the programming environment of these languages, like debugging and profiling. Moreover,

this section attempts to review the available facilities that these software offer to simplify the programming effort.

FreeMat provides a debugging functionality that allows users to examine where the error occurred. FreeMat has a quite simple profiler where only functions and scripts are profiled. Relatively with the programming environment, FreeMat offers a clean and functional environment. It also supports a simple editor with highlighting capabilities and multiple tabs.

Mathnium uses only a command line interface. The fact that Mathnium does not support a graphical interface is one of its' real weaknesses. Mathnium provides some basic options for debugging errors, but it does not have a profiling utility.

The latest version of Octave provides a quite simple graphical environment with a built-in editor. There are some other interesting external front-end for Octave, like kOctave [20] and QtOctave [21]. Octave may also be used as a batch-oriented language. In addition, JHandles package provides some basic features for GUI programming, but it's far from a complete version. Furthermore, Octave supports easy debugging, but hasn't implemented yet a profiler. Finally, it is also possible to execute Octave code directly in a C++ program.

R provides a functional graphical user interface. However, its' incorporating editor is only a text pad and does not offer any utility, like syntax highlighting. Due to its S heritage, R has stronger object-oriented programming facilities than most other statistical computing languages. Finally, R provides a variety of functions for debugging errors and profiling functions and scripts.

Scilab has a simple and practical graphical user interface with a powerful and rich in options built-in editor that supports syntax highlighting, command completion and insertion of breakpoints. Among other features Scilab's graphical user interface provides a tool to translate Matlab scripts to Scilab compatible files. In addition, it supports many debugging and profiling utilities. Last but not least, Scilab is the only of the reviewed languages that allows the user to create a complete graphical user interface.

As it is shown in Table 3, Freemmat provides a debugger, but its profiler is very simple. Mathnium weaknesses are the lack of a graphical user interface and profiler. Octave provides easy debugging, but doesn't include a profiler. R provides a variety of functions for debugging errors and profiling functions and scripts, but his editor does not offer common utilities, like syntax highlighting. Finally, Scilab is the only software that allows users to create a graphical user interface and its' editor supports syntax highlighting, command completion and insertion of breakpoints.

8. Help facilities and documentation

FreeMat comes with a solid documentation. The manual is well written and easy to follow. FreeMat's help environment is very useful and provides searching index. FreeMat provides many examples that help users to find out the syntax and scope of various functions. The website of FreeMat contains documentation links and frequently asked questions. Mathnium provides neither a separate help environment nor a reference manual. Users can search for help in its website where a full list of all Mathnium functions is presented. There are also some examples explaining the key features of the programming language. Octave is shipped with a well-written manual. The help - environment in Octave is not user-friendly and does not provide useful operations like searching. John Eaton, Octave's creator, maintains a website, which provides useful information and many documentation links. Moreover, there exists a mailing list. There are only a few texts referring to Octave [4], [8] and [10].

R comes with a reference manual as well as several brochures describing special features like data import / export functions. R help environment provides searching for functions, but the majority of documentation files are cited in the website of the project. The number of texts which describes R is large. The most recent of them are [3], [6], [12], [13] and [14]. R maintains a commented list of books on its web-site. The help environment in Scilab is very usable and easy-to-handle. Scilab provides plenty of examples in question. Searching through help files is straightforward with the `apropos` command. Many examples of command usage can also be obtained by running commands with empty argument lists. Scilab maintains a website where someone can find useful information and links. Moreover, there are a few texts that describe Scilab [1] and [9].

As it is shown in Table 4, Freemat, R and Scilab provide all the appropriate help facilities that a user needs. On the other hand, Mathnium has only an online documentation that makes it difficult to users to find easily the information that they want. Finally, Octave lacks of a searching index in its environment and its website doesn't offer an online documentation.

9. Computational Evaluation

In order to gain an insight into the practical behavior of each one of the reviewed software, some computational experiments are performed. The computational comparison has been performed on an Intel Pentium IV processor with 3.4 GHz and 1 GB RAM running under Windows XP Professional SP3. The reported CPU times were measured in seconds. The speed comparison tests 40 functions which are very often used within mathematical models and not only. Test set problems are categorized into

five groups: miscellaneous operations, matrix operations, basic algebra, advanced algebra and statistics. The results given in Table 5 show the average times of 10 executions. All runs were made as a batch job. The 'winning' time for each test is given in bold.

The computation evaluation includes a large number of tests which refer to a vast range of research areas. The functions which have been used in speed comparison are the built-in functions of each software. Also it is necessary to mention that neither the functions have been optimized nor a specific compilation has been made. The paper does not target on the algorithms which have been used in each function. In contrast, it focuses on the performance because users mainly care about that.

The software's performance for each test has been calculated using the relation

$$\frac{BT < software >_k}{T < software >_i} \times 100, i = 1, 2, \dots, 5, i \neq k$$

where $BT < software >_k$ is the best timing result for a specific test, run by all five programs and $T < software >_i$ is the timing result of the software i , $i \neq k$ for the same test. The best timing is then set equal to 100%. To calculate the overall performance for each software, we add the percentage values for every test and divide it by the total number of tests. Finally, the largest percentage corresponds to the best overall performance. Functions which are not supported by a program, (denoted by the mark '-'), have not been judged in these calculations and have therefore no influence on the overall timing result.

Below in this section, there are some figures extracted from the speed comparison. There are presented six figures, one for each group of tests as they are shown in the Table 5 and one for the average and overall performance. The time in the y-axis in the figures below is in logarithmic scale, so the time is multiplied by an appropriate number in each case because the logarithm of a number less than 1 is negative.

In Figure 1, some miscellaneous operations is presented like loop test, sorting a vector, factorial of a big integer, plotting etc. All the times in this group have been multiplied by 1000. In this section, Octave has the best performance at execution time, as it is shown in Figure 6. On the other hand, Mathnium is the slowest software. Moreover, R performance is closest to the Octave execution time and at last the results of the rest two programs are not quite satisfactory.

In Figure 2, there is the performance of all software at the section of matrix operations. All the times in this group have been multiplied by 1000. In this section, Scilab is the "winner" of this comparison, as it is shown in Figure 6. On the other hand, Mathnium has the worst execution time and it differs a lot from the execution time of the rest software. It is remarkable the fact that Mathnium has the worst performance at the half of the tests in this group. Another significant issue is the performance of FreeMat which has the second worst execution time. Moreover, Octave

and R software are close to each other and both are quite fast in this section.

In Figure 3, some basic algebra operations are presented like the inverse of a matrix, eigenvalues and eigenvectors etc. All the times in this group have been multiplied by 10. In this section, the best performance belongs to R software in contrast to the previous parts. Mathnium has the worst execution time. Furthermore, Mathnium has the largest delay in 4 out of 7 tests. Moreover, FreeMat and Scilab are very close to the R performance and Octave is following as it is shown in figure 6.

In Figure 4, there is the performance of all software at the section of advanced algebra operations. All the times in this group have been multiplied by 1000. In this section, Scilab is the "winner" of this comparison, as it is shown in Figure 6. The remarkable in this section is that Scilab is the "winner" but the execution time of Scilab and R do not differ in many aspects. On the other hand, Mathnium has again the worst execution time but in this case its time is closer to the other software and more specifically Mathnium is closest to Octave's performance. FreeMat is a bit faster than these two software.

In Figure 5, there is the performance of all reviewed programs at the section of statistics. All the times in this group have been multiplied again by 1000. According to Figure 6, Mathnium has the worst performance and FreeMat computes faster these statistics tests. For the rest software, Scilab has the shortest time after FreeMat and R follows. Octave has the second worst execution time.

In the last figure, the average performance of all the group tests for all the reviewed software is presented. It is obvious; the fact that Mathnium has the worst performance in all sections and as a result it is the last in the final order. On the other hand, Scilab and R software are very close to each other and the final "winner" is Scilab but with a very short difference. This short difference between these two programs can lead us to the conclusion that Scilab and R are equivalent. With another set of data the results may be different, with the R at the first place and Scilab following. In addition, at the third place comes the FreeMat software and Octave has the second worst performance. It is significant the fact that FreeMat is close to the performance of R and Scilab. Apart from the fact that Octave has the second worst performance, Octave has the most adequate libraries as well as Scilab. This conclusion stems from the fact that these two programs participate in all tests of the present paper.

10. Conclusions

The choice of mathematical software is a difficult task. FreeMat, Mathnium, Octave, R and Scilab are easy-to-use languages which allow a fast implementation and prototyping of mathematical and statistical algorithms. Despite their strong similarities, there are substantial differences between these matrix programming languages. They differ

from each other in terms of usability, richness and finally in term of performance.

FreeMat is a free environment for rapid engineering and scientific prototyping and data processing. It is similar to commercial systems such as Matlab from Mathworks, and IDL from Research Systems, but is Open Source. FreeMat offers a clean and functional environment with a user-friendly editor. Although FreeMat misses some functions and especially functions in statistics, its execution time in this area are very satisfactory.

Mathnium is a program for interactive numerical computations and it is inspired by Matlab. It is written in Java, and it provides convenient language constructs which do not require from user to actually write formal Java programs in order to use existing Java classes. Mathnium uses only a command line interface. The lack of a graphical user interface and documentation resources are its' real weaknesses. Moreover, Mathnium has the worst performance in all groups of tests and in statistics lacks some basic functions.

Octave is a language compatible with Matlab, but it is not a top performer on Windows, because it runs under cygwin. It has a wide variety of mathematical and statistical functions that makes it a powerful tool for numerical computations. It includes all the tests of the computational evaluation and its best performance is in miscellaneous operations like plots and creating random numbers. A real weakness is its poor user interface, but as mentioned before that problem can be solved using a compatible external user interface.

R is a free software environment for statistical computing and graphics. R is one of the fastest open source data analysis packages. It provides many additional packages for all kind of statistics. One of its disadvantages is its incorporating editor that is only a text pad and does not offer any utility, like syntax highlighting.

Scilab is a free alternative of Matlab. Scilab proposes more functions than Octave, but it is not 100% compatible with the Matlab language. Scilab offers functions for creating graphical user interfaces. It is the fastest software in the benchmark that was performed. However, the only disadvantage of Scilab was the restrictions referring to the dimensions of data that can create and handle. Nevertheless, this drawback can be overcome with the use of parallel programming which is a strong Scilab's feature.

Finally, the main advantage of Octave is his ability of being totally compatible with Matlab but his computational performance is as satisfactory as Scilab's. Scilab has the best performance in computational evaluation and it may be the best solution for a scientist in the area of mathematical programming. Another significant of Scilab is its friendly user interface which is a real weakness of Octave. In contrast, R may be an ideal alternative for statisticians or econometricians who use commercial software such as S-Plus. Furthermore, Mathnium is the only software which has a facility for the definition of derived data types as classes but his performance in computational evaluation is not satisfactory. Freemate

involves quite satisfactory execution times in speed comparison but it misses a number of functions in some research area like statistics and this is its main disadvantage towards the other software.

11. Bibliography

- [1]. St. Campbell, J-Ph. Chancelier, R. Nikoukhah, *Modeling and Simulation in Scilab/Scicos*. Berlin: Springer, 2005.
- [2]. S. Cojocaru, L. Malahova, A. Colesnicov, Providing modern software environments to computer algebra systems, *Lecture Notes on Computer Science*. 4194 (2006) 129-140.
- [3]. P. Dalgaard, *Introductory Statistics with R*. 2nd Edition, Copenhagen: Springer, 2008.
- [4]. D. Eddelbuettel, Econometrics with Octave, *Journal of Applied Econometrics*. 15 (2000) 531-542.
- [5]. D. Kendrick, H. Amman, Programming Languages in Economics, *Computational Economics*. 14 (1999) 151-181.
- [6]. C. Kleiber, A. Zeileis, *Applied Econometrics with R*. New York: Springer, 2008.
- [7]. U. Kusters, J-P. Steffen, (1996). Matrix programming languages for statistical computing: A detailed comparison of Gauss, Matlab and Ox. Report. Department of Business Administration, Catholic University of Eichstatt.
- [8]. M. Malcolm, Octave: A Free High-Level Language for Mathematics, *Linux Journal*. 8 (1997).
- [9]. M. Mrkaic, Scilab as an Econometric Programming System, *Journal of Applied Econometrics*. 16 (2001) 553–559.
- [10]. A. Quarteroni, F. Saleri, *Scientific Computing with MATLAB and Octave*. Berlin: Springer, 2008.
- [11]. J. Rast, Gauss and Matlab: A comparison, *Journal of Applied Econometrics*. 8 (1993) 307-324.
- [12]. M. Rizzo, *Statistical Computing with R*. Florida: Boca Raton: Chapman & Hall/CRC Computer Science & Data Analysis, 2008.
- [13]. A. Rossini, L. Tierney, N. Li, Simple Parallel Statistical Computing in R, *Journal of Computational and Graphical Statistics*. 16 (2007) 399–420.
- [14]. P. Spector, *Data Manipulation with R*. New York: Springer, 2008.
- [15]. The CRAN (2009). Obtained through the Internet: <http://www.r-project.org/index.html>
- [16]. The FreeMat team (2009). Obtained through the Internet: <http://freemat.sourceforge.net/>
- [17]. The INRIA (2009). Obtained through the Internet: <http://www.scilab.org/>
- [18]. The John W. Eaton (2009). Obtained through the Internet: <http://www.gnu.org/software/octave/>
- [19]. The Mathnium (2009). Obtained through the Internet: <http://www.mathnium.com/>

- [20].The Mattias Hentunen website (2009). Obtained through the Internet: <http://athlone.ath.cx/~matti/kde/koctave/>
- [21].The QtOctave (2009). Obtained through the Internet: <http://qt octave.wordpress.com/what-is-qt octave/>
- [22].The Tibco Spotfire S+ website (2010). Obtained through the Internet: <http://spotfire.tibco.com/products/s-plus/statistical-analysis-software.aspx>

Figures

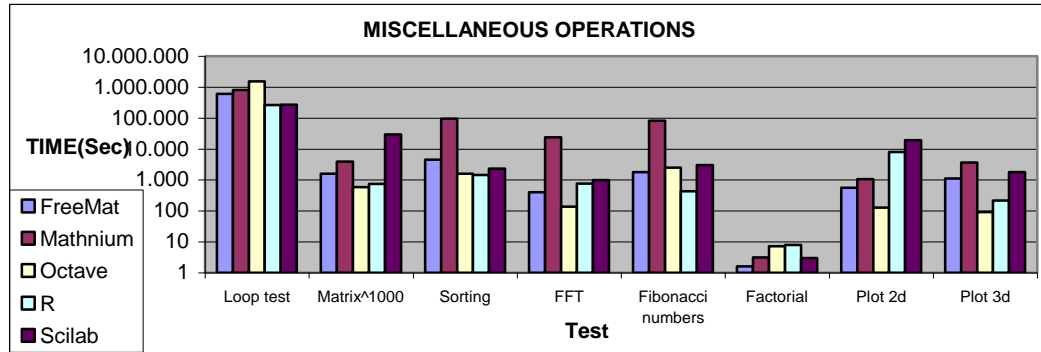


Fig. 1. Miscellaneous Operations

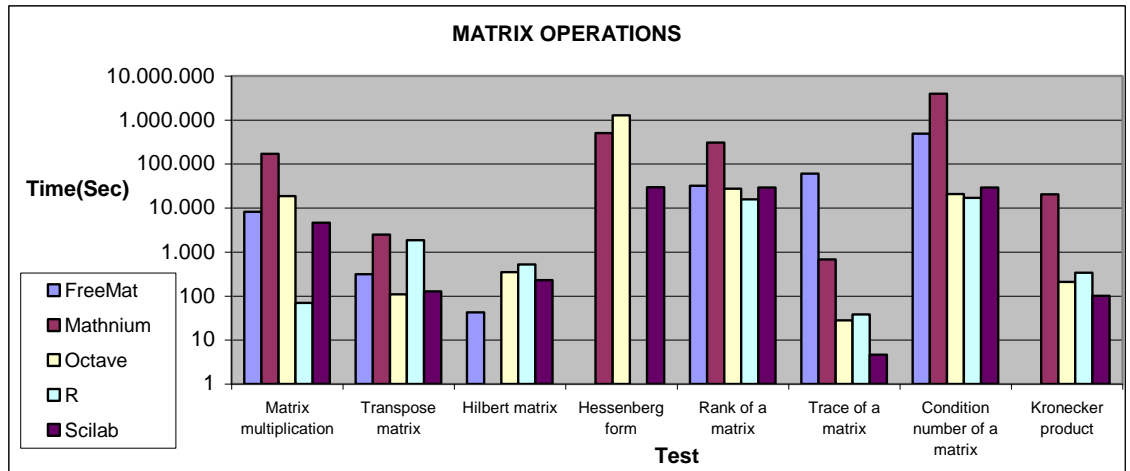


Fig. 2. Matrix Operations

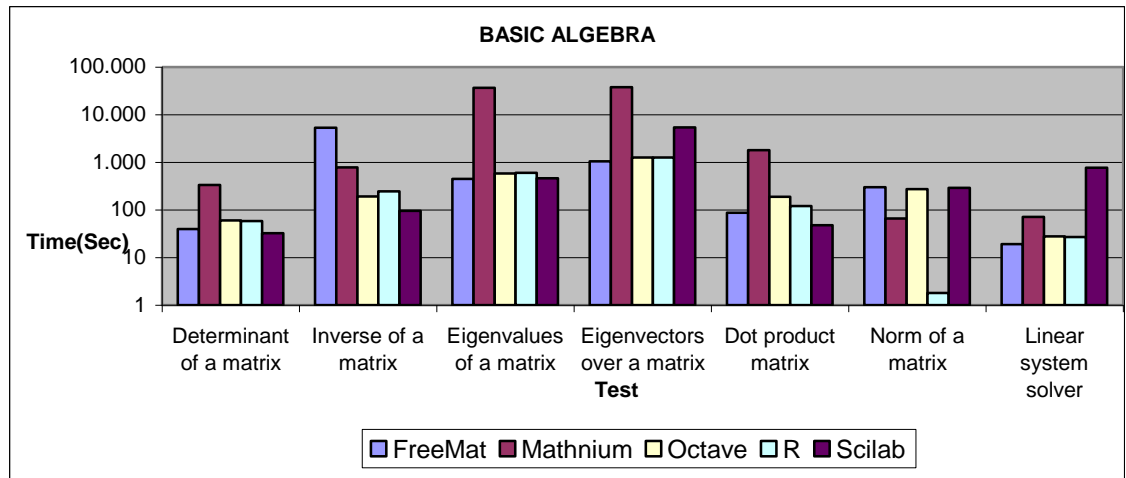


Fig. 3. Basic Algebra

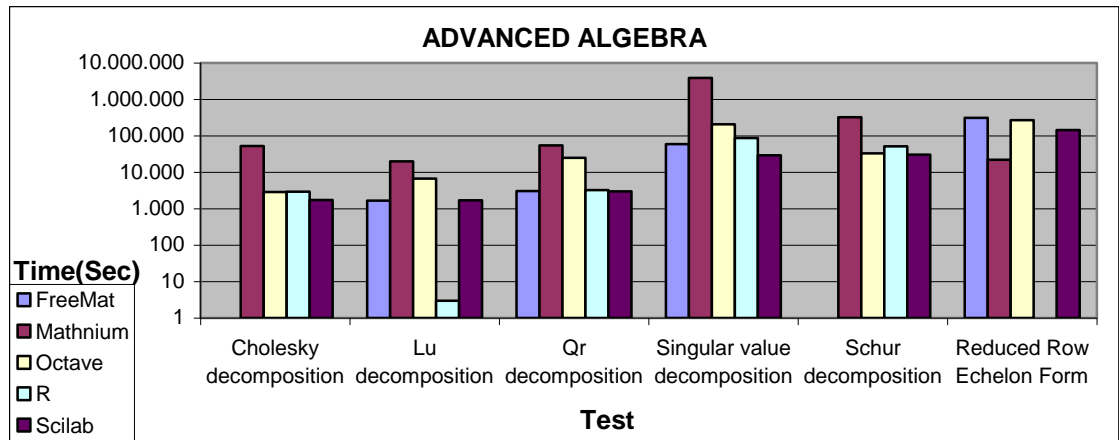


Fig. 4. Advanced Algebra

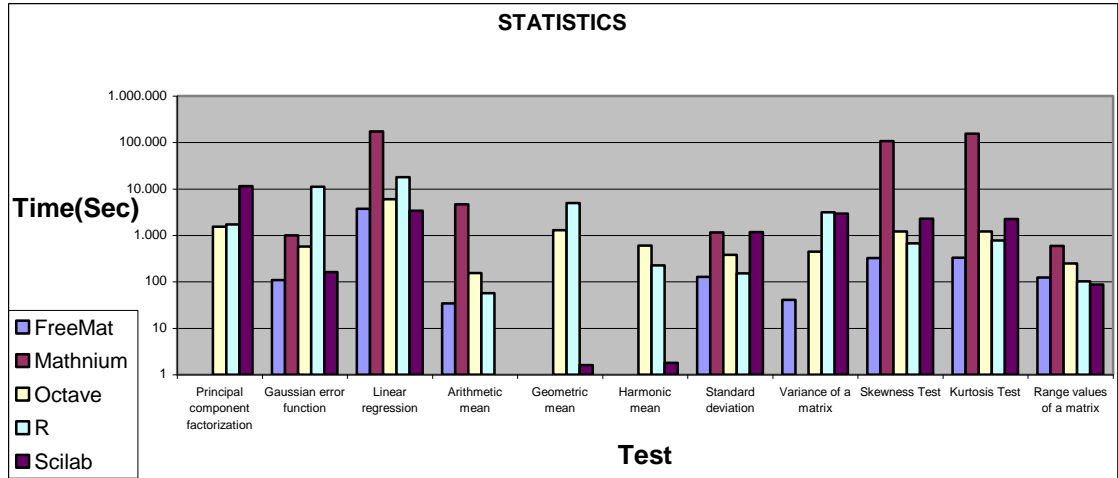


Fig. 5. Statistics

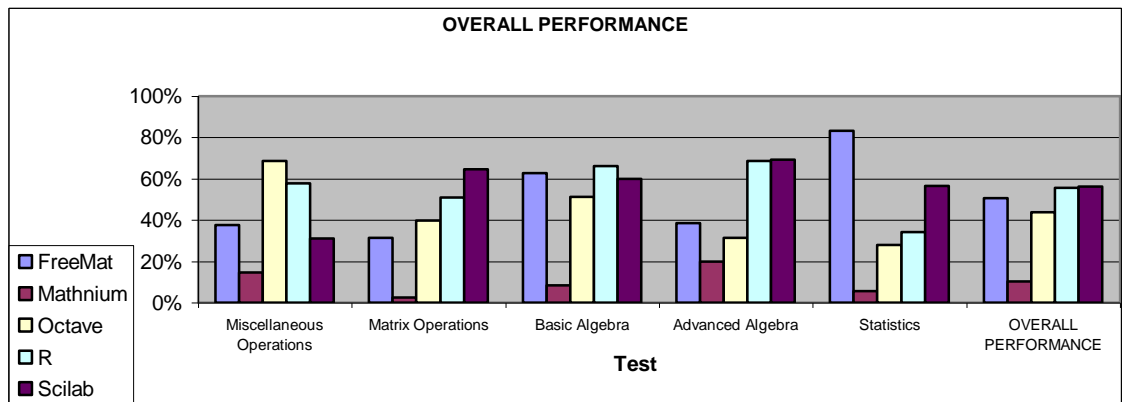


Fig. 6. Overall Performance

Tables

Data type	Freemat	Mathnium	Octave	R	Scilab
Integer	✓	✓	✓	✓	✓
Double	✓	✓	✓	✓	✓
Boolean	✓	✓	✓	✓	✓
Complex	✓	✓	✓	✓	✓
Matrices	✓	✓	✓	✓	✓
Strings	✓	✓	✓	✓	✓
Structures	✓	✓	✓	✓	✓
Cells	✓	✓	✓	✓	✓
Java class		✓			
Sparse matrix	✓	✓	✓	✓	✓

Table 1: Supported data types

Language constructs	Freemat	Mathnium	Octave	R	Scilab
Object-oriented	✓	✓		✓	✓
Dynamic allocation of memory	✓			✓	✓
Sparse matrix	✓	✓	✓	✓	✓
Parallel programming	✓		✓	✓	✓

Table 2: Supported language constructs

Functionality of the programming environment	Freemat	Mathnium	Octave	R	Scilab
Debugger	✓		✓	✓	✓
Profiler	✓			✓	✓
Syntax highlighting	✓		✓		✓
Creation of Graphical User Interface					✓

Table 3: Supported functionality of the programming environment

Help facilities and documentation	Freemat	Mathnium	Octave	R	Scilab
Help environment	✓		✓	✓	✓
Manual	✓		✓	✓	✓
Searching index	✓			✓	✓
Online documentation	✓	✓		✓	✓
Mailing list\User forum	✓		✓	✓	✓

Table 4: Supported help facilities

TEST	FreeMat 3.6 (seconds)	Mathnium 1.051 (seconds)	Octave 3.0.3 (seconds)	R 2.8.0 (seconds)	Scilab 5.0.2 (seconds)
MISCELLANEOUS OPERATIONS					
Loop test 1000x1000	601,606	798,788	1526,000	261,077	271,713
2000x2000 random matrix ¹⁰⁰⁰	1,573	3,886	0,592	0,745	29,398
Sorting of 5000000 random values	4,545	94,692	1,581	1,449	2,300
FFT over 2 ²⁰ random values	0,405	23,912	0,137	0,763	0,991
Calculation of 2000000 Fibonacci numbers	1,798	81,205	2,514	0,430	3,047
Factorial of a big integer (ten digits)	0,002	0,003	0,007	0,008	0,003
Plot 2d on 200000 points	0,563	1,072	0,128	7,988	19,292
Plot 3d on 200000 points	1,105	3,691	0,091	0,216	1,789
<i>Average performance for the tests of this group</i>	37,71%	14,57%	68,49%	57,62%	31,01%
MATRIX OPERATIONS					
Matrix multiplication among two 2000x2000 random matrices	8,187	171,389	18,664	0,070	4,626
Transpose of a 2000x2000 random matrix	0,311	2,494	0,110	1,853	0,127
Creation of a 2000x2000 Hilbert matrix	0,042	-	0,351	0,519	0,229
Hessenberg form of a 2000x2000 random matrix	-	501,603	1274,100	-	29,412
Rank of a 2000x2000 random matrix	32,150	308,015	27,225	15,597	29,273
Trace of a 2000x2000 random matrix	60,195	0,679	0,028	0,038	0,005
Condition number of a 2000x2000 random matrix	491,475	3939,406	20,735	16,853	29,257
Kronecker product of two 200x200 random matrices	-	20,367	0,210	0,337	0,102
<i>Average performance for the tests of this group</i>	31,35%	2,42%	39,75%	50,90%	64,68%
BASIC ALGEBRA					
Determinant of a 2000x2000 random matrix	3,945	33,214	6,007	5,796	3,249
Inverse of a 2000x2000 random matrix	533,880	78,364	18,991	24,409	9,489
Eigenvalues of a 2000x2000 random matrix	44,679	3645,349	58,462	59,596	46,147
Eigenvectors over a 2000x2000 random matrix	104,053	3787,406	125,200	126,105	540,456
2000x2000 dot product matrix	8,665	181,192	18,763	11,995	4,751
Norm of a 2000x2000 random matrix	30,000	6,623	27,196	0,180	29,240
Linear system solve of 1500 equations	1,903	7,151	2,764	2,677	76,925
<i>Average performance for the tests of this group</i>	62,80%	8,26%	51,20%	66,16%	59,88%
ADVANCED ALGEBRA					
Cholesky decomposition of a 2000x2000 random matrix	-	51,931	2,843	2,920	1,716
Lu decomposition of a 1500x1500 random matrix	1,667	19,799	6,709	0,003	1,687
Qr decomposition of a 1200x1200 random matrix	3,055	54,817	24,710	3,234	2,970
Singular value decomposition of a 2000x2000 random matrix	59,016	3871,344	205,740	86,328	29,167
Schur decomposition of a 1500x1500 random matrix	-	325,062	32,601	51,172	30,227
Reduced Row Echelon Form of a 2000x2000 random matrix	311,442	21,890	269,770	-	144,047
<i>Average performance for the tests of this group</i>	38,47%	19,80%	31,24%	68,69%	69,23%
STATISTICS					
PCA over a 3000x300 random matrix	-	-	1,5395	1,7020	11,5281
Gaussian error function on a 2000x2000 random matrix	0,110	1,003	0,571	11,202	0,161
Linear regression over a 2000x2000 random matrix	3,717	172,287	6,025	17,848	3,412
Arithmetic mean over a 2x10 ⁶ random vector	0,034	4,686	0,153	0,057	0,001
Geometric mean over a 2x10 ⁶ random vector	-	-	1,284	4,937	0,002
Harmonic mean over a 2x10 ⁶ random vector	-	-	0,599	0,224	0,002
Standard deviation over a 2x10 ⁶ random vector	0,128	1,156	0,383	0,151	1,178

Variance of a 1200x1200 random matrix	0,041	-	0,448	3,145	2,945
Skewness of 5x10 ⁶ random values	0,325	106,453	1,211	0,674	2,297
Kurtosis of 5x10 ⁶ random values	0,329	153,826	1,205	0,771	2,250
Range values of a 2000x2000 random array	0,123	0,594	0,249	0,102	0,087
<i>Average performance for the tests of this group</i>	83,19%	5,61%	28,07%	34,19%	56,59%
OVERALL PERFORMANCE (%) (100%=Best)	50,70%	10,13%	43,75%	55,51%	56,28%

Table 5: Speed Comparison