Scilab
A Hands on Introduction

by
Satish Annigeri Ph.D.
Professor of Civil Engineering
B.V. Bhoomaraddi College of Engineering & Technology, Hubli
satish@bvb.edu

September 2006

Table of Contents

Preface

Scilab is a software for numerical mathematics and scientific visualization. It is capable of interactive calculations as well as automation of computations through programming. It provides all basic operations on matrices through built-in functions so that the trouble of developing and testing code for basic operations are completely avoided. Its ability to plot 2D and 3D graphs helps in visualizing the data we work with. All these make Scilab an excellent tool for teaching, especially those subjects that involve matrix operations. Further, the numerous toolboxes that are available for various specialized applications make it an important tool for research. Being compatible with Matlab®, all available Matlab M-files can be directly used in Scilab. Scicos, a hybrid dynamic systems modeler and simulator for Scilab, simplifies simulations. The greatest features of Scilab are that it is multi-platform and is free. It is available for many operating systems including Windows, Linux and MacOS X. More information about the features of Scilab are given in the Introduction.

Scilab can help a student understand all intermediate steps in solving even complicated problems, as easily as using a calculator. In fact, it is a calculator that is capable of matrix algebra computations. Once the student is sure of having mastered the steps, they can be converted into functions and whole problems can be solved by simply calling a few functions. Scilab is an invaluable tool as solved problems need not be restricted to simple examples to suit hand calculations.

It is not the aim of this tutorial to be an exhaustive and in-depth look into Scilab. Instead, it attempts to get a novice started with the least fuss and is aimed at anyone who intends to start learning to use Scilab entirely on her own.

Acknowledgments

It goes without saying that my first indebtedness is to the developers of Scilab and the consortium that continues to develop it. I must also thank Dr. A.B. Raju, E&EE Department, BVBCET, Hubli who first introduced me to Scilab and forever freed me from using Matlab.

September 2006 *Satish Annigeri*

Introduction

Scilab is a scientific software package for numerical computations providing a powerful open computing environment for engineering and scientific applications. Developed since 1990 by researchers from INRIA (French National Institute for Research in Computer Science and Control, `http://www.inria.fr/index.en.html`) and ENPC (National School of Bridges and Roads, `http://www.enpc.fr/english/int_index.htm`), it is now maintained and developed by Scilab Consortium (`http://scilabsoft.inria.fr/consortium/consortium.html`) since its creation in May 2003.

Distributed freely and open source through the Internet since 1994, Scilab is currently being used in educational and industrial environments around the world.

Scilab includes hundreds of mathematical functions with the possibility to add interactively programs from various languages (C, Fortran...). It has sophisticated data structures (including lists, polynomials, rational functions, linear systems...), an interpreter and a high level programming language.

Scilab has been designed to be an open system where the user can define new data types and operations on these data types by using overloading.

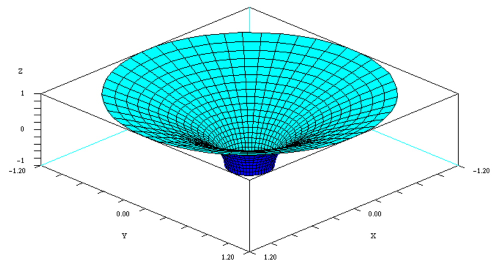
A number of toolboxes are available with the system:

- 2-D and 3-D graphics, animation
- Linear algebra, sparse matrices
- Polynomials and rational functions
- Simulation: ODE solver and DAE solver
- Scicos: a hybrid dynamic systems modeler and simulator
- Classic and robust control, LMI optimization
- Differentiable and non-differentiable optimization
- Signal processing
- Metanet: graphs and networks
- Parallel Scilab using PVM
- Statistics
- Interface with Computer Algebra (Maple, MuPAD)
- Interface with Tcl/Tk
- And a large number of contributions for various domains.

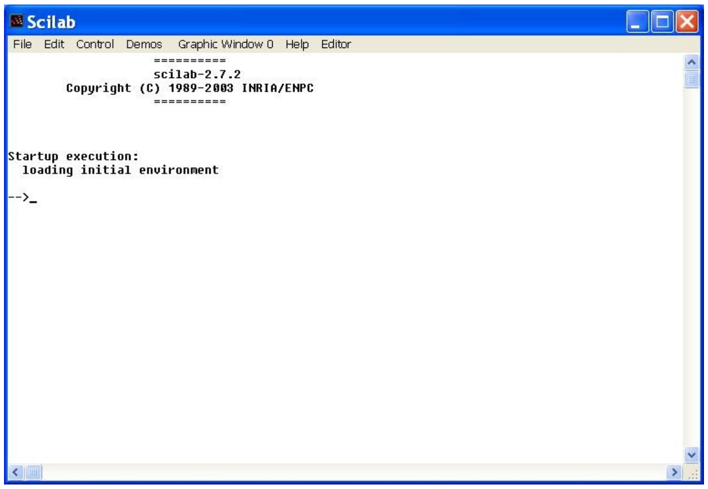
Scilab works on most Unix systems including GNU/Linux and on Windows 9X/NT/2000/XP. It comes with source code, on-line help and English user manuals. Binary versions are available.

Some of its features are listed below:

- Basic data type is a matrix, and all matrix operations are available as built-in operations.
- Has a built-in interpreted high-level programming language.
- Graphics such as 2D and 3D graphs can be generated and exported to various formats so that they can be included into documents.



To the left is a 3D graph generated in Scilab and exported to GIF format and included in the document for presentation. Scilab can export to Postscript and GIF formats as well as to Xfig (popular free software for drawing figures) and LaTeX (free scientific document preparation system) file formats.

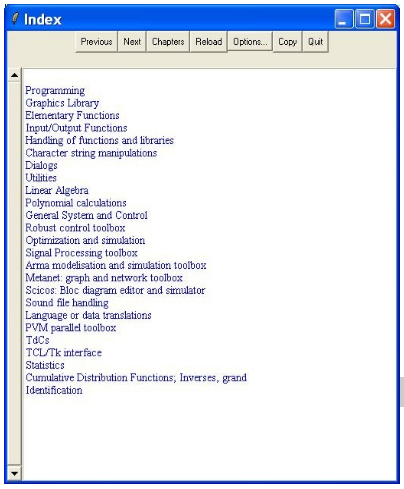


```
                    ==========
                    scilab-2.7.2
        Copyright (C) 1989-2003 INRIA/ENPC
                    ==========


Startup execution:
  loading initial environment

-->_
```

Fig. 1 Scilab environment



Programming
Graphics Library
Elementary Functions
Input/Output Functions
Handling of functions and libraries
Character string manipulations
Dialogs
Utilities
Linear Algebra
Polynomial calculations
General System and Control
Robust control toolbox
Optimization and simulation
Signal Processing toolbox
Arma modelisation and simulation toolbox
Metanet: graph and network toolbox
Scicos: Bloc diagram editor and simulator
Sound file handling
Language or data translations
PVM parallel toolbox
TdCs
TCL/Tk interface
Statistics
Cumulative Distribution Functions; Inverses, grand
Identification

When you startup Scilab, you see a window as shown in Fig. 1 above. The user enters Scilab commands at the prompt (**-->**). But many of the commands are also available through the menu at the top. The most important menu for a beginner is the "Help" menu. Clicking on the "Help" menu opens a help window with a list of topics on which help is available. Clicking on the relevant topic takes you to hypertext linked documents similar to web pages.

Help on specific commands can also be accessed directly from the command line instead of having to navigate through a series of links. Thus, to get help on the Scilab command "**inv**", simply type

```
-->help inv
```

on the command line.

Scilab can be used as a simple calculator to perform numerical calculations. It also has the ability to define variables and store values in them so that they can be used later. This is demonstrated in the following examples:

```
-->2+3
ans =
      5.
-->2/3
ans =
      .6666667
-->2^3
ans =
      8.
```

```
-->a=2
a = 2.
-->b=
      3.
b =
      3.
-->c=a+b
c =
      5.
```

```
-->pi=atan(1.0)*4
pi =
      3.1415927
-->sin(pi/4)
ans =
      0.7071068
-->exp(0.1)
ans =
      1.1051709
```

Usually the answer of a calculation is stored in a variable so that it could be used later. If you do not explicitly supply the name of the variable to store the answer, Scilab creates a variable named "**ans**" to store such results.

You could enter more than one command on the same line by separating the commands by semicolons(**;**). The semicolon suppresses echoing of intermediate results. Try the command

```
-->a=5;
-->_
```

and you will notice that the prompt reappears immediately without echoing **a=5**.

Tutorial 2 – The Workspace and Working Directory

While the Scilab environment is the visible face of Scilab, there is another that is not visible. It is the memory space where all variables and functions are stored, and is called the **Workspace**. Many a times it is necessary to inspect the workspace to check whether or not a variable or a function has been defined. The following commands help the user in inspecting the memory space: **`who`**, **`whos`** and **`who_user()`**. Use the online help to learn more about these commands.

The **`who`** command lists the names of variables in the Scilab workspace. Note the variable names preceded by the "`%`" symbol. These are special variables that are used often and therefore predefined by Scilab. It includes %pi (π), %e (e), %i ($\sqrt{-1}$), %inf (∞), %nan (NaN) and others.

The **`whos`** command lists the variables along with the amount of memory they take up in the workspace. The variables to be listed can be selected based on either their type or name. Some examples are:

`-->whos()`	Lists entire contents of the workspace, including functions, libraries, constants
`-->whos -type constants`	Lists only variables that can store real or complex constants. Other types are boolean, string, function, library, polynomial etc. For a complete list use the command **`-->help typeof`**.
`-->whos -name nam`	Lists all variables whose name begins with the letters nam

To understand how Scilab deals with numbers, try out the following commands and use the **`whos`** command as follows:

`-->a1=5;`	Defines a real number variable with name '**`a1`**'
`-->a2=sqrt(-4);`	Defines a complex number variable with name '**`a2`**'
`-->a3=[1, 2; 3, 4];`	Defines a 2x2 matrix with name '**`a3`**'
`-->whos -name a`	Lists all variables with name starting with the letter '**`a`**'

```
Name     Type          Size        Bytes

a3       constant      2 by 2      48
a2       constant      1 by 1      32
a1       constant      1 by 1      24
```

Now try the following commands:

`-->a1=sqrt(-9)`	Converts '**`a1`**' to a complex number
`-->whos -name a`	Note that '**`a`**' is now a complex number
`-->a1=a3`	Converts '**`a1`**' to a matrix
`-->whos -name a`	Note that '**`a`**' is now a matrix
`-->save('ex01.dat')`	Saves all variables in the workspace to a disk file **`ex01.dat`**
`-->load('ex01.dat')`	Loads all variables from a disk file **`ex01.dat`** to workspace

Note the following points:

- Scilab treats a scalar number as a matrix of size 1x1 (and not as a simple number) because the basic data type in Scilab is a matrix.
- Scilab automatically converts the type of the variable as the situation demands. There is no need to specifically define the type for the variable.

Tutorial 3 – Matrix Operations

Matrix operations that are built-in into Scilab are addition, subtraction, multiplication, transpose, inversion, determinant, trigonometric, logarithmic, exponential functions and many others. Study the following examples:

`-->a=[1 2 3; 4 5 6; 7 8 9];`	Define a 3x3 matrix. Semicolons indicate end of a row
`-->b=a';`	Transpose **`a`** and store it in **`b`**. Aphostrophe (`'`) is the transpose operator.
`-->c=a+b`	Add **`a`** to **`b`** and store the result in **`c`**. **`a`** and **`b`** must be of the same size. Otherwise, Scilab will report an error.
`-->d=a-b`	Subtract **`b`** from **`a`** and store the result in **`d`**.
`-->e=a*b`	Multiply **`a`** with **`b`** and store the result in **`e`**. **`a`** and **`b`** must be compatible for matrix multiplication.
`-->f=[3 1 2; 1 5 3; 2 3 6];`	Define a 3x3 matrix with name **`f`**.
`-->g=inv(f)`	Invert matrix **`f`** and store the result in **`g`**. **`f`** must be square and positive definite. Scilab will display a warning if it is ill conditioned.
`-->f*g`	The answer must be an identity matrix
`-->det(f)`	Determinant of **`f`**.
`-->log(a)`	Matrix of log of each element of **`a`**.
`-->a .* b`	Element by element multiplication.
`-->a^2`	Same as **`a*a`**.
`-->a .^2`	Element by element square.

There are some handy utility functions to generate commonly used matrices, such as zero matrices, identity matrices etc.

`-->a=zeros(5,8)`	Creates a 5x8 matrix with all elements zero.
`-->b=ones(4,6)`	Creates a 4x6 matrix with all elements 1
`-->c=eye(3,3)`	Creates a 3x3 identity matrix
`-->d=eye(3,3)*10`	Creates a 3x3 diagonal matrix, with diagonal elements equal to 10.

It is possible to generate a range of numbers to form a vector. Study the following command:

`-->a=[1:5]`	Creates a vector with 5 elements as follows [1, 2, 3, 4, 5]
`-->b=[0:0.5:5]`	Creates a vector with 11 elements as follows [0, 0.5, 1.0, 1.5, ... 4.5, 5.0]

A range requires a start value, an increment and an ending value, separated by colons (`:`). If only two values are given (separated by only one colon), they are taken to be the start and end values and incremented is assumed to be 1.

You can create an empty matrix with the command:

```
-->a=[]
```

Tutorial 4 – Sub-matrices

A sub-matrix can be identified by the row and column numbers at which it starts and ends. Let us first create a matrix of size 5x8.

`-->a=rand(5,8)*100`	Generates a 5x8 matrix whose elements are generated as random numbers.

Since the elements are random numbers, each person will get a different matrix. Let us assume we wish to identify a 2x4 sub-matrix of **`a`** demarcated by rows 3 to 4 and columns 2 to 5. This is done with **`a(3:4, 2:5)`**. The range of rows and columns is represented by the range commands **`3:4`** and **`2:5`** respectively. Thus **`3:4`** defines the range 3, 4 while **`2:5`** defines the range 2, 3, 4, 5. However, matrix '**`a`**' remains unaffected.

`-->b=a(3:4, 2:5)`	This command copies the sub-matrix of **`a`** into **`b`**

A sub-matrix can be overwritten just as easily as it can be copied. To make all elements of the sub-matrix between the above range equal to zero, use the following command:

`-->a(3:4, 2:5)=zeros(2,4)`	This command creates a 2x4 matrix of zeros and puts it into the sub-matrix of **`a`** between rows 3:4 and columns 2:5.

Note that the sub-matrix on the left hand side and the matrix on the right side (a zero matrix in the above example) must be of the same size.

While using range to demarcate rows and/or columns, it is permitted to leave out both the start and end value in the range, in which case it is assumed to be 1 and the number of the last row (or column), respectively. To indicate all rows (or columns) it is enough to use only the colon (**`:`**). Thus, the sub-matrix consisting of all the rows and columns 2 and 3 of **`a`**, the command is **`a(:, 2:3)`**. Naturally **`a(:, :)`** represents the whole matrix, which of course could be represented simply as **`a`**. However, it is not possible to specify only the start value of the range and leave out the end value or vice versa. Either both must be specified or both must be left out. Scilab refers to the number of the last row (or column) by the symbol "**`$`**". This can be used within range specifications to represent the number of the last row (or column).

It must also be noted that the sub-matrix need not necessarily consist of contiguous rows and columns. For example, to extract the odd rows and column from "a", you could use the following command:

`-->c=a(1:2:$, 1:2:$)`	This command copies the sub-matrix of **`a`** with rows 1, 3, 5 and columns 1, 3, 5, 7 into **`b`**. The rows are represented by the range **`1:2:$`** which implies start from 1, increment by 2 each time and up to **`$`**, which in this case is 5.

Tutorial 5 – Statistics

Scilab can perform all basic statistical calculations. The data is assumed to be contained in a matrix and calculations can be performed treating rows (or columns) as the observations and the columns (or rows) as the parameters. To choose rows as the observations, the indicator is **`r`** or **`1`**. To choose columns as the observations, the indicator is '**`c`**' or **`2`**. If no indicator is furnished, the operation is applied to the entire matrix element by element. The available statistical functions are **`sum()`**, **`mean()`**, **`stdev()`**, **`st_deviation()`**, **`median()`**.

Let us first generate a matrix of 5 observations on 3 parameters. Let the elements be random numbers. This is done using the following command:

`-->a=rand(5,3)`	Creates a 5x3 matrix of random numbers .

Assuming rows to be observations and columns to be parameters, the sum, mean and standard deviation are calculated as follows:

`-->s=sum(a, 'r')`	Sum of columns of **`a`**.
`-->m=mean(a,1)`	Mean value of each column of **`a`**.
`-->sd=stdev(a, 1)`	Standard deviation of **`a`**.
`-->sd2=st_deviation(a, 'r')`	Standard deviation of **`a`**. Sample size standard deviation.
`-->mdn=median(a,'r')`	Median of columns of **`a`**.

The same operations can be performed treating columns as observations by replacing the **`r`** or **`1`** with **`c`** or **`2`**.

When neither **`r`** (or **`1`**) nor **`c`** (or **`2`**) is supplied, the operations are carried out treating the entire matrix as a set of observations on a single parameter.

The maximum and minimum values in a column, row or matrix can be obtained with the **`max()`** and **`min()`** functions respectively in the same way as the above statistical functions, except that you must use **`r`** or **`c`** but not **`1`** or **`2`**.

Tutorial 6 – Plotting Graphs

Let us learn to plot simple graphs. We will have to generate the data to be used for the graph. Let us assume we want to draw the graph of $\cos(x)$ and $\sin(x)$ for one full cycle (2π radians). Let us generate the values for the x-axis with the following command:

```
-->x=[0:%pi/16:2*%pi];
```

In the above command, note that **`%pi`** is a predefined constant representing the value of π . The command to create a range of values, **`0:%pi/16:2*%pi`**, requires a starting value, an increment and an ending value. In the above example, they are 0, $\pi/16$ and 2π respectively. The increment is optional and when not given, it is taken to be 1. Thus, '**`x`**' is a vector with 33 elements.

Next, let us create the values for the y-axis, first column representing cosine and the second sine. They are created by the following commands:

```
-->y=[cos(x) sin(x)]
```

Note that **`cos(x)`** and **`sin(x)`** are the two columns of a new matrix which is first created and then stored in **`y`**. We can now plot the graph with the command:

```
-->plot2d(x,y)
```

The graph generated by this command is shown below. The graph can be enhanced and annotated. You can add grid lines, labels for x- and y-axes, legend for the different lines etc.

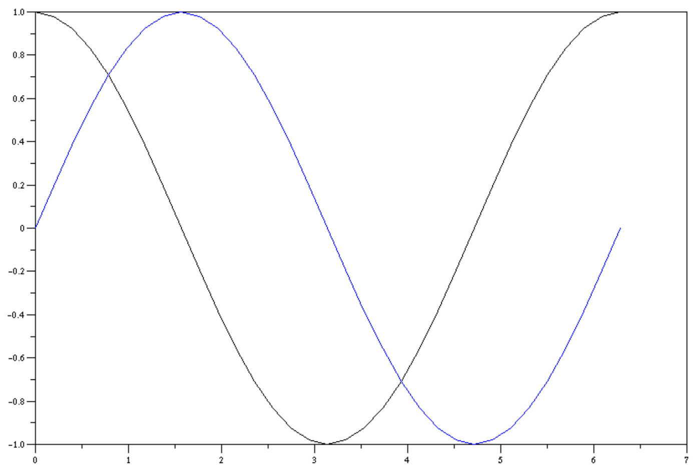


Fig. 2 Graph of sin(x) and cos(x) using function ***`plot2d()`***

You can learn more about the **`plot2d`** and other related functions from the online help.

Tutorial 7 – Scilab Programming Language

Scilab has a built-in interpreted programming language so that a series of commands can be automated. The programming language offers most of the features of any high level language, such as looping (**`for`**, **`while`**), conditional execution (**`if-then-else`**, **`select`**) and functions. The greatest advantage is that the statements can be any valid Scilab commands.

To loop over an index variable '**`i`**' from 1 to 10 and display its value each time, you can try the following commands at the prompt:

```
-->for i=1:10
-->disp(i)
-->end
```

The **`for`** loop is closed by the corresponding **`end`** statement. Once the loop is closed, the block of statements enclosed within the loop will be executed. The **`disp(i)`** command displays the value of **`i`**.

Conditional execution is performed using the **`if-then-elseif-else`** construct. Try the following statements on the command line:

```
-->x=10;
-->if x<0 then disp('Negative')
-->elseif x==0 then disp('Zero')
-->else disp('Positive')
-->end
Positive
```

This will display the word **`Positive`**.

A list of all the Scilab programming language primitives and commands can be displayed by the command **`what()`**. The command produces the following list:

```
if     else   for     while  end    select  case   quit
exit   return help    what   who    pause   clear  resume
then   do     apropos abort  break  elseif
```

You can learn about each command using the help command. Thus **`help while`** will give complete information about **`while`** along with examples and other commands that are related to it.

Tutorial 8 – Functions in Scilab

Functions serve the same purpose in Scilab as in other programming languages. They are independent blocks of code, with their own input and output parameters which can be associated with variables at the time of calling the function. They modularize program development and encapsulate a series of statements and associate them with the name of the function.

Scilab provides a built in editor within Scilab, called SciPad, wherein the user can type the code for functions and compile and load them into the workspace. SciPad can be invoked by clicking on 'Editor' on the main menu at the top of the Scilab work environment.

Let us write a simple function to calculate the length of a line in the x-y plane, given the coordinates of its two ends (x1, y1) and (x2, y2). The length of such a line is given by the expression $l=\sqrt{(x_2-x_1)^2+(y_2-y_1)^2}$. Before defining the function in SciPad, let us try it out in Scilab.

```
-->x1=1; y1=4; x2=10; y2=6;
-->dx=x2-x1; dy=y2-y1;
-->l=sqrt(dx^2 + dy^2)
l =
     9.2195445
```

Note that **x1**, **y1**, **x2** and **y2** are input values and the length '**l**' is the output value. To write the function, proceed as described below:

1. Open SciPad by clicking on 'Editor' on the main menu.
2. Type the following lines of code into SciPad and define the function **len()**:

```
function [l] = len(x1, y1, x2, y2)
dx=x2-x1; dy=y2-y1;
l=sqrt(dx^2 + dy^2);
endfunction
```

   In the code above, **function** and **endfunction** are Scilab keywords and must be typed exactly as shown. They signify the start and end of a function definition.

   The variable enclosed between square brackets is an output parameter, and will be returned to Scilab workspace (or to the parent function from where it is invoked). The name of the function has been chosen as '**len**' (short for length, as the name length is already used by Scilab for another purpose). The input parameters **x1**, **y1**, **x2** and **y2** are the variables bringing in input from the Scilab workspace (or the parent function from where it is called).

3. Save the contents of the file to a disk file by clicking File > Save in SciPad and choose a directory and name for the file.
4. Load the function into Scilab by clicking on 'Load into Scilab' on the SciPad main menu.

This function will be invoked as follows:

```
ll = len(xx1,yy1,xx2,yy2)
```

where **ll** is the variable where the output of the function will be stored and **xx1**, **yy1**, **xx2** and **yy2** are the input variables. Note that their names need not match the corresponding names in the function definition.

The semicolons (`;`) used at the end of the executable statements suppress the echo of intermediate results. You can remove them if you wish to debug the function. Alternately, use the function **disp()** to print out intermediate results within a function to debug.

To use the function during subsequent sessions, load it into Scilab by clicking on 'Load into Scilab'. If there are no syntax errors in your function definition, it will be loaded into Scilab workspace, otherwise the number of the line containing the syntax error is displayed. If it is loaded successfully into the Scilab workspace, you can verify it with the command **whos -type function** and searching for the name of the function, namely, **len**.

Tutorial 9 – Miscellaneous Commands

Some commands related to operations on disks are important and they are listed below. They are required when you want to change the directory in which your function files are stored or from where they are to be read.

`pwd`	Prints the name of the current working directory
`getcwd()`	Same as **`pwd`**.
`chdir('dir')`	Changes the working directory to a different disk location named **`dir`**.

It is possible to save all the variables in the Scilab Workspace to a disk file so that you can quickly reload all the variables and functions from a previous session and continue from where you left off. The commands used for this purpose are:

`save('pf.bin')`	Saves entire contents of the Scilab workspace (variables and functions) in the file **`pf.bin`** in the current working directory.
`load('pf.bin')`	Restores contents of the Scilab workspace from the file **`pf.bin`** in the current working directory.
`save('pf.bin', xy)`	Saves only the variable **`xy`** of the Scilab workspace in the file **`pf.bin`** in the current working directory.

It is possible to determine the size of variables in the Scilab workspace with the following command:

`size(xy)`	Returns a 1x2 matrix containing the number of rows and columns in the variable **`xy`**.
`length(xy)`	Returns the number of elements in **`xy`** (rows multiplied by columns).

Scilab can open files on disk and a number of functions are available for opening, closing reading and writing disk files. The following lines of code illustrate how this can be accomplished:

```
-->n=10; x=25.5; xy=[100 75;0 75; 200, 0];
-->fd=file(“ex01.dat”, “w”); // Opens a file ex01.dat for writing
-->mfprintf(fd, “n=%d, x=%f\n”, n, x);
-->mfprintf(fd, “%12.4f\t%12,4f\n”, xy);
-->mclose(fd);
```

You can now open the file **`ex01.dat`** in a text editor, such as notepad and see its contents. You will notice that the commands are similar to the corresponding commands in C, namely, **`fopen()`**, **`fprintf()`** and **`fclose()`**. Note that in the second command, the format string must be sufficient to print one full row of the matrix **`xy`**. The sequence of operations must always be, open the file and obtain a file descriptor, write to the file using the file descriptor and close the file using the file descriptor.