An Introduction to MacAnova

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1. Getting Started

1.1 *What is MacAnova?*

MacAnova is an interactive computer program for statistical analysis of data. It features powerful commands for such things as regression analysis, analysis of variance, multivariate analysis and time series analysis. Moreover, it is an excellent tool for more elementary analyses, including graphical displays and computation of summary statistics.

Many statistical programs are primarily menu driven, with the user selecting what to do almost exclusively by choosing items from a menu. Although this can provide for an easy interface, it can restrict possible analyses to the specific set built in to the program.

MacAnova, by contrast, is primarily command driven, although the Macintosh version makes some use of menus. To do most things, you must use the keyboard to type commands into a command window or screen. Because MacAnova has a very wide set of commands and functions, as well as a means to combine them to make new commands (so called macros), you are not limited to a predefined set of analyses.

One attractive feature of MacAnova is that you can easily directly translate many statistical formulas to a form that MacAnova recognizes. For example, to compute a sample mean of data named x, you can type `sum(x)/nrows(x)` or, if n has earlier been set to the sample size, you can type `sum(x)/n`.

You can easily make high quality scatter plots and other graphs, for example, as simply as typing `plot(x,y)`.

Although there is extensive built in help, MacAnova takes some getting used to. You need to have a certain minimum level of knowledge and practice before you can make *full* use of it. The purpose of this document is to introduce you to the most important features of MacAnova, illustrating them with examples. Probably a good way to proceed is to read this at the computer, trying out things as they are introduced and using the `help()`[1] command to get more detailed information on each command as it is introduced. Some general help topics you may find useful later, but probably not at the start, are `arithmetic`, `array`, `batch`, `comments`, `keywords`, `logic`, `macros`, `matrices`, `models`, `structures`, `subscripts`, `syntax`, `transformations`, and `vectors`. Help on the special features of the different versions may be found in topics `dos`, `launching`, `macintosh`, and `unix`. Yet more complete information is available in

[1] The parentheses are part of the name of the command. When you use a command, you will usually have stuff inside the parentheses.

the *MacAnova User's Guide*, the most recent version of which (dated March 1993) is for MacAnova 3.11.

The most recent version of MacAnova is Version 3.35, released September 1994. Although it has many new features that are not described in the MacAnova User's Guide, almost everything in the manual is still appropriate, except form some of the information in the Appendices. File `Changes.txt` distributed with MacAnova summarizes the changes.

MacAnova was originally designed for use on Macintosh computers and the Macintosh version is still the most convenient to use. Other versions, for DOS and Unix, have the same capabilities, but the interface is somewhat different. The principle differences are these:

(a) The Macintosh version makes some use of menus; other versions do not.

(b) On the Macintosh, what you type and MacAnova's responses go into an editable document in the *command window*. This can be scrolled back so you can see stuff that has disappeared off the top of the screen. It can also be saved on a hard or floppy disk for later printing or editing. On other computers, what scrolls off the screen is lost, although MacAnova pauses after every screenful so that you can read the output. You can write your input and output to disk using the `spool()` command (see Sec. 3.6 below).

(c) The Macintosh version has up to four windows for graphs and you can switch between them and the command window. In fact, you can have up to nine simultaneous command windows and switch between them. You can print any of the windows, graphic or command, or transfer their contents to a word processor. Non-Macintosh versions have a single graphics window whose contents are lost as soon as you switch back to command mode. There is no easy way to print graphs or import them into a word processor, although the protected mode DOS version allows you to save the contents of the graphics screen to disk.

All the examples here were done on a Macintosh, and the computer output, including high resolutions graphs, copied into a word processor document.

1.2 *Launching Macanova*

On a Macintosh, double click on the MacAnova Icon which looks like this .

On DOS, if the default directory is the one with `MACANOVA.EXE`, simply type `macanova` at the DOS prompt. If `MACANOVA.EXE` is in a standard directory such as `C:\BIN`, you may be able to start it up by typing `macanova` in any default directory.

More details on launching MacAnova are in Appendix A (for Macintosh) and Appendix B (for DOS) and are given in `help` topic `launching`.

After launching, a start up message like the following appears

```
                         M A C A N O V A   3.35

  An Interactive Program for Statistical Analysis and Matrix Algebra
      For information on major features, type 'help(macanova3)'
     For information on linear models and GLM's, type 'help(glm)'
        For latest information on changes, type 'help(news)
           Version of 09/09/94 (Mac with Co-Processor)
         Type 'help(copyright)' for copyright and warranty info
        Copyright 1994, Gary W. Oehlert and Christopher Bingham

          New keyword 'key' on help.  Type 'help(key:"?")'

Cmd>
```

"Cmd>" is the standard prompt requesting that you type a command. On the Macintosh, you can use the mouse to put the cursor anywhere in the window and type in whatever you want, but Macanova obeys only what you type *after* the prompt (actually after 1 space after the prompt). With DOS you don't have any choice; you can only type after the prompt.

Commands are typed in as sequences of letters and symbols. You can use the delete or backspace keys to correct mistakes. On the Macintosh, you can use arrow keys or the mouse to reposition the cursor to edit a command before executing. Until Return or Enter is pressed, a command is not executed and may be edited.

On the Macintosh, if the cursor is not at the very end of the command line, pressing Return will just split the line, but MacAnova won't do anything. However, no matter where the cursor is, pressing Enter works the same as moving the cursor to the end of the command line and then typing Return.

Any information typed after a "#" is considered to be a comment and is ignored by MacAnova. This feature is used in many examples below to explain what is being done.

Example

```
    Cmd>  x <- cat(1.2, 3.5, 2.3) # entering 3 values of data<cr>
```

creates a variable named x with values $x_1 = 1.2$, $x_2 = 3.5$, and $x_3 = 2.3$. A convention that will be used throughout this document is to use italic *`Courier`* font for what is typed by the user and non-italic `Courier` font for what the computer prints. The `<cr>` indicates a Return or Enter and will not appear in later examples. Often, just as here, example lines will have descriptive comments starting with '#'. Comments that are not part of the MacAnova session will be in **`bold face`**.

If you need to type a command that is longer than the screen or window width, you can

just keep typing and it will wrap around to the next line. Alternatively, you can split it yourself at a convenient spot by typing a back slash "\" followed by Return. Thus, as long as you don't type Return at the end of the first line,

```
    Cmd> y <- cat(113.7,91.4,89,133.3,90.6,87.4,96.8,78.4,81,113.9,
    120,110, 92.7,131.5,100.9,120.5,87.3,97.9,83.2,81.2)
```

has the same effect as

```
    Cmd> y <- cat(113.7,91.4,89,133.3,90.6,87.4,96.8,78.4,81,113.9,\
    120,110,92.7,131.5,100.9,120.5,87.3,97.9,83.2,81.2)
```

where Return was typed after "\". To repeat, don't use Return without a backslash in the middle of a command, except inside quotes `"..."` or curly brackets `{...}`.

1.3 *Quitting*

It is just as important to know how to stop MacAnova as to how to start it. On all versions of MacAnova you can exit by typing `quit`, end, `stop` or bye. On the Macintosh, selecting **Quit** on the **File** menu also exits or closing the command window when there is only one such window. When you leave MacAnova, all the data and results in MacAnova's memory (the so-called *workspace*) will disappear. You can save them on disk to use later by using commands `save()` or `asciisave()` before quitting (see Sec. 4.3 below). The Macintosh version asks if you want to save the workspace and the output window when you quit.

Example

```
    Cmd> quit # you could also use "bye", "stop" or "end"
```

1.4 *Learning more about MacAnova*

Your first resource is probably command `help()` (see Sec. 3.6 below). The topics provide the most up-to-date information on functions, commands, and syntax. Get in the habit of using `help()`.

As of now (September, 1994) there is no comprehensive manual for MacAnova 3.35 or later. However, the *MacAnova User's Guide*, University of Minnesota School of Statistics Technical Report 493 as revised March 1993, is a complete reference for MacAnova 3.11. Virtually everything there is still applicable with the exception of the appendices. Of course, it does not include the features and enhancements introduced with version 3.35. File `changes.txt` distributed with MacAnova summarizes these changes.

2. The Basics

2.1 *MacAnova as numeric calculator*

By typing numbers and algebraic symbols you can use MacAnova as a simple calculator.

```
    Cmd> 3 + 5  # space between items is o.k.; simply 3+5 is o.k.
    (1)          8
```

```
Cmd> 2 + 1 0 # but not spaces between digits in a number
ERROR: problem with input near 2 + 1 0

Cmd> 4*7e3 ; 3^4 ; 14.5 %% 5 #
(1)        28000   4 x 7000
(1)           81   3 to the 4th power
(1)          4.5   remainder when 14.5 is divided by 5

Cmd> sqrt(20); sq rt(20) # space in name is an error
(1)       4.4721   √20    "sqrt" means square root
ERROR: problem with input near sqrt(20); sq rt

Cmd> log(3)*(5+sqrt(6)) #combination of functions and arithmetic
(1)       8.1841   ln(3) x (5+√6)
```

These lines illustrate several features (we'll explain about the "(1)" in the output later).

When you type a number or an expression at the Cmd> prompt you get immediate output.

Spaces are generally ignored, except that you can't embed them in numbers or names.

You can use parentheses to force addition or subtraction to be done before other operations.

You can do several things on a single line, separating them by ";". Each part can produce its own output on a new line as if they were typed after different prompts.

You can compute things like square roots by typing their names with a number in parentheses. Among other so called "transformations" available are exp(), cos(), sin(), tan(), log10(), and atanh(). Type help("transformations") for a full list.

You can enter numbers using computer scientific notation: 1.3e4 is $1.3*10^4$, -3.231e-17 is $-3.231*10^{-17}$, etc.

The full set of arithmetic operators consists of "+", "-", "*" (multiplication), "/" (division), "^" (exponentiation), and "%%" (modular division: 14.5 %% 5 computes 4.5, the remainder of 14.5 when divided by 5).

MacAnova more or less follows the normal rules of algebra in evaluating expressions. For example 3 + 4*3 is evaluated as 3 + 12, while (3 + 4)*3 is evaluated as 7*3. Exponentiation is a little tricky in that 2^4*3 is interpreted as 16*3, while 2^(4*3) is evaluated as 2^12. Also * and / are evaluated step by step from left to right so that

3*4/5*6 is evaluated as ((3*4)/5)*6.

2.2 *MacAnova as symbolic calculator*

Besides simple arithmetic such as 3+sqrt(2) involving only numbers, you can create named *variables* with numerical values and do arithmetic and other computations on them as illustrated by the following example

```
Cmd> x <- 10; a <- 1101.1; b <- -2 # store values in variables

Cmd> a + b * x # use variables in an expression
(1)       1081.1
```

Here we have created variables x, a, and b with specific values and then used them in an algebraic formula or expression. These values remain available under these names until you change them, delete them, or you quit MacAnova. Expressions can be almost arbitrarily complicated and can contain transformations as well as other MacAnova functions.

The combined symbol "<-" (less than followed by minus) is the *assignment operator*. The value of the number or expression to the right of it is saved in the variable to the left. Its use is analogous to the use of "=" in certain computer languages such as Fortran and C or to ":=" in Pascal. A very common mistake is to use "=" when you mean "<-".

A few variables such as PI and E, are *predefined* although their values can be changed.

```
Cmd> PI; E # E is base of natural logarithms
(1)       3.1416
(1)       2.7183
```

The names of variables must begin with a letter, but subsequent characters may be numbers or letters or the underscore character '_'. Variable names are case sensitive, which means that residuals, Residuals, and RESIDUALS are all different names. It is a good idea to avoid names with all capital letters, as MacAnova deletes and creates certain variables with all capital names (for example, RESIDUALS). You can get an alphabetized listing of all active variables using commands listbrief() or list().

A variable's name may also start with the character '@' (as in @mean). Such a variable is called a *temporary variable* because it will be automatically deleted at the next "Cmd>" as in the following example

```
Cmd> @xbar <- sum(x)/n; var <- sum((x-@xbar)^2)/(n-1)

Cmd> @xbar # MacAnova has automatically deleted @xbar
UNDEFINED
```

Sometimes you may want to remove a variable from computer memory, perhaps because you have gotten the warning message

```
ERROR: not enough memory, try deleting variables
```

Command delete() does the trick.

```
     Cmd> delete(x, n) #deletes variables x and n

     Cmd> x # x is no longer defined
     UNDEFINED
```

You can delete as many variables as you like in a single use of delete().

2.3 *MacAnova as computing language -- functions and macros*
In a technical sense, MacAnova commands are *functional*. Transformations such as sqrt() or log10() are particular cases of functions. When they are used they have inputs called *arguments* (in log10(3.145), 3.145 is an argument), and they *return* (produce as output) results which can be saved in a variable, combined with other values in an expression, or printed.

Many functions have several arguments, separated by commas, the whole list being contained between parentheses as in the following examples

```
     Cmd> round(17/3,3) # round to three decimals
     (1)          5.667

     Cmd> hypot(3,4) # computes sqrt(3^2+4^2)
     (1)            5
```

Some functions just do things, but don't return any value that can be assigned to a variable. We usually call such functions simply *commands*. For example print() is a command that can be used to print several variables or expressions, perhaps with an increased number of significant digits, as in the following example.

```
     Cmd> w <- sqrt(10); w; print(nsig:12,w)
     (1)         3.1623            Output from 'w'
     w:
     (1)         3.16227766017     Output from print()
```

The argument nsig:12 for print() is an example of a *keyword phrase* of the form name:value, and is typical of the syntax used to control the behavior of many commands and functions. Because print() does not return a value, we get an error message if we try to use it as if it does:

```
     Cmd> z <- print(sqrt(3)) # erroneous try to assign print value
     NUMBER:
     (1)         1.7321   Produced by print()
     ERROR: assignment from null operation Because of use of <-
```

A few functions or commands can be used with no arguments. They still need a pair of parenthesis, but with nothing between them. For example

```
Cmd> listbrief() # list all MacAnova objects
boxcox      colplot     console     CONSOLE     DATAFILE    DEGPERRAD
DELTAT      E           fcolplot    frowplot    getdata     getmacros
MACROFILE   makecols    makefactor  model       PI          readcols
regs        resid       resvsindex  resvsrankits resvsyhat  rowplot
twotailt    yhat
```

Commands that do not return a value usually produce what we call *side effects*. For example, the side effects of print() are the printed values of its arguments and one side effect of regress() is a printed regression analysis. In addition, some commands like regress() create, as side effects, variables with standard names such as SS, DF, RESIDUALS or COEF containing quantities related to the analysis.

In addition to functions, MacAnova has what are known as *macros*. Their usage is almost indistinguishable from that of functions. To use a macro, you type its name followed by arguments separated by commas and enclosed in parentheses. Like functions, macros may return values or have side effects. Macros do differ from functions in some important ways, but most of the time you can treat them the same. Here is an example of the use of the useful macro boxcox which takes two arguments, here cat(3.03,3.01,3.32,3.65,4.42) and .5.

```
     Cmd> boxcox(cat(3.03,3.01,3.32,3.65,4.42),.5)
     (1)      2.7514        2.73      3.0538      3.3822      4.0949
```

Probably the most important difference between functions and macros is their availability. A function can always be used. There is nothing you can do to delete it. Macros, on the other hand, are more like variables -- they can be predefined, deleted, read in from a file, entered at the keyboard and printed. Predefined macros like boxcox, getmacros and resvsrankits are automatically available. Others such as hist must be read from a file on a floppy or hard disk using getmacros or macroread(). When you have some experience with using MacAnova, you can create your own macros to extend the range of what MacAnova can do (see Sec. 7.7 of the User's Guide). File MacAnova.mac, usually in the same Folder or directory as MacAnova, contains dozens of macros you may find useful. You can get a list of all the macros already in MacAnova by command listbrief(macros:T).

```
Cmd> listbrief(macros:T)
boxcox      colplot     console      fcolplot    frowplot    getdata
getmacros   makecols    makefactor   model       readcols    regs
resid       resvsindex  resvsrankits resvsyhat   rowplot     twotailt
yhat
```

You may already have spotted one of the conventions of this document -- when a MacAnova function is referred to by name, it always has a pair or parentheses attached, as in print(). On the other hand, when a macro is referred to by name, just its name is given, as in boxcox. Whenever you use it, a functions or a macro must be followed by parentheses enclosing the arguments, or if there are no arguments, by an empty pair of parentheses.

A function or macro returning a value can be used anywhere a simple number or variable name can be used -- in expressions and as an argument to another function or macro. A simple example is `sqrt(a + 3*boxcox(x,.5))`.

2.4 *More on Variables -- REAL, LOGICAL, and CHARACTER data*

Named variables can contain several types of data. The most common are numbers such as 2.4, -1, or 3.1478x10^{-8}. In MacAnova this type is called `REAL`. Almost as common are variables which have only two possible values, True and False. In MacAnova these are called `LOGICAL`, and True and False are typed or printed simply as `T` and `F`.

The values of some variables are strings of characters. In MacAnova they are called `CHARACTER` variables. When typing `CHARACTER` data on the keyboard, the strings must be enclosed in double quotes, for example,

```
    Cmd> string <- "This is a character string"
```

In some MacAnova output, `LOGICAL` and `CHARACTER` are abbreviated to `LOGIC` and `CHAR`. Some more advanced data types are `STRUCTURE` and `GRAPH`. Function `list()` may be used to list the names of variables, together with their data types and their dimensions, while `listbrief()` just lists their names. If you use one of the keyword phrases `real:T`, `char:T` or `logic:T` as an argument to `list()` or `listbrief()`, only variables of the specified type are listed.

Here are some examples.

```
    Cmd> x <- 1/3; l <- T; s <- "This is a string"; print(x,l,s)
    x:
    (1)     0.33333    REAL  data
    l:
    (1) T                     LOGICAL  data
    s:
    (1) "This is a string" CHARACTER  data

    Cmd> list(x,l,s,PI,DATAFILE,boxcox) # info in alphabetical order
    boxcox            MACRO
    DATAFILE          CHAR    1
    l                 LOGIC   1
    PI                REAL    1
    s                 CHAR    1
    x                 REAL    1

    Cmd> listbrief(x,l,s,PI,DATAFILE,boxcox)
    boxcox      DATAFILE     l            PI          s          x
```

```
    Cmd> list(real:T)
    data              REAL    8      2
    DEGPERRAD         REAL    1
    DELTAT            REAL    1
    E                 REAL    1
    PI                REAL    1
    x                 REAL    1
```

As in this usage, `LOGICAL` values `T` and `F` are often used to represent "yes" and "no" in keyword phrases specifying function options. Other examples are `silent:T` (suppresses output on `regress()`) and `lines:T` (makes `plot()` draw lines between points).

`LOGICAL` values can even be used in arithmetic expressions and a few functions (but not as arguments to functions like `sqrt()` or `log()`), with True being treated as 1 and False as 0.

```
    Cmd> cat(T,F) + 3 # same as cat(1,0) + 3
    (1)            4            3
```

Any character is allowed inside a `CHARACTER` variable, even a `Return` character. One common source of trouble is *forgetting to add the closing double quote to a character string and hitting* `Return` . You expect MacAnova to respond but it doesn't. Without the closing double quote, MacAnova is just waiting for you to put more characters inside the string variable. Type the closing double quote or nothing will ever happen.

You may include a double quote in a `CHARACTER` variable by preceding it with a backslash.

```
    Cmd> print("Hello");print("\"Hello\"")
    Hello
    "Hello"
```

2.5 *Comparisons of numbers and combining LOGICAL values*

One place where `LOGICAL` values naturally arise is when you want to compare the value of one variable with another as in the following example

```
    Cmd> a <- 5; b <- 6; c <- 5 # assign values to a, b, and c

    Cmd> a < b; a > b; a == c # less than, greater than, equal to
    (1) T       True because a is less than b
    (1) F       False because a is not greater than b
    (1) T       True because a equals b

    Cmd> cat(a >= b, a <= c, b != c) # a ≥ b, a ≤ c, b ≠ c
    (1) F       T       T
```

Note that "==" means "is equal to", ">=" and "<=" mean "greater than or equal to" and "less than or equal to," and "!=" means "not equal to." On a Macintosh you can use "≤", "≥" and "≠" instead of ">=", "<=" and "!="

There are three logical operators, "!", "&&" and "||".

"!" is the *not* operator, changing True to False and vice versa.

```
    Cmd> 3 <= cat(2,3);!(3 <= cat(2,3))
    (1) F        T   3 ≤ 2 is False, 3 ≤ 3 is True
    (1) T        F   not(3 ≤ 2) is True, not(3 ≤ 3) is False
```

"&&" is the *and* operator. c && d has value True if and only if *both* c and d have value True:

```
    Cmd> cat(T && T, T && F, F && T, F && F)
    (1) T        F        F        F
```

"||" is the *or* operator. c || d has value True if and only if either c or d or both have value True:

```
    Cmd> cat(T || T, T || F, F || T, F || F)
    (1) T        T        T        F
```

2.6 *Variables with several values -- Vectors and Matrices*

In most of the examples so far, a MacAnova variable contains only a single value, whether REAL, LOGICAL, or CHARACTER. Such variables are usually called *scalar* variables or simply *scalars*. Obviously, this does not get you very far in statistics. What we need are variables that can contain several numbers, perhaps an entire sample of data. The simplest such variable in MacAnova is a *vector*, a variable containing several numbers, several True/False values, or several character strings.

The basic function for creating a vector is cat(), which can have any number of arguments, all of the same type. There have been a number of usages of cat() presented without comment above. Consider the following simple examples.

```
  Cmd> x<-cat(33.5, 27.3, 36.7, 30.5); x# 3.10 in Devore & Peck
  (1)          33.5          27.3          36.7          30.5

  Cmd> w <- cat(T,T,F,T,T,T,F,F,T,T); w # 3.12 in D&P, T means S
   (1) T       T       F       T       T       T       F       F       T
  (10) T

  Cmd> dakotas <- cat("South Dakota","North Dakota"); dakotas
  (1) "South Dakota"
  (2) "North Dakota"
```

Individual elements of a vector may be "extracted" using *subscripts*, values enclosed in square brackets [...], as in the following examples.

```
    Cmd> x[3]; w[7]; j <- 2; dakotas[j]
    (1)          36.7
    (1) F
    (1) "North Dakota"

    Cmd> print(x[cat(3,4)], x[cat(-1, -2)], x[cat(F,F,T,T)])
    VECTOR:
    (1)          36.7          30.5
    VECTOR:
    (1)          36.7          30.5
    VECTOR:
    (1)          36.7          30.5
```

As the first example shows, subscripts can be variables as well as numbers. The second example shows that you can extract several values at once, in several different ways.

If a subscript is itself a *vector of positive integers* such as cat(3,4), the corresponding elements of the variable are extracted as if you had typed, say, cat(x[3],x[4]). There can even be duplicates in the subscript vector -- x[cat(1,1,3)] is the same as cat(x[1],x[1],x[3]).

If the subscript is a *vector of negative integers*, you extract all the *other* elements. Thus x[cat(-1, -2)] extracts all the elements of x except the first and the second. You cannot have duplicate negative subscripts nor can you mix them with positive subscripts.

If the subscript is a *LOGICAL vector*, the values whose positions correspond to True are extracted and the remaining values omitted. A LOGICAL subscript vector must be the same length as the vector it is subscripting.

Sometimes a data set consists of several variables. It is often convenient to combine them in a single MacAnova variable in a sort of table form, with rows corresponding to different cases and columns corresponding to variables. Such a rectangular array is called a *matrix*. Here is a very simple example, which also contains our first example of a command that reads data from a data file (see Sec. 4.4 below).

```
    Cmd> data <- matread("","c4p01") # read data set c4p01 from file
    C4P01          8     2                          Header lines
    ) Data from Devore and Peck file C4P01.DAT      in the file are
    ) MISSING 999                                   echoed to screen
```

```
Cmd> data # see what values were read
(1,1)          0.34          2.8
(2,1)          0.35          1.9
(3,1)          0.39          3.3
(4,1)          0.39          5.6
(5,1)          0.41          4.2
(6,1)          0.41          5.6
(7,1)          0.49          4.2
(8,1)          0.68          7.9
```

There are 8 observations on bivariate data and we require *two* subscripts to extract a particular value. The numbers in parentheses (for example `(3,1)`) are the row and column number of the first value in the line.

```
Cmd> data[3,2] # row 3 and column 2
(1,1)          3.3

Cmd> data[,1] # all of column 1
(1,1)          0.34
(2,1)          0.35
(3,1)          0.39
(4,1)          0.39
(5,1)          0.41
(6,1)          0.41
(7,1)          0.49
(8,1)          0.68

Cmd> data[4,cat(1,2)] ; data[4,]# 2 ways to extract all of row 4
(1,1)          0.39          5.6
(1,1)          0.39          5.6
```

As you can see, an empty subscript selects all the values of that subscript. You can also use negative subscripts or `LOGICAL` vectors as subscripts:

```
Cmd> data[cat(F,F,F,T,F,F,F,F),];data[-cat(1,2,3,5,6,7,8),]
(1,1)          0.39          5.6
(1,1)          0.39          5.6
```

You can create a matrix from a vector by function `matrix()`. For example, to create matrix `data` at the keyboard you can type

```
Cmd> data<-matrix(cat(.34,.35,.39,.39,.41,.41,.49,.68,\
2.8,1.9,3.3,5.6,4.2,5.6,4.2,7.9), 8)
```

The general form is `matrix(v, nr)`, where `v` is a vector and `nr` is the number of rows. It is an error if the length of `v` is not divisible by `nr`. The values in `v` are entered into the result column by column.

You would create vectors corresponding to the columns of `data` by

```
Cmd> x <- cat(data[,1]); y <- cat(data[,2]); print(x,y)
x:
(1)          0.34          0.35          0.39          0.39          0.41
(6)          0.41          0.49          0.68
y:
(1)           2.8           1.9           3.3           5.6           4.2
(6)           5.6           4.2           7.9
```

Here `cat()` has changed each column to a vector with only 1 subscript. The numbers in parentheses (`(1)` and `(6)`) are the subscripts of the first number on that line. Thus `x[6]` has value 0.41.

The comparison operators introduced in Sec. 2.5 can be used to compute `LOGICAL` vectors which can be used as subscripts. For example, suppose you want to select only the elements y of corresponding to values of x > .35 and x ≤ .45. You can use comparison operators and the "&&" operator.

```
Cmd> y[x > .35 && x <= .45] # same as y[cat(F,F,T,T,T,T,F,F)]
(1)          3.3          5.6          4.2          5.6
```

2.7 *Missing values*

Missing values are a common occurrence when you are dealing with real data. You may have measurements of both the height and weight of each of 19 people, but for one reason or another, for two other people, you have only their weights so that two heights are missing. Or, when entering data for computer analysis, you may notice a value is impossible (for example, a human height of 61 feet). MacAnova has a special value, `MISSING`, that can be used to replace such values. When typed from the keyboard, the code for `MISSING` is a question mark, "?", but printed, it prints as `MISSING`.

```
Cmd> a <- cat(3,?,-7,?,4); a
(1)            3     MISSING            -7     MISSING            4
```

Many commands do something fairly sensible with values of `MISSING`. A few give you a warning:

```
Cmd> 5 + a
WARNING: arithmetic with missing values(s)
(1)            8     MISSING            -2     MISSING            9
```

This illustrates that a value of `MISSING` combined arithmetically with anything else gives a missing value.

`LOGICAL values of MISSING are also possible, although the only way to create them is by a comparison of a number with MISSING:`

```
Cmd> a > 0
WARNING: arithmetic comparison with missing values(s)
(1) T       MISSING F       MISSING T
```

Function `ismissing()` can be used to find which values in a `REAL` or `LOGICAL` data set are `MISSING`. `ismissing(x)` returns a `LOGICAL` variable with the same size and shape (dimensions) as `x` whose values are True where `x` is `MISSING`, and False where `x` is not missing.

```
    Cmd> ismissing(cat(1,?,3))
    (1) F        T        F
```

3. Building on the Basics

3.1 *Combining vectors and matrices -- cat(), hconcat() and vconcat()*

We learned above in Sec. 2.6 how to use `cat()` to create vectors from several individual values. You can also use `cat()` to combine several vectors to make a longer vector.

```
    Cmd> a1 <- cat(1,3,5); a2 <- cat(6,7,8); a3 <- 10

    Cmd> cat(a1,a2,a3) # make longer vector like cat(1,3,5,6,7,8,10)
    (1)            1            3            5            6            7
    (6)            8           10
```

Function `cat()` can also be used to change a matrix to a vector.

```
    Cmd> cat(data) # data is the 8 by 2 matrix read from a file
     (1)        0.34         0.35         0.39         0.39         0.41
     (6)        0.41         0.49         0.68          2.8          1.9
    (11)         3.3          5.6          4.2          5.6          4.2
    (16)         7.9
```

First we get all the values in column 1 of `data`, followed by the values in column 2.

Sometimes you will want to make a larger matrix by combining together *side by side* two or more vectors or matrices. Obviously all the pieces must have the same number of rows. For example, suppose you want to put vectors `x` and `y` back together in a matrix, together with a column containing the case numbers.

```
    Cmd> data1<- hconcat(cat(1,2,3,4,5,6,7,8),x,y); data1
    (1,1)              1        0.34          2.8
    (2,1)              2        0.35          1.9
    (3,1)              3        0.39          3.3
    (4,1)              4        0.39          5.6
    (5,1)              5        0.41          4.2
    (6,1)              6        0.41          5.6
    (7,1)              7        0.49          4.2
    (8,1)              8        0.68          7.9
```

This has produced the 8 by 3 matrix `data1`. The general usage of `hconcat()` is

`hconcat(a,b,c,...)`, where each argument is a vector or matrix with the same number of rows.

If you want to combine two or more matrices all with the same number of columns by stacking them *one above the other*, you can use `vconcat()`:

```
    Cmd> vconcat(data[cat(5,6,7,8),], data[cat(1,2,3,4),])
    (1,1)           0.41          4.2
    (2,1)           0.41          5.6
    (3,1)           0.49          4.2
    (4,1)           0.68          7.9
    (5,1)           0.34          2.8
    (6,1)           0.35          1.9
    (7,1)           0.39          3.3
    (8,1)           0.39          5.6
```

This reorders the rows of `data`, putting the rows 5 through 8 ahead of rows 1 through 4.

3.2 *Creating patterned vectors -- run() and rep()*

Suppose you want a vector with values 1, 2, 3, 4, and 5. You learned in Sec. 2.6 that this could be done by `y <- cat(1,2,3,4,5)`. You could enter a vector with values 1, 2, 3, ..., 100 the same way but it would be tedious and easy to make a mistake. Function `run()` provides a short cut. Here is the simplest usage of `run()`:

```
    Cmd> run(8) # produce vector with values 1, 2, 3, ..., 8
    (1)            1            2            3            4            5
    (6)            6            7            8
```

Here are other, fairly self explanatory, uses of `run()`:

```
    Cmd> run(3,11) # values from 3 to 11
    (1)            3            4            5            6            7
    (6)            8            9           10           11

    Cmd> run(3.5,5,.5) # values from 3.5 to 5.0 stepping by 0.5
    (1)          3.5            4          4.5            5

    Cmd> run(5,3.5,-.5) # backwards from 5.0 to 3.5, stepping by -.5
    (1)            5          4.5            4          3.5            3
```

Sometimes you may want a vector consisting of all 1's or some other value. You could use `cat(1,1,1,1,1,1,1)`, say, to get seven 1's, but function `rep()` is easier.

```
    Cmd> rep(1,7) # vector of 7 1's
    (1)            1            1            1            1            1
    (6)            1            1
```

Instead of repeating a single number, you can repeat a vector:

```
    Cmd> rep(run(4),2) # like cat(run(4),run(4))
    (1)          1          2          3          4          1
    (6)          2          3          4
```

There is a more elaborate use of `rep()` that is sometimes useful:

```
    Cmd> rep(run(3), rep(2,3)) # same as rep(run(3), cat(2,2,2))
    (1)          1          1          2          2          3
    (6)          3
```

Each of the numbers in `run(3)` is repeated 2 times. The second argument of `rep()` here is the same length as the first and provides the number of repetitions. Here is an even fancier usage:

```
    Cmd> rep(run(3),cat(2,3,4))
    (1)          1          1          2          2          2
    (6)          3          3          3          3
```

This repeats 1 two times, 2 three times, and 3 four times.

3.3 *Assigning values to the elements of a vector or matrix*

If you want to change one or a few elements in a vector or matrix, you can assign new values directly using subscripts. For example, suppose you learned the value in row 8 of column 2 of the matrix `data` was incorrect and that the correct value should have been .58 instead of .69. You could make the change by

```
    Cmd> data[8,1] <- .58; data
    (1,1)          0.34        2.8
    (2,1)          0.35        1.9
    (3,1)          0.39        3.3
    (4,1)          0.39        5.6
    (5,1)          0.41        4.2
    (6,1)          0.41        5.6
    (7,1)          0.49        4.2
    (8,1)          0.58        7.9
```

You would make the same change in vector x by

```
    Cmd> x[8] <- .58; x
    (1)        0.34        0.35        0.39        0.39        0.41
    (6)        0.41        0.49        0.58
```

You can change several values at once:

```
    Cmd> w <- run(5); w
    (1)          1          2          3          4          5

    Cmd> w[run(2)] <- cat(-10, ?); w[-run(3)] <- 17; w
    (1)        -10    MISSING          3         17         17
```

In this last command line, we first replace elements 1 and 2 (`run(2)`) of w by -10 and a missing value, and then replace elements 4 and 5 (all except elements 1, 2, and 3) by 17. For future use we change back `data[8,1]` and `x[8]` to their original values.

```
    Cmd> data[8,1] <- .68; x[8] <- .68
```

3.4 *Simple summaries of data in vectors and matrices -- sum(), prod(), min(), max(), sort() and rank()*

Functions `sum()`, `prod()`, `min()`, and `max()` compute the sum of, the product of, the minimum of, and the maximum of the values in a vector.

```
    Cmd> cat(sum(y), prod(y), min(y), max(y))
    (1)        35.5       76723         1.9         7.9
```

For comparison, here are the sum and product as computed "by hand":

```
    Cmd> cat(2.8 + 1.9 + 3.3 + 5.6 + 4.2 + 5.6 + 4.2 + 7.9,\
    2.8 * 1.9 * 3.3 * 5.6 * 4.2 * 5.6 * 4.2 * 7.9)
    (1)        35.5       76723
```

Function `sum()` is useful for computing means, variances and standard deviations from the basic formulas $\bar{y}=\sum_{i=1}^{n} y_i/n$ and $s_y^2=\left(\sum_{i=1}^{n}(y_i-\bar{y})^2\right)/(n-1)$.

```
    Cmd> n <- nrows(y); ybar <- sum(y)/n # mean

    Cmd> yvar <- sum((y- ybar)^2)/(n-1) # variance

    Cmd> cat(ybar, yvar) # mean and variance
    (1)       4.4375      3.6027
```

You can compute the range ($y_{max} - y_{min}$) by

```
    Cmd> max(y) - min(y)
    (1)          6
```

Function `sort()` allows you to reorder the elements in a vector in increasing order:

```
    Cmd> yup <- sort(y); ydown <- sort(y,down:T); hconcat(yup,ydown)
    (1,1)          1.9         7.9  Col. 1 is y sorted up
    (2,1)          2.8         5.6  Col. 2 is y sorted down
    (3,1)          3.3         5.6
    (4,1)          4.2         4.2
    (5,1)          4.2         4.2
    (6,1)          5.6         3.3
    (7,1)          5.6         2.8
    (8,1)          7.9         1.9
```

Of course, these also give you another way to compute the minimum and the maximum:

```
Cmd> cat(sort(y)[1], sort(y,down:T)[1])
(1)           1.9          7.9
```

This last also shows that you can use subscripts directly on the values of functions.

One important way of summarizing a vector of numbers, is to compute the *ranks* within the vector of each of the elements, with the smallest value getting rank 1, the next smallest getting rank 2, etc. You can do this in MacAnova using function `rank()`:

```
Cmd> a <- cat( 14.7, 13.1, 16.6, 12.9, 12.5); rank(a)
(1)              4            3            5            2            1
```

Since 14.7 is the 4th number in order of size (there are 4-1 = 3 numbers less than 14.7) it gets rank 4, etc. When there are ties, the ranks of the tied values are the averages of what would be the ranks of any tied values if they were very slightly changed so as to break the tie:

```
Cmd> b <- cat( 14.7, 13.1, 16.6, 12.5, 12.5); rank(b)
(1)              4            3            5          1.5          1.5
```

If the second 12.5 were modified, say to 12.500001, the two last ranks would be 1 and 2 which average to 1.5.

All these functions can have matrices as arguments. In the case of `sum()`, `prod()`, `min()`, and `max()` the result is a *row vector*, a matrix with only one row, containing the result of applying the function to each column. Both `sort()` and `rank()` compute a new matrix, the same size as the argument, with the ordered values or ranks of each column. Let's apply these to the matrix `data`:

```
Cmd> sum(data); prod(data); min(data); max(data)
(1,1)          3.46         35.5  Sums
(1,1)     0.0010138        76723  Products
(1,1)          0.34          1.9  Minima
(1,1)          0.68          7.9  Maxima

Cmd> hconcat(sort(data), rank(data))
(1,1)          0.34          1.9            1            2
(2,1)          0.35          2.8            2            1
(3,1)          0.39          3.3          3.5            3
(4,1)          0.39          4.2          3.5          6.5
(5,1)          0.41          4.2          5.5          4.5
(6,1)          0.41          5.6          5.5          6.5
(7,1)          0.49          5.6            7          4.5
(8,1)          0.68          7.9            8            8
```

In the last, the first two columns are the ordered values in each column of `data`, and the last two columns are the ranks of each column of `data`.

Other descriptive descriptive statistics that are computed from the ordered values in a

sample are the lower and upper (first and third) quartiles and the median (second quartile). The median is the central value in order of size if n is odd, and is the average of the two central values if n is even. A common way to define the lower and upper quartiles is the medians of the lower and upper halves of the data, putting the middle value in both halves if n is odd. As an an example we compute the 3 quartiles of `y`, as well as the inter-quartile range (IQR), a measure of the spread or dispersion of the sample:

```
Cmd> q1 <- sum(sort(y)[cat(2,3)])/2 # lower quartile

Cmd> q2 <- sum(sort(y)[cat(5,6)])/2 # median

Cmd> q3 <- sum(sort(y)[cat(6,7)])/2 # upper quartile

Cmd> cat(q1,q2,q3)
(1)          3.05          4.9          5.6

Cmd> iqr <- q3 - q1; iqr # Interquartile range
(1)          2.55
```

3.5 *Simple descriptive statistics -- describe()*

In the previous section you learned how to compute some basic descriptive statistics from their definitions using basic MacAnova functions such as `sum()`, `max()` and `min()`. In fact, if you try hard enough, practically any statistical analysis that you might do using MacAnova can be accomplished this way. But, as promised at the outset, for most analyses there are ***built-in*** commands and functions that do complete analyses without you having to know computing formulas.

Function `describe()` enables you to compute in one line almost all the descriptive summaries we have seen above. It is best introduced by an example:

```
Cmd> describe(y) # y is the second column of data from D&P 4.1
component: n
(1)             8       Sample size
component: min
(1)           1.9       Minimum
component: q1
(1)          3.05       Lower quartile
component: median
(1)           4.2       Median
component: q3
(1)           5.6       Upper quartile
component: max
(1)           7.9       Maximum
component: mean
(1)        4.4375       Mean (average)
component: var
(1)        3.6027       Variance
```

As printed output this is pretty self-explanatory. It looks just like a side-effect of `describe()`. However, what is printed is actually the value that `describe()` returns. The value can, in fact be saved in a variable.

```
    Cmd> results <- describe(y); results$mean; results$var
    (1)       4.4375   Compare with mean above
    (1)       3.6027   Compare with variance above
```

Variable `results` is an example of a new type of variable called a *structure* (sometimes abbreviated "STRUC" in MacAnova).

```
    Cmd> list(results)
    results          STRUC  8
```

Structures are made up of several named *components*. Here there are eight of them, `n`, `min`, `q1`, `median`, `q3`, `max`, `mean`, and `var`. Individual components can be extracted as shown, by appending `$cname` to the name of the structure, where `cname` is the component name. You can find all names of all the components in a structure by function `compnames()`.

```
    Cmd> compnames(results)
    (1) "n"
    (2) "min"
    (3) "q1"
    (4) "median"
    (5) "q3"
    (6) "max"
    (7) "mean"
    (8) "var"
```

If all you want is one summary value, say the median, you can follow this example:

```
    Cmd> describe(y)$median # or describe(y,median:T)
    (1)          4.2
```

or to compute just the mean and variance

```
    Cmd> describe(y,mean:T,var:T)
    component: mean
    (1)       4.4375
    component: var
    (1)       3.6027
```

You can use `describe()` with a matrix argument, too:

```
    Cmd> describe(data)
    component: n
    (1)            8            8
    component: min
    (1)         0.34          1.9
    component: q1
    (1)         0.37         3.05
    component: median
    (1)          0.4          4.2
    component: q3
    (1)         0.45          5.6
    component: max
    (1)         0.68          7.9
    component: mean
    (1)       0.4325       4.4375
    component: var
    (1)     0.012079       3.6027
```

Each component is now a vector with one value for each column of the argument matrix.

Several other MacAnova functions, including `split()`, `coefs()`, `secoefs()`, `cellstats()`, and `regpred()`, compute structures as their values. See Sec. 7.2 in the User's Guide for information about functions `makestr()` and `changestr()` which allow you to create or modify structures directly.

3.6 *Getting help -- MacAnova command help()*

If you need to refresh your memory about any function or command or about general topics like syntax, you can use MacAnova's `help()` command. Suppose you wanted more detail on the function `round()` used in one of the examples above.

```
    Cmd> help(round)
    round(x) rounds the elements of the numerical variable x to the
    nearest integer, producing a vector, matrix, or array with the
    same shape as x.

    round(x,n) where n is an integer is equivalent to
    10^(-n)*round(x*10^n). If n is a positive integer, this rounds to
    n decimal places.

    If x is a structure, so is round(x) or round(x,n).  If xi is the
    i-th component of x, the i-th component of round(x) or round(x,n)
    is round(xi) or round(xi,n).

    Example: round(3141.593,2) is 3141.59 and round(3141.593,-2) is
    3100.

    See also floor(), ceiling(), structures.
```

Typically, as here, the first line gives the most standard usage, with more complex usages given later. Often, as in the last line, there are cross references to related topics.

There are hundreds of help topics. Here is how you get a list of all the topics:

```
    Cmd> help() # help() with no argument
    Help is available on the following topics:
    addchars     cumgamma     if           nameof       setoptions
    addlines     cumnor       inforead     nbits        setseeds
    addpoints    cumpoi       invbeta      ncols        shell
    addstrings   cumstu       invchi       ncomps       showplot
    . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
```

On the Macintosh, selecting **Help** from the menu or pressing ⌘H is equivalent to typing `help()`. See Appendix A.

The topics available include all the commands and functions, plus some more general topics such as `matrices`, `subscripts`, and `transformations`. To get help on a particular topic, use `help()` with one or more topics as arguments. You have to quote any topic names longer than 12 characters (for example, `"transformations"`), or the names of syntactic elements (`while`, `for`, `break`, `breakall`, `if`, `else`, `elseif`). On the Macintosh, if you use the mouse to select a topic is selected in the command window, **Help** from the menu or ⌘H gets help on the selected topic. Chapter 8 of the User's Guide largely overlaps the help information. Command `help()` reads the information it prints from a file, `MacAnova.hlp`.

Sometimes you may remember only part of the name of a topic, but not the full name. You can use the "wild card" character "*" in a string to get a list of topics matching certain patterns. The three types of patterns recognized are `"part*"`, `"*part"`, and `"*part*"` which match topic names starting with, ending with, or containing part.

```
    Cmd> help("res*") # find all topics starting with "res"
    resid         restore       resvsindex    resvsrankits resvsyhat

    Cmd> help("*plot*") # find all topics containing "plot"
    boxplot     fboxplot    flineplot   lineplot    showplot
    chplot      fchplot     fplot       plot
    colplot     fcolplot    frowplot    rowplot
```

Especially when you're new to MacAnova, you may not even know enough commands intelligently to use the pattern matching just described. All you know is you want to compute some descriptive statistics, or make a graph, or do some sort of residual analysis. You can look for help topics by keys. Here is an example:

```
    Cmd> help(key:"residuals") # find some topics about residuals
    The following help topics concern Residuals
    resid         resvsindex    resvsrankits resvsyhat
    For help on topic foo, enter help(foo) or help("foo")
```

MacAnova found four topics. You could now get help on topic `resid`, say, by typing

`help(resid)`. If you have no idea of the keys available, just do this:

```
    Cmd> help(key:"?")
    Type 'help(key:"heading")', where heading is in following list:
    ANOVA                    Input                    Probabilities
    Categorical Data         LOGICAL Variables        Random Numbers
    CHARACTER Variables      Macros                   Regression
    Combining Variables      Matrix Algebra           Residuals
    Complex Arithmetic       Missing Values           Structures
    Control                  Multivariate Analysis    Syntax
    Descriptive Statistics   Operations               Time Series
    Files                    Ordering                 Transformations
    GLM                      Output                   Variables
    General                  Plotting
```

When you specify a key, you only need as many letters as will make it unique. This `help(key:"des")` is as good as `help(key:"descriptive statistics")` (upper and lower case doesn't matter here).

If you learn how to use `help()`, it isn't that important to have a manual, since most of the details of commands are summarized in their help entries.

4. Using files

4.1 *General*

Although you can do a lot of work without using any of the commands that have to do with external (disk) files, commands that read or write files add a lot of capability to MacAnova. You can record your session in a file on disk using `spool()`, save all your variables in a file using `save()` and `asciisave()`, read data from a file using `vecread()` or `matread()`, and write data and results to a file using `print()` and `matwrite()`.

In all these commands, you need to specify a file name in quotation marks, for example, `matread("mydata.dat")`. MacAnova has no special conventions for file names as long as they are legal for the system on which it is running. File names used in examples below, are just that, examples. There is no need to use the same names, or end them the same same way (like `.dat`).

Things are a little easier on a Macintosh, since you can always use the null file name `""` (two double quotes with nothing between them). This brings up the usual Macintosh scrolling dialog box to let you select or specify a file.

On most commands except `save()` and `asciisave()`, if a file you are writing already exists, whatever you write to the file goes at the end of the information there, leaving what is there intact. If that is not what you want, use the keyword phrase `new:T` as an argument, as in `matwrite("mydata",x,new:T)`. (On a Macintosh, when you save the command window, it always as if you specified `new:T`.)

4.2 *Recording your MacAnova session -- spool()*

Often when you use MacAnova you want some sort of record of what you have done, or at least a permanent copy of those answers you want. Command `spool()` makes this quite easy in MacAnova -- as long as you remember to use it.

Command `spool()` keeps a record of some or all of your MacAnova session on a hard disk or floppy. As soon as you want to start saving stuff, you need to type something like

```
    Cmd> spool("spool.txt") # start spooling on file spool.txt
```

This starts recording (spooling) on file `spool.txt`. From now on, everything you type and everything MacAnova replies except high resolution plots will be written in the file. Of course, this includes any mistakes you make and your false starts. On a Macintosh, you don't need to type the file name but can type

```
    Cmd> spool("") # Null file name allowed only on Macintosh
```

If at some point, you want to suspend spooling, simply type

```
    Cmd> spool() # with no file name
    Spooling on spool.txt suspended
```

When you want to start recording again, you can again type

```
    Cmd> spool() # again with no file name
    Resume spooling on spool.txt
```

Effectively, once you have started spooling, `spool()`, with no argument, toggles it off and on.

When you are done with your session, you can read the spool file into almost any word processor or text editor, edit out what you don't want to keep and add your commentary. One tip -- if your word processor allows a choice of fonts, use a font that has equal width characters such as Courier or Monaco. If you don't, things that lined up on the MacAnova screen will not line up in your document and may be hard to read.

On a Macintosh the use of `spool()` is less necessary since all your input and MacAnova's output remain in the command window. At any time you can select **Save Window** (⌘S) or **Save Window As...** on the **File** menu and the entire contents of the window are written to disk for later editing. After the first time, the name of the file becomes the window title and you can re-save the window just by pressing ⌘S. When you quit, you are given a chance to save the command window on disk. A dialog box asks **Save Changes to Window "xxxxx" before closing?** To save, just click on the **OK** button (or the **Don't Save** button if you don't want to).

You can also use commands `print(file:"fileName",...)` and `write(file:"fileName",...)` to list individual variables in a file. See the Users' Guide or type `help(print,write)`.

4.3 *Saving your work -- save(), and asciisave()*

Sometimes you may not have time to do everything you want or need to in one session, and still have more to do when you have to quit. Commands `save()` and `asciisave()` are specifically designed to help you in this situation. They allow you to save all the current variables and macros in a file so that they can be restored (by command `restore()`) at the start of a later MacAnova session. Here is a typical use of `save()`:

```
    Cmd> save("savework.sav")
    Workspace saved on file savework.sav
```

You can now quit MacAnova. Later, when you restart, everything can be restored to the way it was by

```
    Cmd> restore("savework.sav") # restore("") on Macintosh
    Restoring workspace from file savework.sav
    Workspace saved Fri Sep 16 16:00:03 1994
```

On a Macintosh, instead of `save()` you can use either **Save Workspace** (⌘K) or **Save Workspace As...** on the **File** menu. When you next start up you can just double click on the saved file and MacAnova will be launched with everything restored.

If you use MacAnova on more than one type of computer, you might like to start on on computer, say a Macintosh, save your work, and then finish it later on another type, say a PC compatible computer. The file produced by `save()` isn't any good for this. Instead, use command `asciisave()`:

```
    Cmd> asciisave("savework.asc")
    Workspace saved on file savework.sav
```

This produces a text file which can be restored by MacAnova on any computer (by `restore("savefile.asc")`) or even sent via E-mail.

Command `save()` can also be a life saver if your computer is unstable and prone to crashing. If you save your work from time to time, you never will lose much if the computer goes down. After using `save("savework.sav")` or `asciisave ("savework.sav")` once, you can update the save file simply by `save()` or `asciisave()`, without a file name. On a Macintosh, simply press **⌘K**.

4.4 *Reading data from files -- functions vecread() and matread() and macro readcols*

Except when analyzing small amounts of data that can easily be typed in at the keyboard, you will probably want to work with data that is in a file on disk. The data may have been provided by someone else, entered by you using a word processor or editor or possibly exported from a spreadsheet.

The simplest type of data file readable by MacAnova consists of just numbers. Here is a listing of file `rabbit.dat` containing 12 determinations of the survival time in minutes under anaerobic conditions of certain rabbit nerves:

```
      16.2  22.5  21.4  19.6  24.8  21.4
      19.0  14.7  13.3  23.0  16.8  20.1
```

You can read these data into MacAnova by

```
    Cmd> x<-vecread("rabbit.dat" )# form is vecread(fileName)

    Cmd> x # print out what you've read in
     (1)          16.2        22.5        21.4        19.6        24.8
     (6)          21.4          19        14.7        13.3          23
    (11)          16.8        20.1
```

Function `vecread()` reads the numbers in the file sequentially, line by line to the end, and returns them as a vector. A question mark (?) is interpreted as `MISSING`. If `vecread()` finds anything it can't read, it skips it, printing a warning message. The one exception to this is that an exclamation point "`!`" in the file stops the reading right there. Suppose `rabbit.dat` actually was of the following form:

```
      Data on twelve rabbit nerves
      16.2  22.5  21.4  19.6  24.8  21.4
      19.0  14.7  13.3  23.0  16.8  20.1
```

Then, after `x<-vecread("rabbit.dat")`, Macanova will read the data correctly but will also print out:

```
    WARNING: nonnumeric character(s) ignored on standard input
```

If, instead the first line read "`Data on 12 rabbit nerves`", the 12 would be read as a number and vecread() would return 13 numbers, the `12` followed by the actual data. So, to be on the safe side, a file to be read by `vecread()` should contain only numbers.

Often a data file consists of several columns, with each column corresponding to a variable and each line to the data for a case. Consider the following file `crops.dat`:

```
     1926  20.1   7.2
     1927  23.6   7.1
     1928  26.3   7.4
     1929  19.9   6.1
     1930  16.7   6.0
     1931  23.2   7.3
     1932  31.4   9.4
     1933  33.5   9.2
     1934  28.2   8.8
     1935  35.3  10.4
     1936  29.3   8.0
     1937  30.5   9.7
```

The column 1 is a year and columns 2 and 3 are the average yields of wheat and potatoes, respectively, in each year. You can use macro `readcols` to read `crops.dat` into three MacAnova variables:

```
    Cmd> readcols("crops.dat",year,wheat,potatoes)

    Cmd> print(year,wheat,potatoes)
    year:
     (1)          1926        1927        1928        1929        1930
     (6)          1931        1932        1933        1934        1935
    (11)          1936        1937
    wheat:
     (1)          20.1        23.6        26.3        19.9        16.7
     (6)          23.2        31.4        33.5        28.2        35.3
    (11)          29.3        30.5
    potatoes:
     (1)           7.2         7.1         7.4         6.1           6
     (6)           7.3         9.4         9.2         8.8        10.4
    (11)             8         9.7
```

Since `readcols` uses `vecread()`, it recognizes "`?`" as `MISSING`, skips everything that is not a number and is terminated by "`!`".

Command `vecread()` is useful only when a file contains a single data set. Another MacAnova command, `matread()`, is designed to read data sets from files containing many data sets, all in a special format. It cannot read files that `vecread()` can read, and vice versa. See the Users' Guide or type `help(matread)` for details on the actual format. Here is a listing of file `crops.mat` containing the same data as `crops.dat` but in a format readable by `matread()` as a data matrix named `yields`. It is not readable by `vecread()` because it has a header line giving the number of rows and columns and several comment lines starting with "`)`".

```
    yields      12     3
    ) Col. 1: year
    ) Col. 2: wheat = wheat harvest
    ) Col. 3: potatoes = potato harvest
     1926  20.1   7.2
     1927  23.6   7.1
     1928  26.3   7.4
     1929  19.9   6.1
     1930  16.7   6.0
     1931  23.2   7.3
     1932  31.4   9.4
     1933  33.5   9.2
     1934  28.2   8.8
     1935  35.3  10.4
     1936  29.3   8.0
     1937  30.5   9.7
```

Here is how you read read the data in `crops.mat`:

```
    Cmd> data<-matread("crops.mat","yields")
    yields      12     3
    ) Col. 1: year
    ) Col. 2: wheat = wheat harvest
    ) Col. 3: potatoes = potato harvest

    Cmd> dim(data) # data is a matrix with 12 rows and 3 columns
    (1)          12           3
```

To get each column in a separate variable, you can either to it "by hand"

```
    Cmd> year <- data[,1]; wheat<- data[,2]; potatoes <- data[,3]
```

or use macro `makecols`:

```
    Cmd> makecols(data,year,wheat,potatoes)

    Cmd> list(year,wheat,potatoes) # now we have 3 vectors
    potatoes         REAL    12
    wheat            REAL    12
    year             REAL    12
```

The header line and descriptive comments are echoed to the screen.

5. Examples of statistical analyses

5.1 *Introduction*

This section includes some examples of statistical analyses using MacAnova. There is very little discussion of the analyses or explanation of the commands illustrated. Use `help()` or see the Users' Guide to get details of the general use of these commands. See a statistics textbook for information about the statistical techniques illustrated.

5.2 *Paired t analysis*

Table 6.3.1 of Snedecor and Cochran (7th Edition, Iowa State Press 1980) gives the number of lesions on each of two halves of eight tobacco leaves. One half of each leaf was exposed to one preparation of a virus extract and the other half was exposed to another preparation. A paired analysis, based on the differences between the two halves of each leaf, is appropriate.

```
    Cmd> x1<-cat(31,20,18,17,9,8,10,7) # Data for preparation 1

    Cmd> x2<-cat(18,17,14,11,10,7,5,6) # Data for preparation 2

    Cmd> d <- x1 - x2; d ;n <- nrows(d) # differences
    (1)          13          3          4          6         -1
    (6)           1          5          1
```

```
    Cmd> stemleaf(d) # make stem and leaf display
        1    -0*|1
        3    +0*|11
        4    +0t|3
        4    +0f|45
        2    +0s|6
     High  13
             1*|1  represents 11  Leaf digit unit = 1

    Cmd> describe(d, n:T, mean:T, var:T)
    component: n
    (1)          8
    component: mean
    (1)          4
    component: var
    (1)      18.571
```

You could use MacAnova as a calculator to compute a paired t-test and a confidence interval for the mean difference from these values. Instead, you can use functions `tval()` and `tint()` which are specifically designed for this problem. You can use macro `twotailt` to compute P-values. Of course, they assume a random sample of differences and normality for validity.

```
    Cmd> tt <- tval(d-0)# sample size and t-statistic

    Cmd> cat(tt, twotailt(tt,n-1))
    (1)       2.6253     0.034144  t-statistic and 2 tail P-value

    Cmd> tint(d,.95) # compute 95% confidence interval
    (1)       0.3972       7.6028
```

The Student's t-statistic computed by `tval()` tests the null hypothesis H_0 that the expected difference is zero. Since the 0.034144 < .05 you can reject H_0 at $\alpha = .05$. With confidence 95% the expected difference is between .03982 and 7.6028.

5.3 *Two-sample t-test*

We analyze data on the weight gains in grams of 19 female rats, 12 on a high protein diet and 7 on a low protein diet, from Table 6.9.1 of Snedecor & Cochran:

```
    Cmd> high <- cat(134,146,104,119,124,161,107,83,113,129,97,123)

    Cmd> low <- cat(70,118,101,85,107,132,94)

    Cmd> n1<- nrows(high); n2<-nrows(low); cat(n1,n2)
    (1)          12           7
```

```
Cmd> describe(makestr(high,low), n:T, mean:T, var:T)
component: n
  component: high
(1)          12
  component: low
(1)           7
component: mean
  component: high
(1)         120
  component: low
(1)         101
component: var
  component: high
(1)      457.45
  component: low
(1)      425.33
```

Now you can use `t2val()` and `t2int()` to do a two-sample t-test and compute a two-sample confidence interval for the difference between the means.

```
Cmd> tt <- t2val(high,low) # test statistic to test H0: μ1 = μ2

Cmd> cat(tt, twotailt(tt,n1+n2-2)) # value of t and P-value
(1)       1.8914      0.07573  Not significant at 5% level

Cmd> t2int(high,low,.95) # 95% confidence interval for μ1 - μ2
(1)      -2.1937       40.194  Includes 0
```

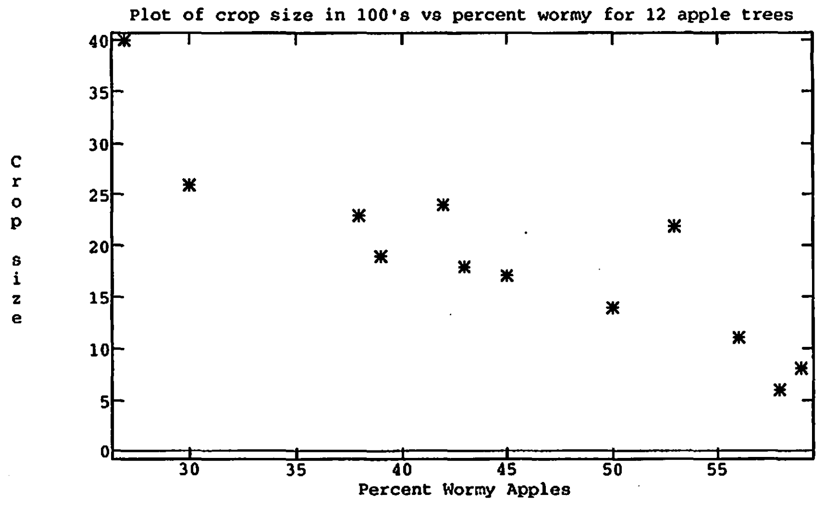
5.4 *Simple linear regression*

Here we analyze data from Table 9.7.1 of Snedecor and Cochran which gives the percentage of wormy fruit (pcwormy) and the number of apples harvested, in 100's, (`cropsize`) for 12 apple trees. The goal is to predict or explain the amount of wormy fruit in terms of the number of applies on the tree by a simple linear regression of pcwormy on `cropsize`.

```
Cmd> cropsize<-cat(8,6,11,22,14,17,18,24,19,23,26,40)

Cmd> pcwormy<-cat(59,58,56,53,50,45,43,42,39,38,30,27)
```

First we make a scatter plot of `cropsize` against pcwormy:

```
Cmd> plot(pcwormy, cropsize,ymin:0\
xlab:"Percent Wormy Apples", ylab:"Crop size",title:\
"Plot of crop size in 100's vs percent wormy for 12 apple trees")
```



There is a fairly strong negative relationship between pcwormy and `cropsize`. Notice the use of keyword phrases with keywords `title`, `xlab`, `ylab` and `ymin` to control the appearance of a plot. Keyword phrase `lines:T` would connect successive points with lines, or you could use command `lineplot()`. You can select the plotting symbols used with command `chplot()`.

Now we do the actual regression analysis

```
Cmd> regress("pcwormy=cropsize") # basic regression command
Model used is pcwormy=cropsize
                             Coef      StdErr          t
CONSTANT                   64.247      3.6029     17.832
cropsize                   -1.013     0.17215    -5.8842

N: 12   MSE:       27.384 DF: 10  R^2: 0.77590
Regression F(1,10):       34.624 Durbin-Watson: 1.68987
To see the ANOVA table type 'anova()'

Cmd> twotailt(cat(17.832, -5.8842), 10)
(1)   6.5683e-09  0.00015431  P-values for t-stats
```

Both coefficients, the intercept or `CONSTANT` and the slope, the coefficient of `cropsize`, are significantly different from zero at the 5% level.

The general form of `regress()` for simple linear regression is `regress("y=x")`, where x and y are the names of vectors containing the independent and dependent variables, respectively.

Once the regression has been computed, you can retrieve the coefficients and their standard errors using function `secoefs()` which computes a structure. To get just the coefficients you can use `secoefs(se:F)` as an argument, while to get just the standard errors, you can use `secoefs(coefs:F)`:

```
Cmd> secoefs() # this gets both coefficients and std. errors
component: CONSTANT
  component: coefs
(1)       64.247
  component: se
(1)       3.6029
component: cropsize
  component: coefs
(1)       -1.013
  component: se
(1)      0.17215

Cmd> beta<-secoefs(se:F); ses<-secoefs(coef:F) #get separately

Cmd> # beta contains coefficients, ses contains standard Errors

Cmd> # Now compute lower and upper 95% confidence limits

Cmd>  n <- nrows(cropsize)# sample size

Cmd> critval<-invstu(1-.025, n-2) # Student's t critical value

Cmd> beta-critval*ses # lower confidence limits
component: CONSTANT
(1)       56.219
component: cropsize
(1)      -1.3966

Cmd> beta+critval*ses # upper confidence limits
component: CONSTANT
(1)       72.275
component: cropsize
(1)     -0.62941
```

5.5 *One-way Analysis of Variance*
Here is a table of yields of four varieties of wheat, each grown on several plots with similar soils (Table 48 of *Biometricheskiye Metodi* of V. Yu. Urbakh, Science Press, Moscow 1964):

Variety 1	Variety 2	Variety 3	Variety 4
17.0	15.8	17.4	15.7
17.2	17.0	16.6	16.8
16.1	16.4	16.2	15.1
17.0		15.6	15.2
16.8		15.5	
		17.2	

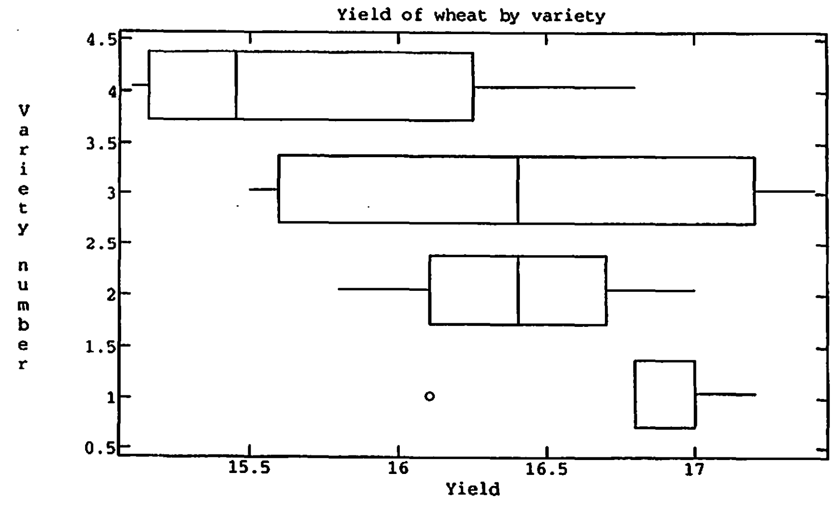
Here is a partial analysis of these data using the `tabs()`, `boxplot()` and `anova()` commands.

```
Cmd> yield <- cat(17,17.2,16.1,17,16.8) # enter yield data,

Cmd> yield <- cat(yield,15.8,17,16.4) # making one long vector

Cmd> yield <- cat(yield,17.4,16.6,16.2,15.6,15.5,17.2)

Cmd> yield <- cat(yield,15.7,16.8,15.1,15.2)

Cmd> #Now enter variety numbers in another long vector

Cmd> variety<-factor(cat(rep(1,5),rep(2,3),rep(3,6),rep(4,4)))

Cmd> hconcat(variety, yield) # look at them together
 (1,1)             1         17
 (2,1)             1       17.2
 (3,1)             1       16.1
 (4,1)             1         17
 (5,1)             1       16.8
 (6,1)             2       15.8
 (7,1)             2         17
 (8,1)             2       16.4
 (9,1)             3       17.4
(10,1)             3       16.6
(11,1)             3       16.2
(12,1)             3       15.6
(13,1)             3       15.5
(14,1)             3       17.2
(15,1)             4       15.7
(16,1)             4       16.8
(17,1)             4       15.1
(18,1)             4       15.2
```

```
Cmd> list(variety,yield) # variety is a factor
variety          REAL    18    FACTOR with 4 levels
yield            REAL    18

Cmd> tabs(yield,variety) # compute variety means and variances
component: mean
(1)        16.82       16.4       16.417        15.7
component: var
(1)        0.182       0.36      0.63367      0.60667
component: count
(1)            5          3            6            4
```

Although the sample sizes are rather small, a box plot shows what is going on as well as the numbers do:

```
Cmd> boxplot(split(yield,variety),\
title:"Yield of wheat by variety",\
xlab:"Yield",ylab:"Variety number")
```



There is some apparent difference between varieties. To test for its reality, you can compute an analysis of variance.

```
Cmd> anova("yield=variety") # form of anova() for one-way ANOVA
Model used is yield=variety
WARNING: summaries are sequential
                                        DF          SS           MS
CONSTANT                                 1      4821.6       4821.6
variety                                  3      2.8237      0.94122
ERROR1                                  14      6.4363      0.45974
```

For one-way ANOVA, the argument to anova() is a string of the form "response = factor", where factor was created using function factor().

A "side effect" of anova() is the creation of two vectors, SS and DF, containing the sums of squares and their degrees of freedom, respectively.

```
Cmd> hconcat(DF,SS,SS/DF) # compare with ANOVA table
(1,1)              1        4821.6        4821.6
(2,1)              3        2.8237       0.94122
(3,1)             14        6.4363       0.45974

Cmd> f <- (SS[2]/DF[2])/(SS[3]/DF[3]) # compute F-statistics

Cmd> cat(f,1-cumF(f,DF[2],DF[3])) # F statistic and P-value
(1)        2.0473      0.15348    Not significant at .10 level
```

5.6 *Randomized Block (Two-way) Analysis of Variance*
Here is a table of data from Table 14.2.1 of Snedecor and Cochran, from an experiment in which four seed treatments and a check (no treatment) were compared in a randomized block design with 4 replicates. The response is the percentage of seedlings in each plot that failed to emerge.

	Replicate #				
Treatment	1	2	3	4	5
Check	8	10	12	13	11
Arasan	2	6	7	11	5
Spergon	4	10	9	8	10
Semasan, Jr	3	5	9	10	6
Fermate	9	7	5	5	3

First, enter the data as one long vector, treatment by treatment, and then the replicate numbers and treatment numbers *as factors*:

```
Cmd> failures<-cat(8,10,12,13,11, 2,6,7,11,5,\
4,10,9,8,10, 3,5,9,10,6, 9,7,5,5,3)

Cmd> reps<-factor(rep(run(5),5))

Cmd> treatment<-factor(rep(run(5),rep(5,5)))

Cmd> hconcat(reps, treatment, failures) # see them all
 (1,1)              1            1             8
 (2,1)              2            1            10
 (3,1)              3            1            12
 (4,1)              4            1            13
```

```
    (5,1)          5          1          11
    (6,1)          1          2           2
    (7,1)          2          2           6
    (8,1)          3          2           7
    (9,1)          4          2          11
   (10,1)          5          2           5
   (11,1)          1          3           4
   (12,1)          2          3          10
   (13,1)          3          3           9
   (14,1)          4          3           8
   (15,1)          5          3          10
   (16,1)          1          4           3
   (17,1)          2          4           5
   (18,1)          3          4           9
   (19,1)          4          4          10
   (20,1)          5          4           6
   (21,1)          1          5           9
   (22,1)          2          5           7
   (23,1)          3          5           5
   (24,1)          4          5           5
   (25,1)          5          5           3

Cmd> tabs(failures,treatment,mean:T,count:T) # treatment means
component: mean
(1)         10.8          6.2          8.2          6.6          5.8
component: count
(1)            5            5            5            5            5

Cmd> tabs(failures, reps, mean:T,count:T) # block means
component: mean
(1)          5.2          7.6          8.4          9.4            7
component: count
(1)            5            5            5            5            5

Cmd> anova("failures=reps+treatment") # do analysis of variance
Model used is failures=reps+treatment
                                  DF           SS           MS
CONSTANT                           1       1413.8       1413.8
reps                               4        49.84        12.46
treatment                          4        83.84        20.96
ERROR1                            16        86.56         5.41

Cmd> f <- (SS[3]/DF[3])/(SS[4]/DF[4]) # Compute F-statistic

Cmd> cat(f,1-cumF(f,DF[3],DF[4])) # F-statistic and P-value
(1)       3.8743    0.021886    Significant at 5% level
```

The form of anova() for a randomized block command is anova("response = blocks + treatment"), where response is the variable being analyzed, and blocks and treatments are vectors of block number and treatment number created by function factor().

5.7 *Multiple Regression*

As an example we analyze some data in file MacAnova.dat distributed with MacAnova (it may not be in the file named macanova.dat on the computer you are using).

```
Cmd> hald <- matread("macanova.dat","halddata")
halddata      13       5 format
) Hald data from A. Hald, Statistical Theory with Engineering
) Applications
) Wiley, New York, 1960, p. 647
) Col. 1: X1 = percent tricalcium aluminate
) Col. 2: X2 = percent tricalcium silicate
) Col. 3: X3 = percent tetracalcium alumino ferrite
) Col. 4: X4 = percent dicalcium silicate
) Col. 5: Y  = cumulative heat of hardening after 180 days
)              (calories/gm)

Cmd> makecols(hald,x1,x2,x3,x4,y); list(x1,x2,x3,x4,y)
x1               REAL    13
x2               REAL    13
x3               REAL    13
x4               REAL    13
y                REAL    13

Cmd> regress("y=x1+x2+x3+x4")
Model used is y=x1+x2+x3+x4
                               Coef       StdErr            t
CONSTANT                     62.405       70.071       0.8906
x1                           1.5511      0.74477       2.0827
x2                          0.51017      0.72379      0.70486
x3                          0.10191      0.75471      0.13503
x4                         -0.14406      0.70905     -0.20317

N: 13    MSE:       5.983 DF: 8  R^2: 0.98238
Regression F(4,8):        111.48 Durbin-Watson: 2.05260
To see the ANOVA table type 'anova()'

Cmd> anova() # also look at the sequential ANOVA table
Model used is y=x1+x2+x3+x4
WARNING: summaries are sequential
                                  DF           SS           MS
CONSTANT                           1  1.1837e+05  1.1837e+05
x1                                 1       1450.1       1450.1
x2                                 1       1207.8       1207.8
x3                                 1       9.7939       9.7939
x4                                 1      0.24697      0.24697
ERROR1                             8       47.864        5.983

Cmd> f<-(sum(SS[run(2,5)])/4)/(SS[6]/DF[6]) # regression F stat.

Cmd> cat(f,1-cumF(f,4,DF[6])) # F and P-value; highly signif
(1)       111.48  4.7562e-07

Cmd> beta<-secoefs(se:F);ses<-secoefs(coef:F)
Cmd> critval<-invstu(1-.05/2,DF[6])

Cmd> beta - critval*ses # lower limits
component: CONSTANT
(1)      -99.179
component: x1
(1)    -0.16634
component: x2
(1)      -1.1589
component: x3
(1)      -1.6385
component: x4
(1)      -1.7791

Cmd> beta + critval*ses # upper limits
component: CONSTANT
(1)       223.99
component: x1
(1)       3.2685
component: x2
(1)       2.1792
component: x3
(1)       1.8423
component: x4
(1)        1.491
```

```
Cmd> resvsrankits(dumb:T,\
title:"Rankit plot of residuals from Hald data")
               Rankit plot of residuals from Hald data
           +--+-------+-------+-------+-------+-------+-------+---+
           |                          :                          *|
           |                          :                           |
        1.5+                          :                           +
 S         |                          :                           |
 t         |                          :                 *         |
 u        1+                          :                           +
 d         |                          :            *              |
 e         |                          :         *                 |
 n      0.5+                          :     *                     +
 t         |                          :                           |
 i         |                          *  *                        |
 z        0+.......................*..:...........................+
 e         |                          :                           |
 d         |                          :                           |
       -0.5+                          :                           +
 R         |                          :                           |
 e         |                *   *     :                           |
 s       -1+                          :                           +
 i         |        *    *            :                           |
 d         |                          :                           |
 s     -1.5+                          :                           +
           |*                         :                           |
           +--+-------+-------+-------+-------+-------+-------+---+
            -1.5     -1     -0.5      0      0.5      1      1.5
                                   Rankits
```

Note the use of dumb:T as an argument to the graphing macro. This caused the plot to be completely composed of printed characters. Although not as nice as the high resolution plots, a "dumb" blot has the advantage that it can be spooled to a disk file (see Sec. 4.2) and easily included in a word processor document on any computer.

Appendix A MacAnova on a Macintosh

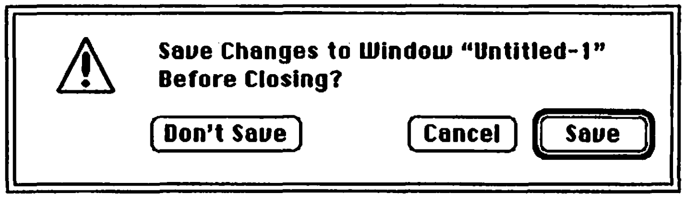
A.1 *Command Windows*

On the Macintosh, all input and non-graphics output occurs in an editable, scrollable window, referred to below as a *command window*. In fact, you can have up to nine such windows, the front most one being the active one.

The line or lines immediately after the last `Cmd>` prompt in the active command window is the *command line*. You execute the command line by hitting Return when the insertion point (the "I-beam" cursor) at its end, or by hitting Enter when the insertion point is anywhere else. In fact, hitting Enter is the same as using the mouse or arrow keys to move the insertion point to the end of the line and then hitting Return. Up until you hit Enter or Return at the end of the line, you can go back and edit the line. Because of the behavior of Enter, you don't need to move back to the end of the line to execute it.

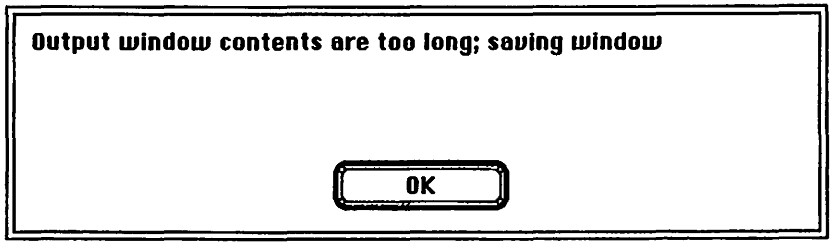
You can move around the command window using your mouse or the arrow keys or by certain command key combinations. See the **Windows** menu below.

All command windows have a close box and a zoom box. If you close a window or quit, a dialog box similar the following appears


Save Changes to Window "Untitled-1" Before Closing?

If you click on **Save**, the usual scrolling dialog box appears allowing you to select a folder and specify a file name. If you click on **Don't Save**, nothing is saved, while **Cancel** stops the closing or quitting.

A command window holds up to about 28,000 characters, but the larger the contents of active window the more slowly MacAnova will print. For this reason, you may wish periodically to clean up the command window by deleting unwanted material or to open new ones; see the **Windows** menu below. When the active command window gets too full, the following alert box appears:


Output window contents are too long; saving window

You are given an opportunity to save it. Whether or not you do, a new window is opened to continue your session.

A.2 *Files*

All files associated with MacAnova should be in the same folder as the MacAnova application itself. The most important of these are the help file `MacAnova.hlp` and the initialization file `MacAnova.ini` (type `help(customize)`). In addition, the macro files distributed with MacAnova, `MacAnova.mac`, `Design.mac` and `Tser.mac`, normally belong in this same folder. In order to use macros `getdata` and `getmacros` which read from files whose names are in variable `DATAFILE` and `MACROFILE`, respectively, it is a good idea to have lines like the following in `MacAnova.ini`.

```
DATAPATH  <- "HardDisk:MacAnova Folder:"
DATAFILE  <- paste(DATAPATH,"MacAnova.dat",sep:"")
MACROFILE <- paste(DATAPATH,"MacAnova.mac",sep:"")
```

A.3 *Launching MacAnova*

If your Macintosh does not have a hard disk, you will need two 800K (double density) or 1.44M (high density) floppy disks, one for the MacAnova application, together with the help file and macro file , (`MacAnova.hlp` and `MacAnova.mac`), and if there is room a data file. On the other disk should be a System Folder and any other files you need. First, of course, you will have to turn on the computer, and then, if necessary, open the disk icon to find and open the folder containing the MacAnova application.

MacAnova may be started up in several ways.

1. Double clicking the MacAnova application icon .

2. Double clicking on a Save File icon created by `save()` or `asciisave()` or by **Save Workspace** on the **File** menu. This restores the workspace previously saved.

3. Double clicking on an Output Window icon , created when you save the command window using **Save Window** or **Save Window As...** on the **File** menu. This initializes the command window with commands and output from a previous run.

4. Selecting both a Save File icon and an Output Window icon and then double clicking restores *both* the previous workspace and previous output. This means you can end a session and restore things exactly to how they were at the point you quit.

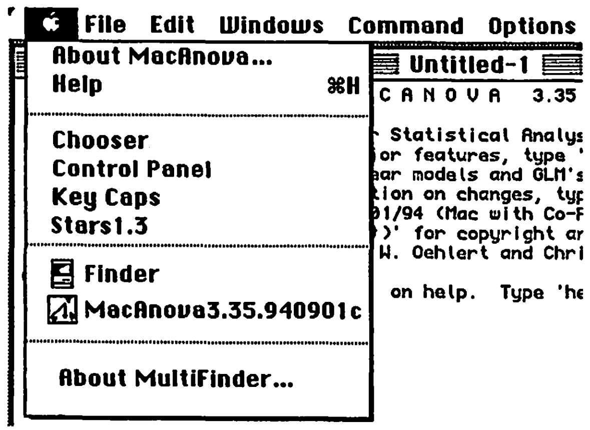
5. There is also a non-interactive mode. If you hold down ⌘ (the command key) while MacAnova is starting, you will be asked to select a file of commands and a spool file for the output. MacAnova will not open a command window but will take all its commands from the command file and write all its output to the spool file.

If running under System 7, you may want to put an alias of MacAnova in the `Apple Menu Items` folder in the System folder.

A.4 *Menus*

There are 6 menus, the , **File**, **Edit**, **Windows**, **Command** and **Options** menus.

A.4.1 *The menu*

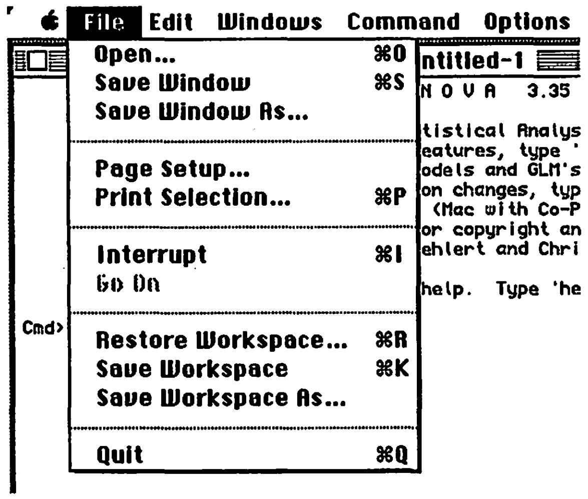


About MacAnova displays a dialog box giving the version and copyright information.

Help is roughly equivalent to typing `help()`. You will get a complete listing in the Command Window of all topics available. When a topic name in the window is selected using the mouse, **Help** gives you help on that topic. If your keyboard has a `help` key, hitting `help` is equivalent to selecting **Help**. See Sec. 3.6.

The rest of the items are either Desk Accessories, or under System 7, applications. These have no effect on MacAnova, but launch other programs that can run at the same time. Note, however, at the current time, MacAnova does not "background"; when it is not the front most application, it does nothing.

A4.2 *The* **File** *menu*



Open... allows you to load the contents of a previously saved output window into a new window. It becomes the active window. You use the usual scrolling dialog box to select the file.

Save Window writes the active command window to a file overwriting anything already in the file if it exists. If there is no file already associated with the window, you are asked to provide a name and select a folder using a scrolling dialog box. This file may be printed or edited using any word processor, including MacWrite and Microsoft Word, or Desk Accessory editor such as MockWrite or MiniEdit. See Sec. 4.2.

Save Window As... writes the active command window in a new file.

Page Setup... brings up a standard page setup dialog box. If a command window is the front window, the options chosen will affect the printing of command windows. If a graphics window is in front, they will affect printing of any graphics window. If you don't select **Page Setup...**, the page setup dialog box will be displayed the first time you print a command or graphics window.

The **Print Selection** menu item can also be **Print Window** or **Print Graph**. Selecting it initiates printing of text selected in the active command window, the entire window, or the frontmost graphics window.

Interrupt breaks off output and most commands. `*****  Interrupt  *****` is printed followed by a new `Cmd>` prompt. It is usually selected by **⌘.** or **⌘!** .

Go On is active only after a plotting command with `pause:T` as an argument which causes MacAnova to pause, allowing you to **Copy** a plot to the clipboard or print it. When you select **Go On** (or press any key) MacAnova continues.

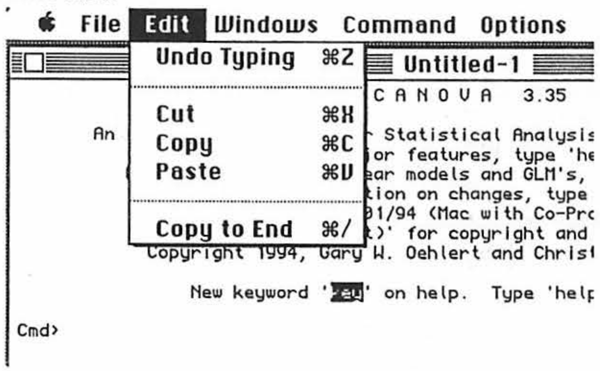
Restore Workspace... allows you to restore a workspace previously saved by `save()` or `asciisave()`. Selecting **Restore Workspace** is equivalent to typing `restore("")`. It brings up a scrolling dialog box for you to select the file. See Sec. 4.3.

Save Workspace... saves the current workspace containing all your variables and macros. If the workspace has not been saved previously on the current run, **Save Workspace** is equivalent to typing `save("")` and you will be presented with a scrolling dialog box to select the save file. If the workspace has been saved previously on this run, it will be saved again to the same file, without asking you to select a file, as if you had simply typed `save()`. Since **Save Workspace** can be selected by **⌘K**, this provides a quick and easy way to play it safe, saving your workspace every few minutes to minimize your losses in case of a crash. See Sec. 4.3.

Save Workspace As... always asks you for a file name before saving your variables and macros.

Quit terminates MacAnova. Alternatively you can type `quit`, `stop`, `bye` or `end`, or, if there is only a single command window, click in its close box. You will be asked whether you want to save the workspace or the command window. To bypass these requests, hold the option key down.

A.4.3 *The* **Edit** *menu*



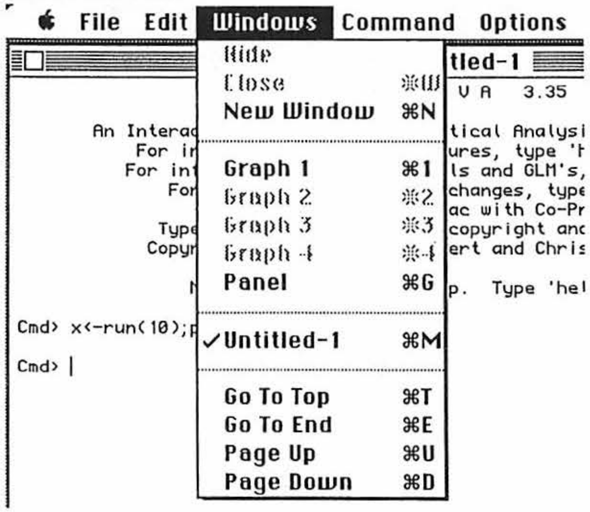
```
                    C A N O V A   3.35
      An
                     Statistical Analysis
                    or features, type 'he
                    ear models and GLM's,
                    tion on changes, type
                    01/94 (Mac with Co-Pro
                    t)' for copyright and
          Copyright 1994, Gary W. Oehlert and Chris

              New keyword '   ' on help.  Type 'help

Cmd>
```

Instead of **Undo Typing**, the first item may be **Undo Paste, Undo Output, Redo Typing** or **Redo Output**. All of these provide a useful capability for undoing or redoing your previous action as long as nothing in the window has changed. **Undo Output** is active immediately after the output from executing a command line. If you select it, output is deleted back to the end of the previous command line. This is useful if you made a typing error. Hit **⌘Z**, make the correction, and hit the Enter key to redo the command. If instead of changing the command, you immedately select **Redo Output**, the deleted output is restored.

When the Command Window is in front, **Cut**, **Copy**, and **Paste** do just what you expect on a Macintosh. When a graphics window is in front, only **Copy** is effective, copying the entire graph to the Clipboard.

Copy to End When text is selected in the output window, **Copy to End** copies the selected text to the end of the command line, leaving the insertion point after the copied text. You can then edit it, if necessary, before executing it. In the same circumstance, simply hitting the Enter key copies the selected text to the command line, but also adds a Return, thus (usually) executing the copied text immediately.

A.4.4 *The* **Windows** *menu*



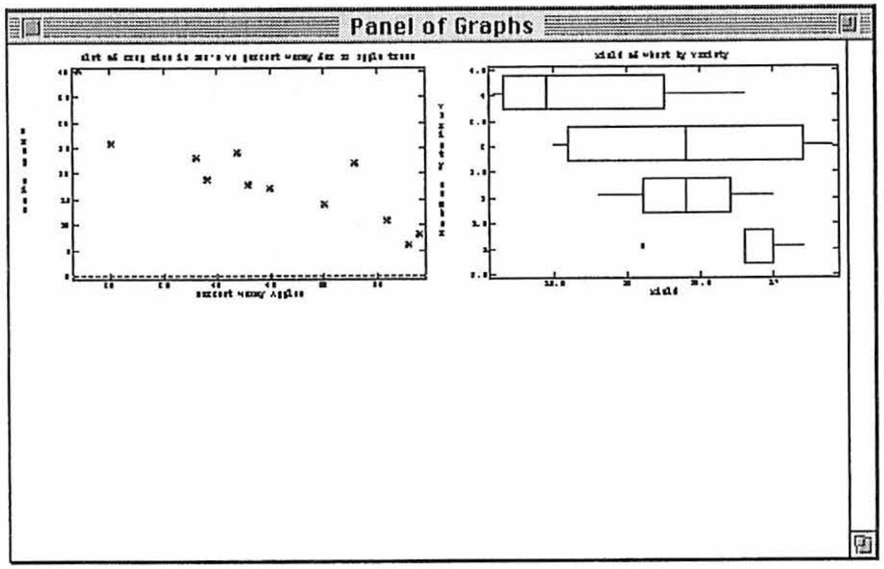
```
Cmd> x<-run(10);
Cmd> |
```

Hide and **Close** are operative except when there is only one command window and it is in front. **Hide** hides the frontmost window, but the window can be made visible again by selecting its name on the **Windows** menu. Selecting **Close** is equivalent to clicking in the Close box of the window; it removes the window entirely. If it is a command window that has changed since it was opened, you are asked if you want to save it.

New Window opens a new command window with the name **Untitled-n** where n is an integer. A prompt `Cmd>` is printed and the window becomes the active command window. You can have no more than 9 command windows at any one time.

Graph 1, **Graph 2**, **Graph 3**, and **Graph 4**. Selecting any of these makes the indicated graphics window the front window. If a graph window does not exist, the corresponding item is not highlighted.

Panel MacAnova maintains a fifth graphics window, the **Panel of Graphs** window, with miniature copies of the other four windows in its corners. Selecting **Panel** makes it the front window. Here is an example of a **Panel of Graphs** window when graphs have been drawn in **Graph 1** and **Graph 2**.



Clicking on any of the small copies brings the full sized window forward. The **Panel of Graphs** window can be copied to the clipboard or printed just like the other graphics windows.

Hitting Return when any graphics window is in front, brings forward the active command window.

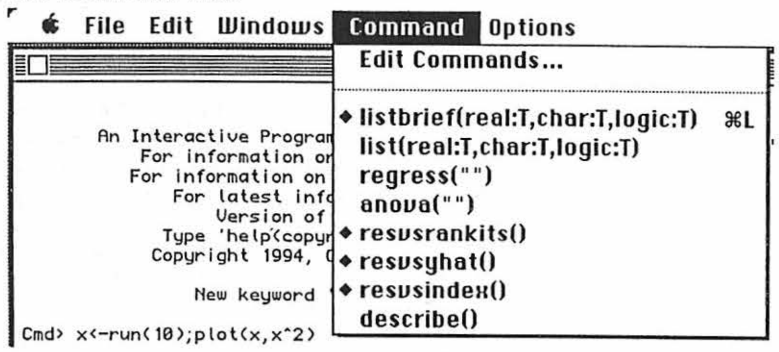
Untitled-1 There can be up to 9 command window names listed here. Selecting one makes it the active window. In the run from which this snapshot was taken there was only one command window named **Untitled-1**.

Go To Top scrolls to the start of the text in the active command window, but does not change the selection point. If there is a Home key, it does the same.

Go To End scrolls to the end of the text in the active command window and moves the selection point there. If there is a End key, it does the same.

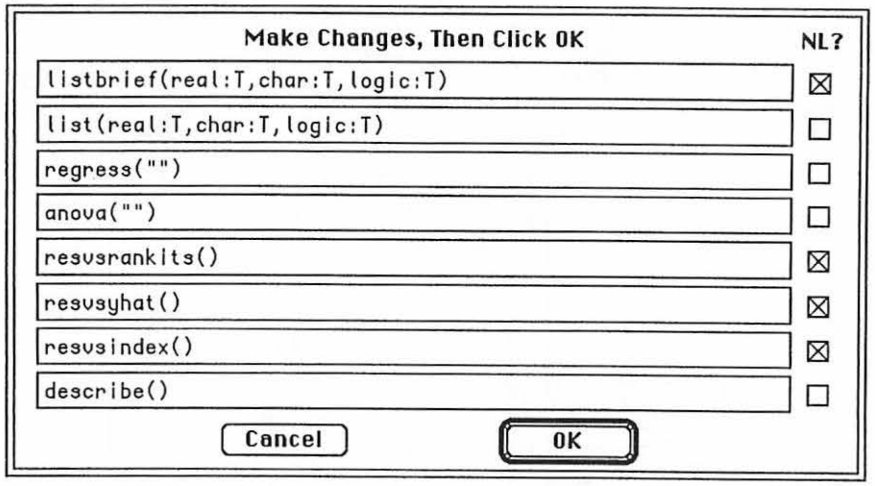
Page Up and **Page Down** scroll the active command window up or down without moving the insertion point.

A.4.5 *The* **Command** *menu*



```
An Interactive Progra
  For information o
 For information on
    For latest inf
       Version of
   Type 'help(copy
  Copyright 1994,

      New keyword

Cmd> x<-run(10);plot(x,x^2)
```

Edit Commands brings up the following dialog box so that you can change any or all of the commands in the last 8 lines of the **Command** menu.



Make Changes, Then Click OK

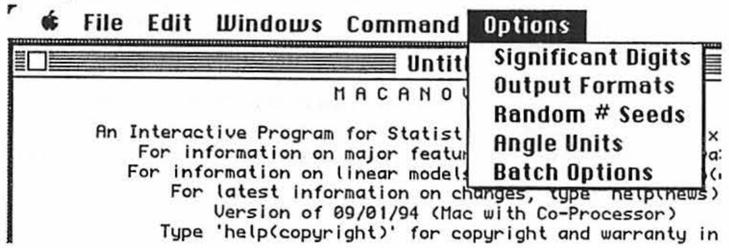
	NL?
`listbrief(real:T,char:T,logic:T)`	☒
`list(real:T,char:T,logic:T)`	☐
`regress("")`	☐
`anova("")`	☐
`resvsrankits()`	☒
`resvsyhat()`	☒
`resvsindex()`	☒
`describe()`	☐

Check the box at the right if a Return should automatically be added to the command.

The last 8 items in the **Command** menu are predefined commands that are copied to the command line by selecting them with the mouse. A ◆ in the left margin indicates that the command will be followed by a Return, resulting in immediate execution. If ◆ is absent, no Return is added and you can edit the command before it is executed. The

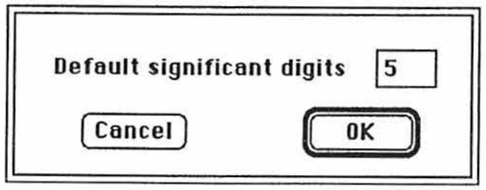
selection point will be inside a set of empty parenthesis (**describe()**) or empty quotation marks (**anova("")**). Thus selecting **resvsrankits()** results in an immediate residuals versus rankits plot, while selecting **anova("")** allows you to specify a model. You can replace or modify any of these commands using item **Edit Commands**. If you want to do anything complicated you should probably write a macro to do what you want and have only the macro invocation in the menu.

A4.6 *The* **Options** *Menu*



```
                    M A C A N O
An Interactive Program for Statist                x
  For information on major featu                  a:
 For information on linear model                  (
    For latest information on changes, type 'help(news)
       Version of 09/01/94 (Mac with Co-Processor)
    Type 'help(copyright)' for copyright and warranty in
```

Each of the items on the **Options** menu opens a dialog box allowing you to set various options that would otherwise have to be set by command `setoptions()`. For example, if you select **Significant Digits**, the following dialog box appears:



Default significant digits 5

Clicking **OK** executes the command `setoptions(nsig:5)`, specifying that the default output format will be floating point with 5 significant digits. **Output Formats** allows you more control over the default format. **Random # Seeds** allows you to set values to initialize the built in random number generator. **Angle Units** allows you to select which will be the default units of angles assumed by trigonometric functions and other commands -- radians, degrees, or cycles (360° = 2π radians = 1 cycle). **Batch Options** allows you to set certain options pertaining to command `batch()`.

A.5 *Graphics windows*

When one of the plotting commands is executed, a new graphics window is created, up to a maximum of four, not counting the **Panel of Graphs** window. When all the windows are in use, MacAnova prints

```
    ERROR: graph windows full - delete a graph and type showplot()
```

Before any more plots can be made, you will have to close one or more graphics window. When you have freed up a slot, type `showplot()` and the graph you wanted will appear.

Alternatively, you can always specify a window number on any graphing command by keyword phrase `window:n`, where n is an integer from 1 to 4 or 0. `window:0` reuses the most recent used graphics window.

If `pause:T` is an argument to any plotting command, MacAnova pauses after the plot allowing you to **Copy** the graph to the clipboard or print it. When you select **Go On** on the **File** menu or press any key, MacAnova continues. Using `pause:T` together with `window:0` is particularly effective if you use a `for` or `while` loop to make a sequence of plots with differing data or parameters.

When a graphics window is the front window, selecting **Copy** on the **Edit** menu (**⌘C**) copies the entire graph to the Clipboard. From there it can be pasted into the Scrapbook, or into a word processor or graphics editor window.

When `file:fileName` is an argument to a plotting command, PostScript commands, recognized by many Apple LaserWriters and some other printers, are written to the named file. Be sure to use keyword phrase `new:T` the first time you write PostScript to a file. With the right programs, the file can be printed directly on a LaserWriter. It may be possible, if you know how, to include it as encapsulated PostScript in a word processor document. If both `file:fileName` and `ps:F` are arguments to a plotting command, instead of PostScript, a "dumb" type plot that can be printed on a line printer is written to the file.

A.6 *Other features*

Interrupting MacAnova. Some operations such as listing the values in a long vector or a large analysis of variance may take a long time to complete. If you wish to interrupt MacAnova during a long operation, select **Interrupt** from the **File** menu or press **⌘.** or **⌘I**. MacAnova may take a few moments to respond but will eventually stop what it is doing, print `*****   Interrupt   *****`, followed by a `Cmd>` prompt. Not all commands respond to **Interrupt**, but most do.

Executing other programs while in MacAnova Although command `shell()` is not implemented on the MacIntosh, you can run other programs without quitting MacAnova if you are running under Multifinder or System 7. Just click on the desk top to return to the finder or (under System 7) use the Applications menu at the far right end of the Menu bar, and then start another application up in the usual manner. If you are not using Multifinder or System 7, you are limited to executing Desk Accessories (DA's) installed in your menu. One type of DA that is particularly useful is a DA text editor. Two of the most popular of these are MockWrite and MiniEdit.

Editing Macros This can be done at least two ways.

(a) You can write out the macro to a file using command `macrowrite()`. If you are running under Multifinder or System 7, you can then switch to an editor or word processor to edit the file. Be sure to save it as a *text file* when you are done and to update the first line if the number of lines in the macro has changed. When you are done, return to MacAnova (or restart it if necessary) and read the macro back in using `macroread()`. It is a good idea to print it out to make sure it all got read. If some lines are missing from the end, it means the number of lines on the header was wrong.

(b) You can edit a macro right in the command window. First display the current version of the macro by typing its name. It will be printed, complete with enclosing quotation marks, and with any internal quotation marks preceded by '\'. Make the necessary changes. Then, moving the insertion point to the `Cmd>` prompt, type

```
        name <- macro(
```

without a closing parenthesis or Return, where `name` is the name of the macro or perhaps a new name. Use your mouse to select the entire text of the edited macro, *including the enclosing quotation marks*, and then select **Copy to End** on the **Edit** menu or press **⌘/**. This will copy the macro to the end of the Command Window immediately aftrer `macro(`. Then type the closing '`)`' and hit Return or Enter to re-create the edited macro.

A.7 *Miscellaneous information*

MacAnova for the Macintosh was compiled using MPW C. It comes in two versions, one using a 68881 math coprocessor and 68020 instructions, and one that will run on a vanilla Macintosh without a coprocessor. They work identically, but the coprocessor version is much faster except on a Power PC for which you should use the version without a coprocessor. See the file `Readme.txt` distributed with MacAnova. Bother versions require System 4.2 or later and at least 1 megabyte of ram. Although you could run MacAnova on a two floppy Macintosh, a hard disk is *strongly* recommended. MacAnova works well under Multifinder and under System 7 but does not take advantage of all their features. In particular, at present MacAnova does no computations in the background.

As distributed, the co-processor version has name of the form `MacAnova3.35.YYMMDDc`, where `YYMMDD` is the date (for example 940909) of compilation, and the non co-processor version has name `MacAnova3.35.YYMMDDn`. For information on obtaining a disk, contact

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Appendix B MacAnova on an IBM Compatible

B.1 *Introduction*

This appendix summarizes features special to the DOS versions of MacAnova. There is as yet no Windows version. There are two DOS versions, a *real mode* one that should run on any PC compatible with sufficient memory, and a *protected mode* version that requires at least a 386. See B.6 below for a list of differences between them. The most important difference is in the maximum allowed size of variables: The real mode version is limited to variables taking no more than 65,000 bytes of memory (8,125 `REAL` numbers), while the protected mode version has no such limit, and can use any available extended memory or even the hard disk to work with large data sets. Under Windows, both must be run from the DOS prompt

There are no menus and once a line has scrolled off the screen it is lost unless you previously had used `spool()` (see Sec. 4.2).

B.2 *Initialization file*

The initialization file (see help topic `customizing`) is named `MACANOVA.INI` and should be in the same directory as `MACANOVA.EXE` and `MACANOVA.HLP`.

B.3 *Launching MacAnova under DOS*

MacAnova is started up by typing

```
        macanova [-q] [file options] [screen options]
```

at the DOS prompt, where items in `[...]` optional.

If `-q` is present, no startup message will be printed.

The possible **file options** are `-f initFile`, `-r saveFile`, `-b batchFile`, `-h helpFile`, `-m macroFile`, and `-d dataFile`, where each must be a valid file name.

If `-f initFile` is specified, file `initFile` is executed silently as a batch file at startup instead of `MACANOVA.INI` (see help topic `customizing`).

If `-r saveFile` is specified, the equivalent of `restore("saveFile")` is executed at startup and the initialization file is not read. See Sec. 4.3.

If `-b batchFile` is specified, the equivalent of `batch("batchFile")` is executed after initialization (see help topic `batch`).

If `-h helpFile` is specified, MacAnova will use `helpFile` as the default file of help documentation rather than the standard help file `MACANOVA.HLP`.

If `-d dataFile` is specified, MacAnova `CHARACTER` variable `DATAFILE` will have `"dataFile"` as value. `DATAFILE` is used by pre-defined macro `getdata` to make it easy to read data from a standard file of data sets. If `-d dataFile` is not specified, `DATAFILE` will have default value `"path\MACANOVA.DAT"`, where `path` specifies the directory where `MACANOVA.EXE` is located, for example, `C:\MACANOVA\`.

If `-m macroFile` is specified MacAnova, `CHARACTER` variable `MACROFILE` will have `"macroFile"` as value. `MACROFILE` is used by pre-defined macro `getmacros` to make it easy to read macros from a standard library of macros. If `-m macroFile` is not specified, `MACROFILE` will have default value `"path\MACANOVA.MAC"`, where `path` specifies the directory where `MACANOVA.EXE` is located.

Even if `-d` or `-m` is not used, the default values of `DATAFILE` and `MACROFILE` can be changed in the initialization file `MACANOVA.INI`. The help file can be changed by `help(file:"fileName")` which command could also be in `MACANOVA.INI`.

The permissible **screen options** are `-l nlines` and `-w ncols`, where `nlines` and `ncols` are integers greater than 5 and 20, respectively. These set the default number of screen lines and columns, respectively. The default values are 25 and 80. If your monitor has a different size, say with 24 lines, you will want to use `-l 24` on the command line or put `setoptions(lines:24)` in your `MACANOVA.INI` file.

If `input.txt` is a file which contains MacAnova commands to do an entire analysis,

```
        macanova < input.txt > output.txt
```

will run MacAnova and save all the results in file `output.txt`.

B.4 *Graphics under DOS*

The real mode version of MacAnova under DOS supports CGA, EGA, VGA, 8514, and Hercules graphics adaptors. Drivers for these are available in files `CGA.BGI`, `EGAVGA.BGI`, `HERC.BGI`, and `IBM8514.BGI` which are distributed with MacAnova. They are copyrighted by Borland and cannot be resold. They should be placed in the same directory as `MACANOVA.EXE`. After each plot, MacAnova pauses with the plot on the screen until you hit Return, at which point the plot is erased, the text window is refreshed, and you are returned to the `Cmd>` prompt.

The protected mode version is currently limited to VGA graphics. Moreover, it cannot make high resolutions plots when Windows is active (we hope this restriction will soon disappear). Currently it also has fewer and less satisfactory line types available for high resolution plotting.

To be able to print a MacAnova high resolution plot when running the real mode version, you need a special TSR (Terminate and Stay Resident) program which must be executed prior to launching MacAnova. Then, when a MacAnova plot is on the screen, the `PrintScreen` button on the keyboard should print the plot. The standard one that comes with DOS, `GRAPHICS.COM`, may work only with IBM printers. There may be others distributed with MacAnova.

When using the protected mode version when Windows is not running, keyword phrase `screendump:"filename"` on any graphics command will save a copy of the graphics screen in PCX format. This can be used by various graphics and word processing programs. This is not available in the real mode version, although it may be possible to capture graphic images in a disk file for incorporation in a word processor using a TSR program. One may be distributed with MacAnova. The TSR `GRAB.COM` distributed with Word Perfect is one option you may already have available.

The `file:fileName` option on the plotting commands by default writes PostScript to the named file. PostScript is a page description language recognized by some printers, including Apple LaserWriters, . Be sure to use keyword phrase `new:T` the first time you write PostScript to a file. If both `file:fileName` and `ps:F` are arguments to a plotting command, the plot written to the file is a "dumb" type that can be printed on a line printer.

B.5 *Other features*

You can execute DOS commands directly from MacAnova by prefixing the line to be executed with '!' in the first position after the `Cmd>` prompt or by using the command `shell()`. Type `help(shell)`. Under the real mode version, you are limited to DOS commands that require relatively little memory. These include most of the standard things like `DIR`, `CD`, `TYPE`, and `MORE`. Under the protected mode version, you can execute almost any program. In this version there is a pre-defined macro `edit` that uses `shell()` to invoke an editor (default is `EDIT`) allowing you to edit macros and data sets without quitting MacAnova. Type `help(edit)`. If you have a very small editor, you can do the same in the real mode version. You will have to read in `edit` from the distributed macro file `MacAnova.mac` and probably need to edit it.

Command `putascii()` permits output arbitrary codes to your terminal. For example, `putascii(7)` rings the bell.

B.6 *Differences between versions*

Here is a short table comparing the two versions:

	Real Mode Version	Protected Mode Version
Maximum size of objects	65,000 bytes == 8,125 REALs	Limited only by memory and disk space
Interrupt key	Control C or Control Break	Control Break only
High resolution plots	White on black	Black on white
Graphics modes supported	CGA, EGA, VGA, 8514, and Hercules	VGA
High resolution plots when Windows is active	Yes	No
Full range of high resolution line types	Yes	Only two
`screendump:T` available on high resolution plots	No	Yes
Has pre-defined macro `edit`	No	Yes
Memory available for `shell()`	Very restricted	Quite large programs can be run

B7. *Other information*

MacAnova is written in the C programming language. The real mode DOS version of MacAnova is compiled under version 4.0 of Borland C++. The protected mode version is compiled under a version of the Gnu C++ compiler, adapted for DOS by D. J. Delorie. Both are distributed as self extracting archives along with a self-extracting archive of auxilliary files such as `MACANOVA.HLP`.. For information on obtaining a copy of MacAnova, contact

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