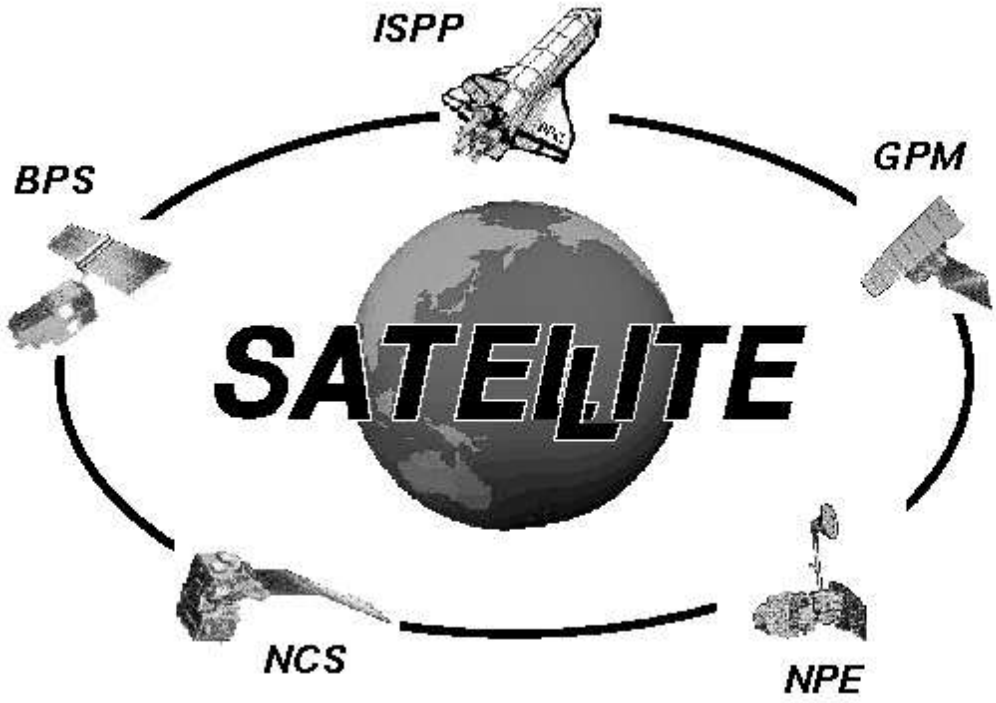
System Analysis Total Environment for Laboratory
— Language and InTeractive Execution



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— User's Manual —

Contents

Chapter 1

What is SATELLITE?

1.1 Concept of SATELLITE

It is generally agreed that the biological system is one of the most complex and sophisticated mechanisms on earth. However, in this moment, since there are few systematic theories for approaching such systems, trial and error studies based on knowledge of physiology, psychology, etc., has to continue. Environment to support and realize the ideas of scientists could be so important to advance the research. We assert that the establishment of basic platform for data analysis and model simulation could be relevant for analyzing the complex systems such as neural systems.

The basic concept of system analysis forms the cycle: data analysis, modeling, computer simulation, evaluation and experimental testing, as shown in Figure 1.1. **SATELLITE** (System Analysis Total Environment for Laboratory — Language and InTeractive Execution) has been developed considering this scheme.

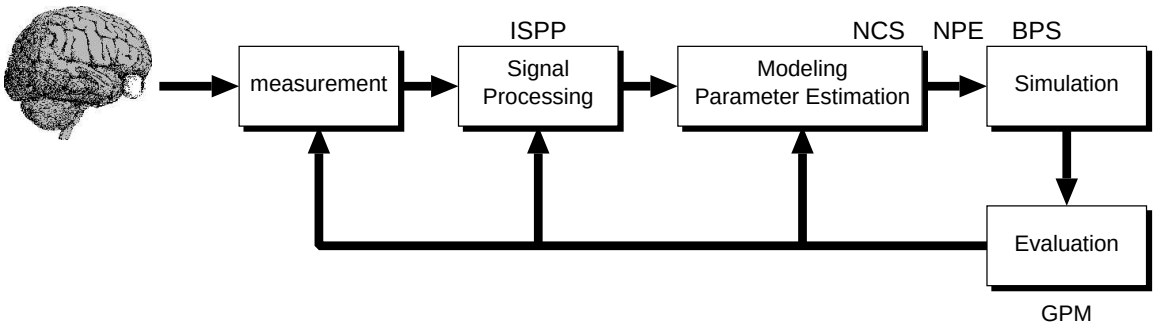


Figure 1.1: A general flow chart of biological system analysis.

SATELLITE consists of the SATELLITE-shell which provides interactive and C-like language processing system, and several modules which together cover more than 200 commands and (signal processing, numerical simulation, etc. See also Figure 1.2). The most important facility of SATELLITE-shell is an interactive operating environment. User can execute command sequence from the text file (batch processing) in case of the complex and large scale simulations (see also Figure 1.3). One can also visualize data and print it.

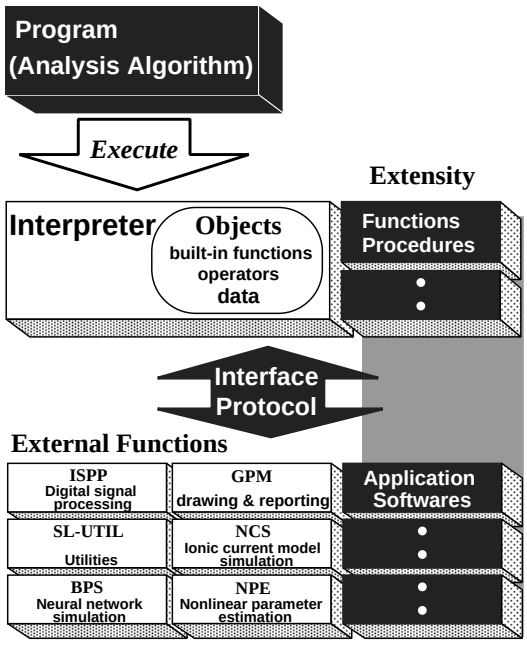


Figure 1.2: A modular scheme of SATELLITE system.

1.2 SATELLITE Modules

SATELLITE organizes analysis techniques for various systems by grouping its functions into modules, according to the purpose or method. There are several modules containing basic tools for system analysis, such as digital signal processing, numerical simulation, model parameter estimation, etc., as listed below. Details are described in the subsequent chapters.

SYSTEM module is a gathering of basic functions for handling data. It includes the functions such as picking up data, finding a maximum or minimum of a sequence, modifying data format, displaying header information of data files, etc.

ISPP (Interactive Signal Processing Package) is a module for data analysis based on signal processing and statistical theories. They are extremely important for modeling and extracting the characteristics from experimental data. Built-in commands can be applied to not only the time series, but also the multi-dimensional data (see also Figure 1.4).

NCS (Neural Circuit Simulator) is a neural modeling and simulation environment. In this system, special description language is utilized to describe the neuronal properties and the network structure. This language offers an environment in which the large scale physiological model can be described easily in NCS (see also Figure 1.5).

BPS (Back-Propagation Simulator) is developed to examine neural network characteristics and capabilities. Function for tracing weight change offers precious data for analysis of learning process, local minima, and internal network representation (see also Figure 1.6).

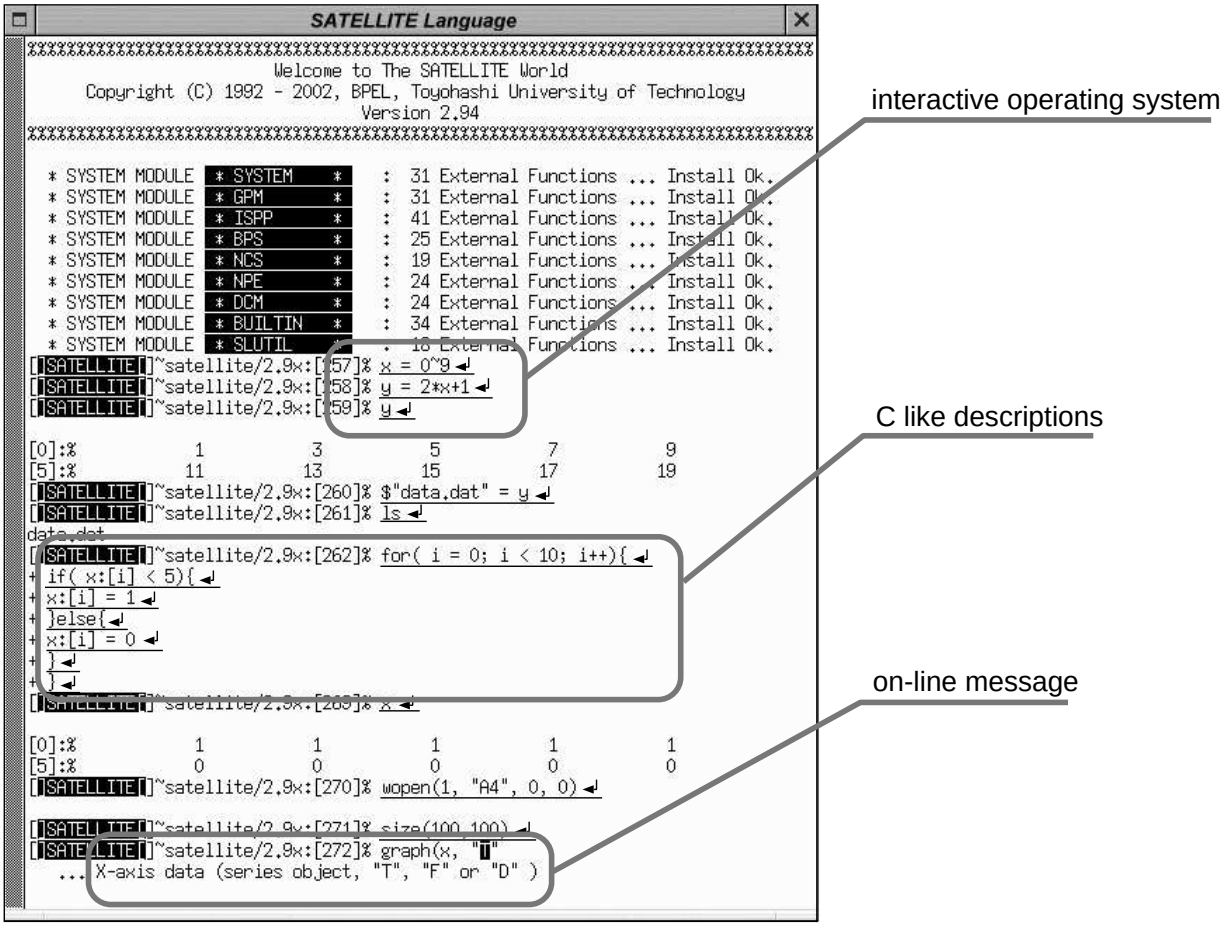


Figure 1.3: SATELLITE — interactive terminal.

GPM (Graphic Package Module) From the standpoint of data analysis, visualization of data is much more important than numerical evaluation. GPM module provides various graphic functions for making charts, contour maps, bird's-eye pictures, etc. The images can also be printed.

1.3 Platform Support

SATELLITE runs on the following platforms:

Operating system	:	from SunOS 4.1.2
	:	from Solaris 2.5
	:	from HP-UX 9.05
	:	from HP-UX 10.01
	:	from DEC OSF/1 V3.0
	:	from Digital UNIX V3.2c
	:	from FreeBSD 2.1.0R
	:	from Linux 2.0.0
Window system	:	from X Window Ver.11 R4
	:	from OSF/Motif Ver.1.1
Language to code	:	C Language

1.4 Examples

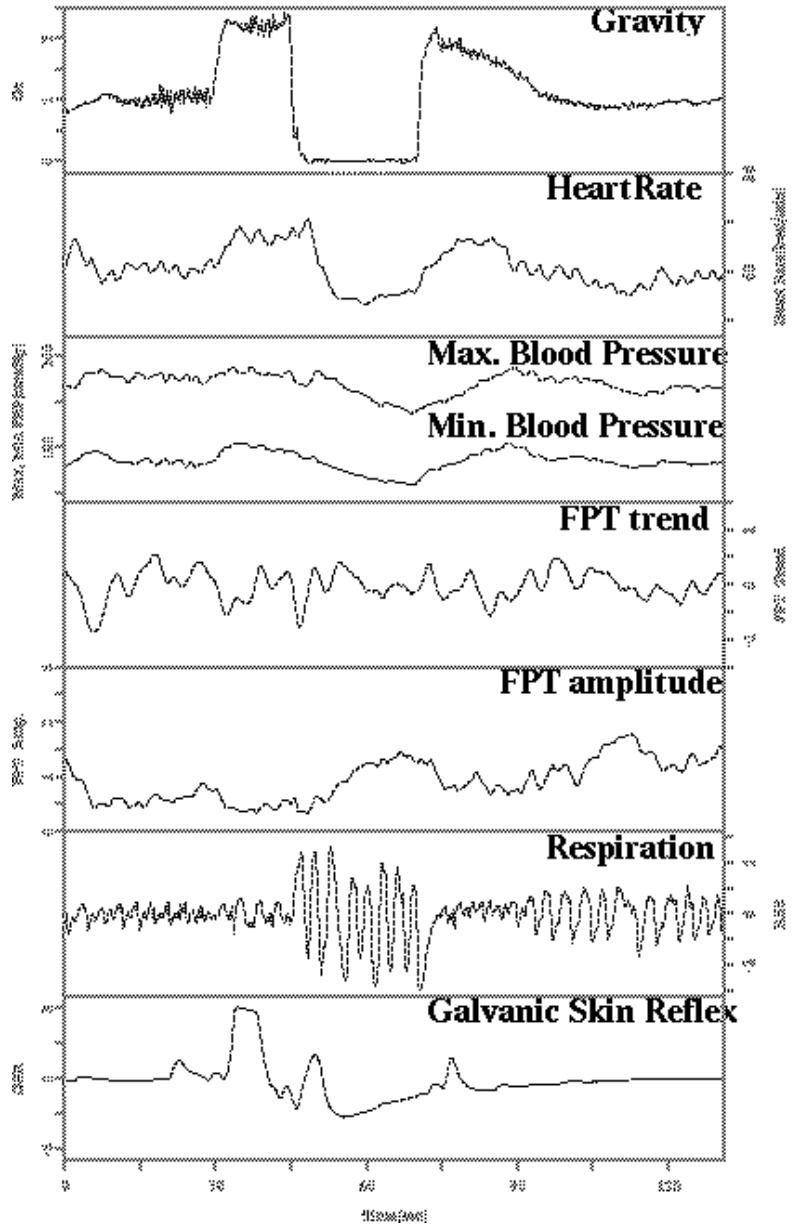


Figure 1.4: Biological signals during micro gravity (Example of ISPP).

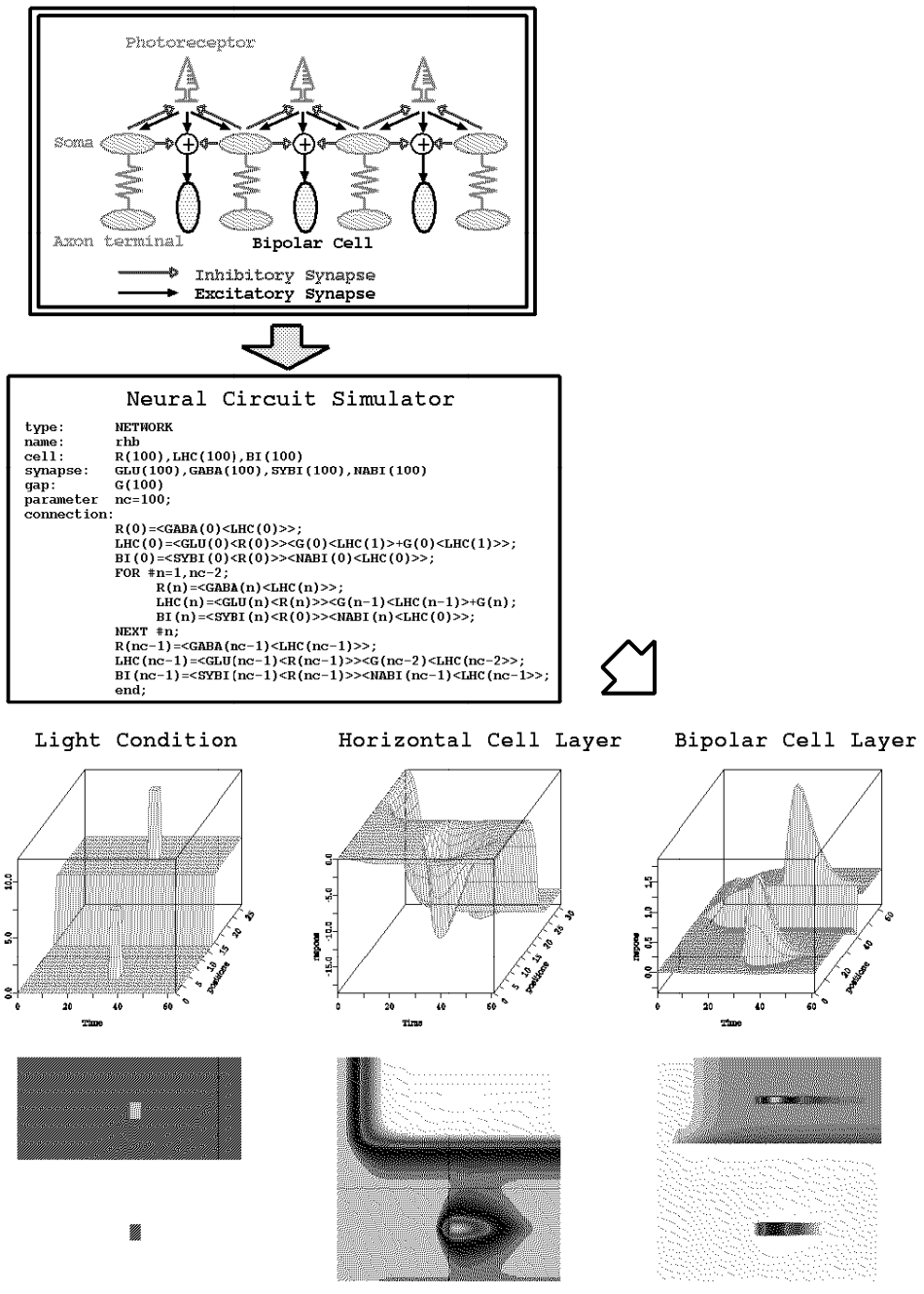


Figure 1.5: Simulation of a realistic neural etwork (Example of NCS).

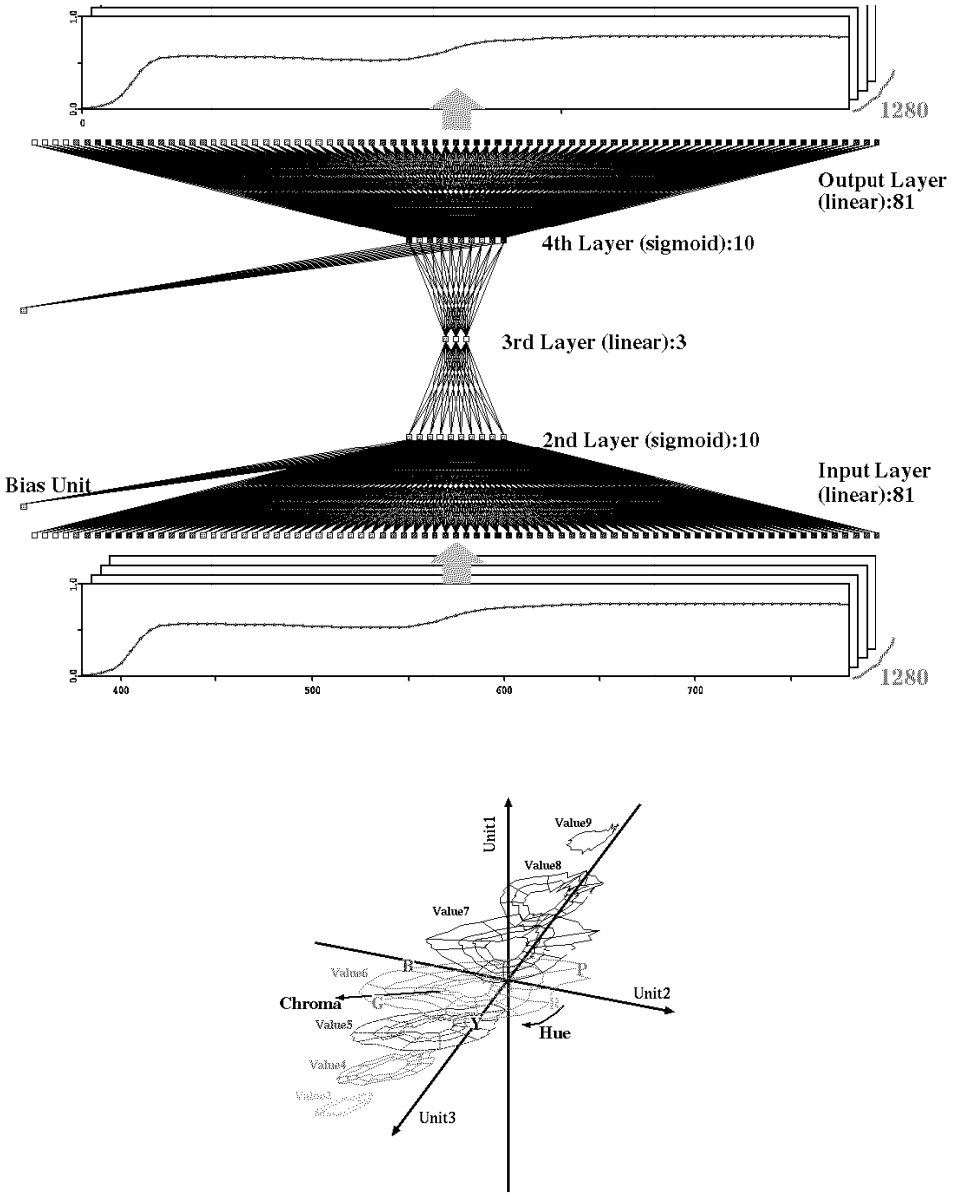


Figure 1.6: Simulation of artificial neural network (Example of BPS).

Chapter 2

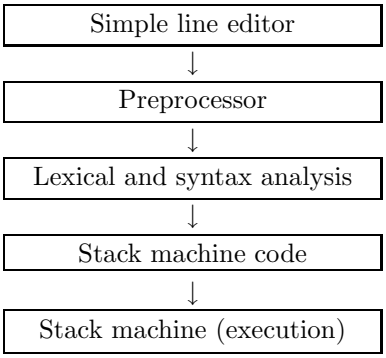
SATELLITE Shell and its functions

2.1 Introduction

Signal processing techniques, simulations using mathematical models, etc., are effective for analysis of the organizations and biological systems. Various software systems, such as Mathematica, LabVIEW and AVS have been provided. However, if we use these software products, the whole efficiency may fall remarkably because of data conversion to other systems.

SATELLITE enables to perform the consistent processing even if we use the completely different application software systems. It places simulators and signal processing packages as its external functions and organizes them along with API (Application Program Interface) specification. The merit of SATELLITE is that several different data sets, such as (multi-dimensional) time series, matrices, and so on, can be processed to make analyzing the biological system easier.

The processing system of SATELLITE is an interpreter. Programs are translated into the intermediate stack code. The stack machine code is executed by stack machines. Therefore, the repetition procedures or functions, such as **for** command and **while** command, are performed at slightly higher speed. The internal composition is shown as follows:



If the program is syntactically correct, the processing system will translate it into the stack machine code, and execute it. Frequently, one may want to use an editor, check a file name, change a current directory, use UNIX commands, etc. If the token that appears at the beginning of a sentence is not defined and is not substitution, SATELLITE passes such commands to Bourne shell of UNIX.

2.2 How to start SATELLITE

SATELLITE is started by typing “sl”, shown as follows:

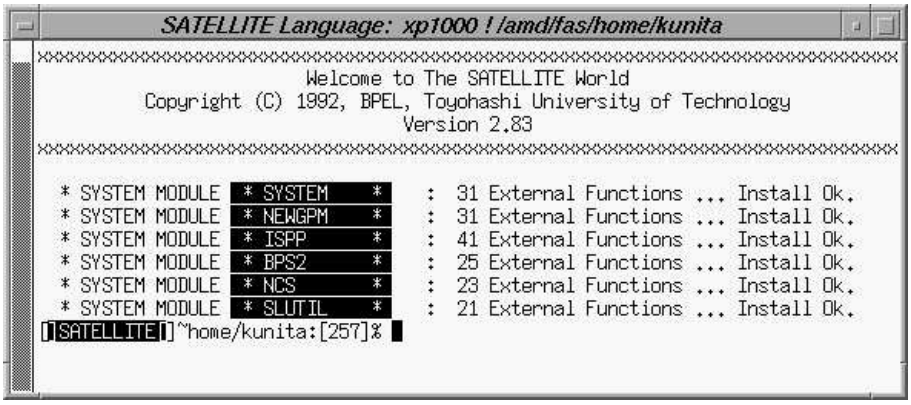


Figure 2.1: X-Window after starting SATELLITE

```
% sl ↩
```

where ↩ stands for CR key. The X-Window after starting SATELLITE is shown in Figure 2.1.

Right after starting, the rc file (/usr/local/satellite/lib/satellite/rc.sl) which is prepared by the system is automatically read at first, and the setup file (~/.setup.sl) which is set by each user is read the next. Since these files are processed in the state of "echo off", messages of UNIX commands are not displayed on a terminal, except the standard output errors. To display the messages, it is necessary to use the standard output errors, or redirect the output as

```
echo "Welcome to SATELLITE WORLD" > /dev/tty
```

Fundamentally, we can write anything to the system rc file and the user setup file, as long as it is syntactically correct. However, the starting will become slow if we call external executions frequently. Generally we put the definitions of system modules in the system rc file, and the definitions of user modules (commands), aliases, sampling frequency, the functions used often, and the variables used in the user setup file.

This system is terminated by typing either "close", "exit", or Ctrl-D, shown as follows:

```
[]SATELLITE[]/home/tom:[1]% close ↩
[]SATELLITE[]/home/tom:[1]% exit ↩
[]SATELLITE[]/home/tom:[1]% ^D
```

Right after terminating, the user clean file (/.clean.sl) is executed. Then the history is saved to the file (/.history.sl), after execution of the closing commands of system modules, release of the system common area (shared memory), destruction of system parameter area (temporary directory), dispatch of the end signals to all child processes, etc., are performed.

The options for starting SATELLITE are as follows:

`-` read a program from a standard input (terminal)

`-rc` do not read the system rc file

`-setup` do not read the user setup file

`-clean` do not read the user clean file

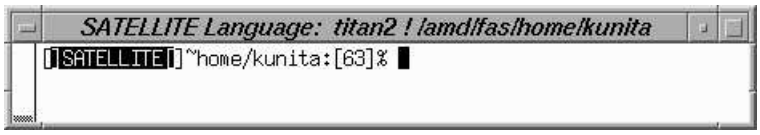


Figure 2.2: Title of the window while using SATELLITE

`-log` specify a directory name for the error log file

`-work` specify a directory name for the work domain (system parameter area)

The work directory (SLxxxx) is deleted after termination.

`-temp` same as `-work`

Moreover, if we have another file to read automatically besides the user setup file, we can specify it as follows:

```
% sl setup2.sl ↩
```

Not providing option "-" means that reading from the standard input (terminal) is not performed and the system closes right after termination. However, if the files are read, except the rc file, the setup file, and the clean file, the system state is "echo on". Then the command messages are displayed.

2.3 Operation

2.3.1 Prompts and a window title

The interpreter shows prompt. As shown below, the prompt of SATELLITE displays the current directory name and the line number. Only last two parts of a current directory name are displayed because of the length of the prompt. When a path name is not complete, "~" appears before the path name. For example,

```
[]SATELLITE[]/home/tom:[62]% cd work ↩
[]SATELLITE[]~tom/work:[63]%
```

Moreover, when a program exceeds 1 line, we are urged by the prompt "+". For example, if we input

```
[]SATELLITE[]~tom/work:[63]% n = 0 ↩
[]SATELLITE[]~tom/work:[64]% for(i = 0; i < 10; i++) { ↩
```

the following is displayed:

```
+
```

In such case, process is completed by inputting the following:

```
n = n + 1 } ↩
```

In the case of X-Window terminal emulator (Xterm, Kterm, DECterm, etc.), the host name and the complete path name of the directory are displayed at the window title (see Figure 2.2). That helps us compensate the imperfect information displayed at the prompt.

Table 2.1: Key binds of the line editor for SATELLITE

beginning of line	^A	
backward char	^B,	←
interrupt	^C	
delete char	^D,	DEL
end of file	^D	
listing up files	^D	
end of lines	^E	
forward char	^F,	→
backward delete char	^H,	BS
newline	^J	
kill line	^K	
newline	^M	
down history	^N,	↓
up history	^P,	↑
tty start output	^Q	
tty stop output	^S	
keyword completion	^W	
filename completion	TAB,	ESC-ESC
command completion	TAB,	ESC-ESC

2.3.2 Editing

The micro line editor for deletion or insertion of characters offers comfortable environment for interactive programming from a terminal. This editor has internal buffers for editing. The contents in the buffers are usually consistent with the character sequences which a user inputs, and displayed on the editing line (back from the prompt).

Line editing

SATELLITE has a "GNU Emacs-like" micro line editor. The editing line is always in insert mode, and we can move the cursor position by Ctrl-F (→), Ctrl-B (←), Ctrl-A, and Ctrl-E keys. Moreover, Ctrl-D (DEL), Ctrl-H (BS), and Ctrl-K can perform deletion of characters. For example, when we input the character sequence shown as follows:

```
[]SATELLITE[]~tom/rose:[63]% n = 0 ↩
```

the cursor is at the right-hand side of "0" now. By pressing Ctrl-H, "0" is eliminated and the cursor is moved left. On the other hand, the cursor is moved left by Ctrl-B, without eliminating "0". The cursor moves to the head of the sentence, that is, to the position of "n", by pressing Ctrl-A. The list of key binds is shown in Table 2.1.

History

The inputs from a terminal are recorded in the history buffers. By pressing Ctrl-P, the history buffers are traced back and the history is copied to the editing buffers. Ctrl-N performs the history search in ascending order. We can freely edit and execute commands from the history buffers. For example,

```
[]SATELLITE[]~tom/rose:[63]% n = 0 ↩
[]SATELLITE[]~tom/rose:[64]% j = 0 ↩
[]SATELLITE[]~tom/rose:[65]%
```

The following can be displayed by pressing Ctrl-P.

```
[]SATELLITE[]~tom/rose:[65]% ^P
[]SATELLITE[]~tom/rose:[64]% j = 0
```

Again, the following can be displayed by pressing Ctrl-P.

```
[]SATELLITE[]~tom/rose:[64]% j = 0 ^P
[]SATELLITE[]~tom/rose:[63]% n = 0
```

Moreover, the following can be displayed by pressing Ctrl-N.

```
[]SATELLITE[]~tom/rose:[63]% n = 0 ^N
[]SATELLITE[]~tom/rose:[64]% j = 0
```

When a character sequence is already in the editing buffer, only the history lines whose heads match the character sequence are called. For example,

```
[]SATELLITE[]~tom/rose:[63]% n = 0 ↩
[]SATELLITE[]~tom/rose:[64]% j = 0 ↩
[]SATELLITE[]~tom/rose:[65]% n
```

By pressing Ctrl-P, the following is displayed:

```
[]SATELLITE[]~tom/rose:[65]% n ^P
[]SATELLITE[]~tom/rose:[63]% n = 0
```

Completion of file names and commands

If TAB key is pressed after inputting characters the help commands will be uniquely identified by the head of the editing buffer. A command name will be completed and the full name will be displayed on the terminal (and the editing buffer). The first candidate is shown if the command cannot be specified uniquely. The next candidate is called by pressing TAB key again. For example, suppose that there are six files in the current directory, namely, report1.tex, report2.tex, report3.tex, work1.tex, work2.tex, and work3.tex. The file name or the directory name that starts with "wo" is searched and displayed from the current directory, shown as follows:

```
[]SATELLITE[]~tom/rose:[88]% wo TAB
[]SATELLITE[]~tom/rose:[88]% work1.tex
```

The 2nd candidate is displayed by pressing TAB key again as follows:

```
[]SATELLITE[]~tom/rose:[88]% work1.tex TAB
[]SATELLITE[]~tom/rose:[88]% work2.tex
```

The candidates are searched in paths and order described by the environment variable PATH. If the search cycle is completed, the editing buffer is cleared. After that, if TAB key is pressed again, the first candidate will be called again. If there is no candidate, there is nothing to display.

Completion of file names, UNIX commands, and directory names can be performed in the arbitrary position of the editing buffer. The keywords for discrimination between both cases are the blank, just before the cursor, the equaling character (=), and the character sequence divided by a double quotation mark (").

Reserved words or variable names in the symbol table of the interpreter can also be completed by pressing Ctrl-W. For example, if we want to complete the reserved word or the variable name that starts with "i",

```
[]SATELLITE[]~tom/rose:[89]% i ^W
[]SATELLITE[]~tom/rose:[89]% if
```

By pressing Ctrl-W again, the 2nd candidate is displayed as follows:

```
[]SATELLITE[]~tom/rose:[89]% if ^W
[]SATELLITE[]~tom/rose:[89]% inline
```

Listing files

File names can be listed by Ctrl-D halfway. This function is helpful for checking the file names while typing a program, or using UNIX commands such as **cd**, **cp**, **mv**, etc. For example,

```
[]SATELLITE[]~tom/rose:[8]% cd /home/tom/TeX/
```

As shown above, we can get the subdirectory names under /home/tom/Tex/ by pressing Ctrl-D, without interrupting the input of character sequences.

```
[]SATELLITE[]~tom/rose:[8]% cd /home/tom/TeX/ ^D
RETINA1/        RETINA2/        work1.tex       work2.tex
[]SATELLITE[]~tom/rose:[8]% cd /home/tom/TeX/
```

Character "/" is appended to the end of directory names, "*" to executable file names, "@" to symbolic links, "=" to sockets, "—" to FIFOs (pipe with a name), "%" to character devices, and "#" to block devices, respectively. After displaying the list, the command inputted halfway is redisplayed.

We can also obtain the list of the files that start with certain characters. In the following example, all of file and subdirectory names that start with "RE" will be displayed.

```
[]SATELLITE[]~tom/rose:[9]% cd /home/tom/TeX/RE ^D
/home/tom/TeX/RETINA1/ /home/tom/TeX/RETINA2/
[]SATELLITE[]~tom/rose:[9]% cd /home/tom/TeX/
```

In the special case, the list of all files and subdirectories which are consistent with the character sequences including wild cards in the current directory can be displayed as follows:

```
[]SATELLITE[]~tom/rose:[10]% ␣ ^D
```

where ␣ stands for a blank.

Calling UNIX commands

When the token not registered as reserved word or variable name appears in the head of the sentence, the system leaves the processing to the UNIX shell. We can deal with UNIX commands in the same way as the UNIX shell. When the variable with the same name as UNIX command is already registered, we can avoid duplication by attaching the backslash (\) to the head of the commands.

2.3.3 Preprocessor

The character sequence edited by the simple line editor is handed over to the preprocessor. It mainly performs (1) history substitution, (2) alias substitution, and (3) parameter passing to SATELLITE commands.

History substitution

!! refers to the last history items.

!str refers to the newest history item which starts with "str".

In both cases the head of the sentence is recognized as a history item, and the replacement can be performed without destroying the character sequences before and after it.

Alias substitution

If aliases are already defined, just the first token of the sentence is replaced. That is similar to the C shell of UNIX.

Parameter passing

One of the strongest points of SATELLITE is that several parameters required in each function can be passed interactively. The details are described in §**2.9.1**.

2.3.4 Arithmetical operation

To perform arithmetical operations using SATELLITE, we can input them directly. For example doing multiplication 3×6,

```
[]SATELLITE[]~tom/rose:[13]% 3*6 ↩
18
[]SATELLITE[]~tom/rose:[14]%
```

Similarly dividing, as follows:

```
[]SATELLITE[]~tom/rose:[14]% 3/6 ↩
0.5
[]SATELLITE[]~tom/rose:[15]%
```

2.4 Data handling

2.4.1 Objects and classes

Data obtained from biological systems or numerical simulations is usually a multi-dimensional series. We rarely pay attention to one value but rather deal with a set. SATELLITE deal with such a time series as a single data class (object) and provides a data structure, namely "Series object", which can treat the differences between the temporal changes and the spatial changes of the multi-dimensional data efficiently (see also Figure 2.3).

There are 4 other kinds of object classes than the Series class: Snapshot, String, Scalar, and File classes. These classes are divided with respect to values they deal with (numerical values and character

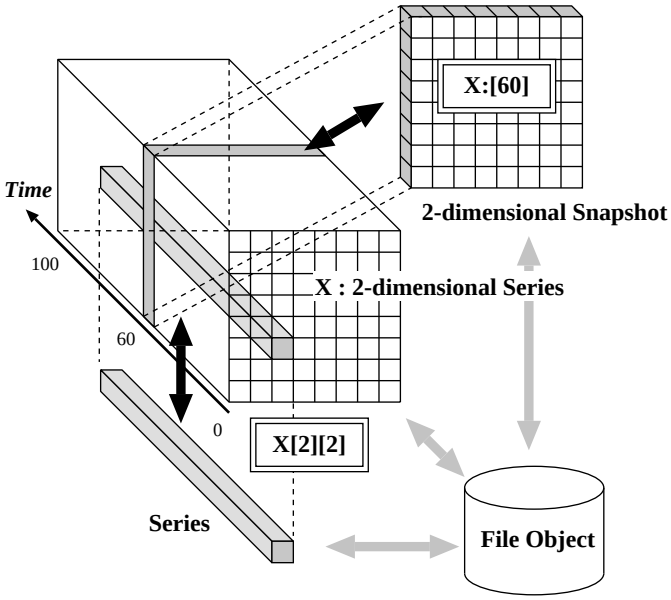


Figure 2.3: Objects and their interrelationship

sequences). Scalar, Snapshot, Series, and File are objects expecting numerical values. The characteristics of classes are inherited in the order of listing, taking Scalar as a super class. The Snapshot object is a set of Scalar objects equivalent to the multi-dimensional arrangements for general-purpose languages. The Series object can be viewed as a series of Snapshots in time, that is, 1-dimensional arrangement of Snapshot objects. The File object requires a file name for handling the specified data on the UNIX system.

Each object encapsulates data and processing methods. Arithmetical operations are different for Scalar, Series, Snapshot, String, and File objects. In case of the Scalar object, the addition is performed by adding up only 1-point data, as shown in Figure 2.4.

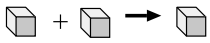


Figure 2.4: Addition between two Scalar objects

In case of the Series object, all values on the time-axis must be added simultaneously, as shown in Figure 2.5.

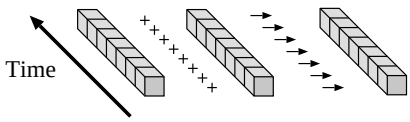


Figure 2.5: Addition between two Series objects

5 kinds of object classes used in SATELLITE are explained in the pages that follow.

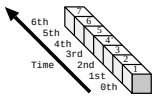


Figure 2.6: Data organization in 1-dimensional Series object

Series object

Series is the object class in which a set of multi-dimensional data is lined to the direction of a time-axis (Figure 2.3). The Series object that includes a single value is the same as 1-dimensional array in general-purpose languages (Figure 2.6). The operation between two or more Series classes is possible only when each size of a data set (Snapshot) is the same. That is, we cannot deal with a 2-dimensional Series object and a 1-dimensional Series object together. Moreover, when the length of the direction of the time-axis is different, the operation is performed within the limits of the shorter one, and the remainder is copied as it is.

A mixed operation between a Series object and a Scalar object can be performed, e.g., the multiplication of the Scalar object and each element in the Series objects. The characteristics of Series objects are the implicit calculations repeated to each element and the operation functions for time series data by the operators "[ ]" and ":[ ]", such as selection, filling, etc.

Here, some examples of operations on Series objects are shown below. Data from 1 to 7 are stored in a 1-dimensional Series object by the following command (see also Figure 2.6):

```
[]SATELLITE[]~tom/rose:[27]% x = 1~7 ↩
```

Here, "~" is the operator for generating an arithmetical series with a margin 1 (see §**2.5** for further details).

```
[]SATELLITE[]~tom/rose:[28]% x ↩
[0]:%          1          2          3          4          5
[5]:%          6          7
[]SATELLITE[]~tom/rose:[29]%
```

We can check the 3rd element as follows:

```
[]SATELLITE[]~tom/rose:[29]% x:[3] ↩
4
[]SATELLITE[]~tom/rose:[30]%
```

The next example shows the operation on a multi-dimensional object. The object class is defined as follows (see §**2.4.2** for further details):

```
[]SATELLITE[]~tom/rose:[30]% series y[2][2] ↩
```

A value of y[0][1] is assigned, e.g.,

```
[]SATELLITE[]~tom/rose:[31]% y[0][1] = x ↩
```

To display the value of y[0][1], type as follows (see also Figure 2.7):

```
[]SATELLITE[]~tom/rose:[32]% y[0][1] ↩
[0]:%          1          2          3          4          5
```

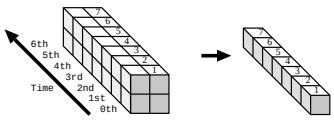


Figure 2.7: Data organization in 2-dimensional Series object (Example 1)

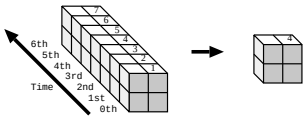


Figure 2.8: Data organization in 2-dimensional Series object (Example 2)

```
[5]:%          6          7
[]SATELLITE[]~tom/rose:[33]%
```

To obtain the spatial data of certain time, type (see also Figure 2.8),

```
[]SATELLITE[] tom/rose:[33]% y:[3] ⏎
[0][1]:%          0          4
[0][0]:%          0          0
[]SATELLITE[] tom/rose:[34]%
```

Snapshot object

Snapshot is the object class similar to matrix (Figure 2.3). It is for dealing with static data sets, and used as a subset of a Series object or a matrix. Only on Snapshot objects with the same size can be performed operations. For the mixed operation with a Scalar object, the same operation is repeatedly performed between each element of the Snapshot and the Scalar.

Some examples of operations on Snapshot objects are shown below (Figure 2.9). First, an object class is defined as follows (see §**2.4.2** for further details):

```
[]SATELLITE[]~tom/rose:[34]% snapshot z[2][2] ⏎
[]SATELLITE[]~tom/rose:[35]% z ⏎
[0][1]:%          0          0
[0][0]:%          0          0
[]SATELLITE[]~tom/rose:[36]%
```

A value is assigned to the item of this object as follows:

```
[]SATELLITE[]~tom/rose:[37]% z[0][1] = 4 ⏎
[]SATELLITE[]~tom/rose:[38]% z ⏎
```

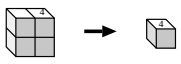


Figure 2.9: Data organization in 2-dimensional Snapshot object.

Figure 2.10: A Scalar object.

```
[0][1]:%          0          4
[0][0]:%          0          0
[]SATELLITE[]~tom/rose:[39]%
```

We can get the value of certain item as follows:

```
[]SATELLITE[]~tom/rose:[39]% z[0][1] ↩
4
[]SATELLITE[]~tom/rose:[40]%
```

Scalar object

Scalar is the object class for numbers, such as variables to control sequences, elements in Series objects, etc.(Figure 2.10). It is expressed as the double precision number.

```
[]SATELLITE[]~tom/rose:[41]% k = 0.8 ↩
[]SATELLITE[]~tom/rose:[42]% k ↩
0.8
[]SATELLITE[]~tom/rose:[43]%
```

File object

This class is used for saving data in a file on a hard disk. Data can be loaded from files and stored to files. Therefore, we can deal with it as with other objects, without taking care of the format or the data type. Moreover, mixed operations with the Series object are also possible.

The File object has almost the same structure as Series, and can store two or more sets of multi-dimensional data (Series, Snapshot) in the direction of the "Record" (see Figure 2.11). Record corresponds to the time of the Series object, and has flexible length. Each data stored in a record must have the same size. Moreover, since the number of dimensions and indexes of the File object depends on that of the object stored in the first place, the object with the different number of dimensions and indexes is stored after conversion.

Storing is performed by assigining a data element to File object. For example, y (a Series or Snapshot object) is stored to the record 0 of data.dat.

```
[]SATELLITE[]~tom/rose:[26]% $"data.dat":[0] = y ↩
```

In case of loading data, we just type the name of a File object in an editing line. SATELLITE will automatically treat it as the Series object. For example, data in the record 0 of data.dat is loaded to x:

```
[]SATELLITE[]~tom/rose:[27]% x = $"data.dat":[0] ↩
```

All records of data.dat can be loaded to y as follows:

```
[]SATELLITE[]~tom/rose:[28]% y = $"data.dat" ↩
```

Both x and y are Series objects, and their dimension and index numbers depend on data.dat. For example, when 2-dimensional data is stored in a record, x is 2 dimensional Series object and y is 3-dimensional one.

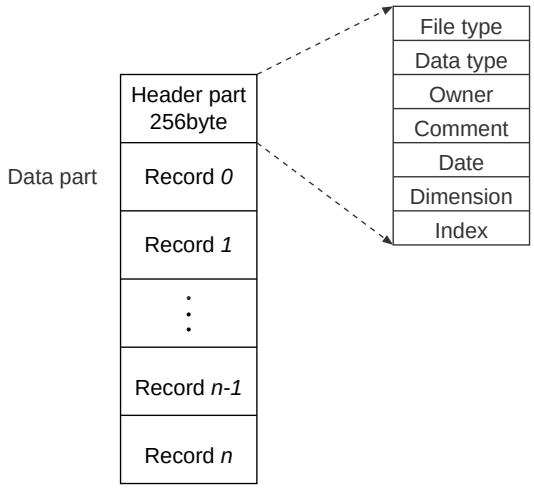


Figure 2.11: Data file structure

String class

File names are basic and important information for managing data. They usually include the attributes or "serial numbers" of data. The String object is used for labeling, e.g., in the case of drawing a chart, outputting a message from a program, etc. The concatenation, deletion, repetition, and separation are performed by sending operators "+", "-", "*", and "/", respectively. A character sequence should be marked by double quotation marks (").

For example, concatenating a character sequence with another one is performed as follows:

```
[]SATELLITE[]~tom/rose:[29]% "test" + ".dat" ↩
test.dat
[]SATELLITE[]~tom/rose:[30]%
```

Moreover, we use "-" to delete a character sequence.

```
[]SATELLITE[]~tom/rose:[30]% "test.dat" - ".dat" ↩
test
[]SATELLITE[]~tom/rose:[31]%
```

For repetition of a character sequence, "*" is used.

```
[]SATELLITE[]~tom/rose:[31]% "ABC" * 4 ↩
ABCABCABCABC
[]SATELLITE[]~tom/rose:[32]%
```

In order to separate a character sequence, "/" is used.

```
[]SATELLITE[]~tom/rose:[32]% "A,BC,D,EFG,H,IJK," / "," ↩
[0]% A     BC    D     EFG   H
[5]% IJK
[]SATELLITE[]~tom/rose:[33]%
```

where "[0]%" and "[5]%" represent the index of data for displaying two or more elements.

2.4.2 Class definition

Class definition of variables in SATELLITE does not restrain the types permanently, but generates the objects whose contents are flexible. Definition of Series objects, with no index specifies the 1-dimensional time series:

```
[]SATELLITE[]~tom/rose:[35]% series x ↩
```

The Series object 64 × 64 is defined by as follows:

```
[]SATELLITE[]~tom/rose:[36]% series y[64][64] ↩
```

Definition of Snapshot objects is performed as follows:

```
[]SATELLITE[]~tom/rose:[37]% snapshot a[10], b[20][20] ↩
```

In the case of Snapshot, we cannot omit the size. Scalar objects are defined as follows:

```
[]SATELLITE[]~tom/rose:[38]% scalar i, j, k ↩
```

Scalar objects are not allowed to have the size, that is, each object deal with only one value. Finally, definition of String objects is performed as follows:

```
[]SATELLITE[]~tom/rose:[39]% string str, mstr[10] ↩
```

It is possible for String objects to specify their size.

2.4.3 Conversions between two or more object classes

The object class (type) of variables in SATELLITE is determined at the time of substitution. It is the same as the size of the class on the right side of the equality work. The above-mentioned definition method is used only for receiving values as arguments of a function, assigning values to multi-dimensional objects, etc. We do not need to define the class in the case where it is determined by the assignment as follows:

```
[]SATELLITE[]~tom/rose:[50]% a = 1 ↩
```

We cannot use undefined variables for the arguments of functions or procedures. For example, **FFTC** in the ISPP module is one of such commands;

```
[]SATELLITE[]~tom/rose:[51]% fftc(P,x,y,u,v) ↩
```

where P is a flag for specifying the calculation method, x and y are input series, and u and v are output series of the **FFTC** command. In this case, u and v should be defined before calling **FFTC** function.

Conversion between two object classes is automatically performed. In this way, we can change an object class to another one. In case of the operation between String and Scalar objects, for example, the Scalar value is converted to a character sequence. The resulting class is String, e.g.,

```
[]SATELLITE[]~tom/rose:[52]% "test" + 3 ↩
test3
[]SATELLITE[]~tom/rose:[53]% "" + 3.1415926 ↩
3.14159
[]SATELLITE[]~tom/rose:[54]%
```

The reason why the result of "" + 3.1415926 becomes 3.14159 is due to round off for displaying. A numerical value is obtained after changing String into Scalar as follows:

```
[]SATELLITE[]~tom/rose:[54]% 3 + "3.1415926" ↩
6.1415926
[]SATELLITE[]~tom/rose:[55]% 0 + "1.08e-2" ↩
0.0108
[]SATELLITE[]~tom/rose:[56]%
```

Similarly other object conversions can be performed, such as Series → String, String → Series, etc. Conversion between more than two objects can be also performed.

2.4.4 Type of object

To obtain the object class of the variable whose class is unknown, the **TYPEOF** command is used. Suppose that x is Series object and y is Snapshot object. Then we can get type of each class of these variables by the following:

```
[]SATELLITE[]~tom/rose:[56]% typeof(x) ↩
series
[]SATELLITE[]~tom/rose:[57]% typeof(y) ↩
snapshot
[]SATELLITE[]~tom/rose:[58]%
```

In order to get the index of a object, we use the **INDEX** command. For example, if we define a series object as

```
[]SATELLITE[]~tom/rose:[58]% a = 1~10 ↩
```

then the index of the object can be obtained by

```
[]SATELLITE[]~tom/rose:[59]% index(a) ↩
10
[]SATELLITE[]~tom/rose:[60]%
```

In case of multi-dimensional data, such as b[10][50], the information is displayed as follows:

```
[]SATELLITE[]~tom/rose:[60]% snapshot b[10][50] ↩
[]SATELLITE[]~tom/rose:[61]% index(b) ↩
[0]:%          10          50
[]SATELLITE[]~tom/rose:[62]%
```

2.5 Expressions and operators

Expression relates not only simple arithmetical operations but also substitutions, functions, etc. The results of the evaluation of expressions are displayed automatically, except for substitutions. Although the notation of operators of SATELLITE is different from its internal functions' one, they are internally treated equally. The operator and the internal function appeared in an expression is sent to the linked object and the first argument object respectively, as a message. Therefore, even if two operators or internal functions are the same, their performance may be different and depending on the object class. Operators include arithmetical operators, relational operators, logical operators, increment and decrement

Table 2.2: Priority table for operators (in order of the high priority).

( )	[ ]	: [ ]				
^						right
!	−	++	−−			left
~						left
*	/	%				left
+	−					left
>	>=	<	<=	==	!=	left
&&						left
||						left
=	+=	−=	*=	/=	^=	right

Notice: In the above table, "right" means that the operator is combined with the right-hand side object, and "left" means that the operator is combined with the left-hand side object.

operators, the substitution operator "=", the "~" operator for generating a sequence with margin 1, the operator "( )" for connecting two or more series, etc. Followings are the examples of usage:

```
[]SATELLITE[]~tom/rose:[56]% x = -3~-1 ↩
[]SATELLITE[]~tom/rose:[57]% x ↩
[0]:%        -3        -2        -1
[]SATELLITE[]~tom/rose:[58]% y = 1~3 ↩
[]SATELLITE[]~tom/rose:[59]% y ↩
[0]:%         1         2         3
[]SATELLITE[]~tom/rose:[60]% z = (x, 0, y) ↩
[]SATELLITE[]~tom/rose:[61]% z ↩
[0]:%        -3        -2        -1         0         1
[5]:%         2         3
[]SATELLITE[] tom/rose:[62]%
```

Operators are interpreted by following the priority shown in Table 2.5. The following example demonstrates for comparison operators.

```
[]SATELLITE[]~tom/rose:[63]% (z > 0) * z ↩
[0]:%        -0        -0        -0         0         1
[5]:%         2         3
[]SATELLITE[]~tom/rose:[64]%
```

Objects are destroyed after performing operations. If we want to keep the results of operations, we have to assign them to variables. The variable mentioned here can be regarded as a simple container for objects, without restricting the type of data. Therefore, even if object names are the same, there is some possibility that their contents become different after substitution. Memory management of objects is done by "garbage collecting" method.

2.6 Internal constants

SATELLITE has defined several internal constants in order to ease programming or operating internal functions. There are three kinds of internal constants:

- Floating point constants, such as 3.0, 1.0e−5, etc, and character sequence constants, such as "Welcome to SATELLITE World".
- Mathematical constants

  $180/\pi$: DEG = 57.2957...

  The base of log : E = 2.7182...

  Euler's constant : GAMMA = 0.5772...

  Golden ratio : PHI = $(\sqrt{5}+1)/2$ = 1.6180...

  π : PI = 3.1415...

- User-defined constants defined by the command **CONST**

  For example,

  ```
  []SATELLITE[]~tom/rose:[56]% const Degree = PI/180 ↩
  ```

SATELLITE treats the internal constants and user-defined constants equally. Moreover, we can change the internal constant to the user-defined one by the command **CONST**. **CONST** can deal with the expression in which its right-hand side is a formula or an object like Series. It is evaluated right after it is defined. The difference between variables and constants is just in permission of substituting objects.

2.7 Control sequence

As in C language, we can use **IF**, **WHILE**, **DO-WHILE**, **For** as control sequences, and { **...** } for grouping statements together.

- **if** `( expr1 ) stmt1`
- **if** `( expr1 ) stmt1` **else** `stmt2`
- **while** `( expr1 ) stmt1`
- **do** `stmt1` **while** `( expr1 )`
- **for** `( expr1 ; expr2 ; expr3 ) stmt1`

`expr1`, `expr2`, and `expr3` are general expressions including substitutions or functions. `stmt1` and `stmt2` are single statements. A set of statements in parentheses { **...** } is also regarded as the single statement. AND operator "&&", OR operator "| |" , and other relation operators can be used in expressions. If the result of evaluation of an expression is equal to zero, it is treated as "false", or else "true". In the case where two or more results are obtained by a logical operation, such as a comparison between two Series objects, if all of them are not equal to zero, it is regarded as "true".

2.7.1 IF sequence

If the result of the conditional expression `expr1` is "true", the first statement `stmt1` is performed. If the condition `expr1` is evaluated as "false", the next statement `stmt2` is executed, instead of `stmt1`.

IF sequence(1):

```
if ( expr1 ) {
    stmt1;
}
```

IF sequence(2):

```
if ( expr1 ) {
    stmt1;
} else {
    stmt2;
}
```

For example, processing of "If x is smaller than n, then add x to s" is described as follows:

```
[]SATELLITE[]~tom/rose:[86]% if (x < n) { ↩
+ s = s + x ↩
+ } ↩
[]SATELLITE[]~tom/rose:[87]%
```

Processing of "If x is smaller than n, then add x to s, or else subtract x from s" is described as follows:

```
[]SATELLITE[]~tom/rose:[87]% if (x < n) { ↩
+ s = s + x ↩
+ } else { ↩
+ s = s - x ↩
+ } ↩
[]SATELLITE[]~tom/rose:[88]%
```

2.7.2 WHILE and DO-WHILE sequences

WHILE and **DO-WHILE** sequences controll the loops. They perform the statement `stmt1` repeatedly until the condition `expr1` is true. In case of **WHILE** sequence, the evaluation of `expr1` is performed before the execution of `stmt1`, including its effects. On the other hand, the statement in case of **DO-WHILE** is processed after execution of `stmt1`.

WHILE sequence:

```
while ( expr1 ) {
    stmt1;
}
```

DO-WHILE sequence:

```
do {
    stmt1;
} while ( expr1 );
```

Processing of "While x is smaller than n, add x to s" is described by the **WHILE** sequence as follows:

```
[]SATELLITE[]~tom/rose:[89]% while (x < n) { ↩
+ s = s + x ↩
+ n++ ↩
+ } ↩
[]SATELLITE[]~tom/rose:[90]%
```

The same example by the **DO-WHILE** sequence is as follows:

```
[]SATELLITE[]~tom/rose:[90]% do { ↩
+ s = s + x ↩
+ n++ ↩
+ } while (x < n) ↩
[]SATELLITE[]~tom/rose:[91]%
```

2.7.3 FOR sequence

In **FOR** sequence, the first expression `expr1` is evaluated only once, that is, during the initialization of a loop. **FOR** sequence is terminated if `expr2` is false, which is evaluated before each iteration. Expression `expr3` is used for the re-initialization of a loop after repetition.

FOR sequence:

```
for( expr1; expr2; expr3 ) {
    stmt1;
}
```

For example, processing of "Add x to s n times" is described by the **FOR** sequence as follows:

```
[]SATELLITE[]~tom/rose:[91]% for (i=1; i<=n; i++) { ↩
+ s = s + x ↩
+ } ↩
[]SATELLITE[]~tom/rose:[92]%
```

BRAKE forces termination of a loop. **CONTINUE** returns a loop to its starting point.

2.8 Functions and procedures

2.8.1 The scope of variables and constants, and arguments in functions and procedures

The variables in SATELLITE are effective only in the function or the procedure where they are defined, that is, it is not allowed to refer to those variables in another function or procedure. In order to compare external variables in a function or a procedure, we need to use the reserved word **EXTERNAL**.

Internal constants and the constants are defined by **CONST**. They are available in functions or procedures after their definitions. Although we can define constants in a function or a procedure locally, they become effective after processing.

Since all arguments of the functions and procedures in SATELLITE are handed over as variables, the results obtained by operations on arguments inside return to the root.

2.8.2 Internal functions

SATELLITE has defined some internal functions for mathematical calculations or system management. The mathematical function library apply to all objects. All internal functions have the same priority. Mathematical and system functions are shown in the following list (cf. Command Reference Manual):

List of mathematical functions

`abs(x)` $|x|$

`acos(x)` $\cos^{-1} x$

`asin(x)` $\sin^{-1} x$

`atan(x)` $\tan^{-1} x$

`atan2(x,y)` $\tan^{-1} x/y$, same as `atan(x/y)`

`cos(x)` $\cos x$

`exp(x)` e^x

`exp2(x)` 2^x

`int(x)` the integer part of x (rounding off decimal fractions)

`mod(x,y)` the remainder of x/y, same as `x % y`

`log(x)` $\log_e x$ (a natural logarithm)

`log2(x)` $\log_2 x$

`log10(x)` $\log_{10} x$

`pow(x,y)` x^y, same as `x^y`

`sgn(x)` the sign of x

`sin(x)` $\sin x$

`sqrt(x)` $\sqrt{x}$

`tan(x)` $\tan x$

List of system functions

`abort()` Termination of a program by force

`alias(x,y)` Alias operation

`history(x)` History operation

`index(x)` Acquisition of an object's index

`inline(x)` Execution of a program from a file

`length(x)` Acquisition of the number of data points / elements

`printf(x, ...)` Indication of objects

`read(x)` Reading an object

`strlen(x)` Acquisition of the length of a character sequence

`typeof(x)` Acquisition of an object class

`undef(x)` Elimination of a variable

`unix(x)` Execution of UNIX command

`write_type()` Specification of a file type for writing

`GarCo()` Garbage collection

`Symbols()` Indication of a variable name (in symbol table)

Note: `x` and `y` are the function arguments. "..." stands for the arguments in which the number of them is variable.

2.8.3 User-defined function

We can define functions and procedures of our own. For example, the function `plusten` that performs "Add 10 to the argument n" is given as follows:

```
[]SATELLITE[]~tom/rose:[57]% func plusten(n) { ↩
+ return n + 10 ↩
+ } ↩
[]SATELLITE[]~tom/rose:[58]%
```

The following is an example of calling this function:

```
[]SATELLITE[]~tom/rose:[58]% num = 8 ↩
[]SATELLITE[]~tom/rose:[59]% plusten(num) ↩
18
[]SATELLITE[]~tom/rose:[60]%
```

Moreover, functions can be called recursively. The function `fac` (for obtaining $x!$) is described as follows:

```
[]SATELLITE[]~tom/rose:[60]% func fac(x) { ↩
+ if (x <= 0) return 1 else return x * fac(x-1) ↩
+ } ↩
[]SATELLITE[]~tom/rose:[61]%
```

The next example is the procedure that performs "Substitute n for the argument x and $n+1$ for the argument y". At first, we have to define x and y before calling the procedure, as mentioned in §**2.4.3**.

```
[]SATELLITE[]~tom/rose:[61]% scalar x, y ↩
[]SATELLITE[]~tom/rose:[62]% proc plusone(n, x, y) { ↩
+ x = n ↩
+ y = n + 1 ↩
+ } ↩
[]SATELLITE[]~tom/rose:[63]%
```

The following is an example of calling this procedure:

```
[]SATELLITE[]~tom/rose:[62]% plusone(14, x, y) ↩
[]SATELLITE[]~tom/rose:[63]% x ↩
14
[]SATELLITE[]~tom/rose:[64]% y ↩
15
[]SATELLITE[]~tom/rose:[65]%
```

The variables used in a function and procedure are local ones. They are effective only in the function or procedure unless **EXTERNAL** is used. In order to use global variables, it is required to define every time in the function or the procedure. The following is the same operation as the above mentioned example except for using **EXTERNAL** definition of x and y:

```
[]SATELLITE[]~tom/rose:[65]% proc subplusone(n) { ↩
+ external x, y ↩
+ x = n ↩
+ y = n + 1 ↩
+ } ↩
[]SATELLITE[]~tom/rose:[66]%
```

Another example follows:

```
[]SATELLITE[]~tom/rose:[66]% func glplusone(gn) { ↩
+ external x, y ↩
+ subplusone(gn) ↩
+ z = x + y ↩
+ return z ↩
+ } ↩
[]SATELLITE[]~tom/rose:[67]% scalar x, y, z ↩
[]SATELLITE[]~tom/rose:[68]% glplusone(4) ↩
9
[]SATELLITE[]~tom/rose:[69]% x ↩
4
[]SATELLITE[]~tom/rose:[70]% y ↩
5
[]SATELLITE[]~tom/rose:[71]% z ↩
0
[]SATELLITE[]~tom/rose:[72]%
```

Since functions never check their arguments classes, the ones having multi-defined operators and mathematical functions are performed exactly, regardless of the object class of arguments (multi-state functions) except the class the operators cannot deal with. The example of a sigmoidal function is shown. At first, it is defined as follows:

```
[]SATELLITE[]~tom/rose:[72]% func sig(t) { ↩
+ return 1/(1+exp(-t)) ↩
} ↩
[]SATELLITE[]~tom/rose:[73]%
```

When the argument t is a Scalar object, the return value of the function is also the Scalar object.

```
[]SATELLITE[]~tom/rose:[73]% sig(0) ↩
0.5
[]SATELLITE[]~tom/rose:[74]%
```

In the case where t is a Series object, we have

```
[]SATELLITE[]~tom/rose:[74]% sig(-10~10) ↩
[ 0]:%   4.54e-05  0.0001234  0.0003354  0.0009111   0.002473
[ 5]:%   0.006693    0.01799    0.04743     0.1192     0.2689
[10]:%        0.5     0.7311     0.8808     0.9526      0.982
[15]:%     0.9933     0.9975     0.9991     0.9997     0.9999
[20]:%          1
[]SATELLITE[]~tom/rose:[75]%
```

Thus, the series from -10 to 10 obtained by the operator "~" (21 data points) is handed over to `sig( )`. The result is the Series object with 21 elements. We can easily make programs dealing with time series using mathematical formulas only. In the above mentioned example, the result is obtained just as we intended in cases where the argument is a Scalar, Snapshot, Series, or File object. If the argument t is a String object, an error message is returned.

```
[]SATELLITE[]~tom/rose:[75]% sig("test") ↩
sl:  string not supported method
[]SATELLITE[]~tom/rose:[76]%
```

2.8.4 Input and output

There are some external functions and commands for displaying objects. Using **PRINT**, we only have to arrange the objects to display (separated by commas). In SATELLITE, the message is displayed on line according to specific format, e.g.,

```
[]SATELLITE[]~tom/rose:[70]% x = 3 ↩
[]SATELLITE[]~tom/rose:[71]% print "x = ", x, "\n" ↩
x = 3
[]SATELLITE[]~tom/rose:[72]% print (1, 2, 3, 4, 5), "\n" ↩
[0]:%          1          2          3          4          5
[]SATELLITE[]~tom/rose:[73]%
```

The function **PRINTF** is also available, We can specify the precision of displayed elements. Although the usage is similar to the printf function of C language, it is internally different.

```
[]SATELLITE[]~tom/rose:[73]% x = 3 ↩
[]SATELLITE[]~tom/rose:[74]% printf("x = %d\n", x) ↩
x = 3
[]SATELLITE[]~tom/rose:[75]% printf("%9.4f\n",(1,2,3,4,5)) ↩
[0]:%    1.0000    2.0000    3.0000    4.0000    5.0000
[]SATELLITE[]~tom/rose:[76]%
```

The **READ** function reads an object from a terminal. It receives an object class as argument in character format and converts it to the class. The return value is the read object. In case of the objects that consist of two or more elements like Series, the elements are separated by commas. For example,

```
[]SATELLITE[]~tom/rose:[77]% y = read(series) ↩
1,2,3,4,5,6,7,8
```

The numerical values are stored in y as follows:

```
[]SATELLITE[]~tom/rose:[78]% y ↩
[0]:%          1          2          3          4          5
[5]:%          6          7          8
[]SATELLITE[]~tom/rose:[79]%
```

2.8.5 Data stream handling

The redirection of data displayed on terminal to variables or UNIX commands can be performed by the data stream handling in SATELLITE. It is similar to a pipe in UNIX. The function **UNIX** is used for interfacing UNIX with SATELLITE. It hands over a UNIX command to the shell. In SATELLITE, the input data is converted into the String object. Then it can be substituted to a variable. Data from the standard output can also be handed over to an UNIX command using the "<<" operator.

The example of the collective operation for all files listed by the ls command of UNIX in a current directory is shown as follows. Function **UNIX** is used:

```
[]SATELLITE[]~tom/rose:[79]% files = unix("ls *.dat") ↩
[]SATELLITE[]~tom/rose:[80]% files ↩
[0]%      fnama1.dat      fname2.dat      fname3.dat
[3]%      fname4.dat      fname5.dat
[]SATELLITE[]~tom/rose:[81]% for(i=0;i<length(files);i++){ ↩
+        (Operation of files[i])
+ } ↩
[]SATELLITE[]~tom/rose:[82]%
```

The following is the example in which the data generated in SATELLITE is stored into a text file.

```
[]SATELLITE[]~tom/rose:[82]% t = 2 * PI * 0~1024 / 1024 ↩
[]SATELLITE[]~tom/rose:[83]% unix("cat > data.txt")<<sin(t) ↩
```

The next example is the reverse operation, that is, from a text file to an object.

```
[]SATELLITE[]~tom/rose:[84]% s = unix("cat data.txt") ↩
```

The String object s is converted to the Series object t by the following:

```
[]SATELLITE[]~tom/rose:[85]% t = 0 + s ↩
[]SATELLITE[]~tom/rose:[86]% t ↩
[   0]:%    0.000    0.006    0.012    0.018    0.024
[   5]:%    0.030    0.036    0.042    0.049    0.055
       (Omitted)
[1015]:%    -0.05    -0.04    -0.04    -0.03    -0.03
[1020]:%    -0.02    -0.01    -0.01    -0.00    -0.00
[]SATELLITE[]~tom/rose:[87]%
```

2.9 Programming

2.9.1 Online message

One of the special features of SATELLITE is that it allows us to deal with parameters interactively while displaying their explanation. The parameters are separated by comma. Here, the example is shown, e.g., for function **GRAPH**:

```
[]SATELLITE[]~tom/rose:[13]% graph ↩
[]SATELLITE[]~tom/rose:[13]% graph(x,
.....  Y-AXIS DATA ( Object or T F D )
```

It is required to input the object of Y-axis. If we input "volt", for example, the following is displayed:

```
[]SATELLITE[]~tom/rose:[13]% graph(volt ↩
[]SATELLITE[]~tom/rose:[13]% graph(volt,"T",
.....  X-AXIS DATA ( Object or T F D )
```

Next, the object of X-axis follows. Messages are displayed for all input parameters. If a default parameter is acceptable, we just press the CR key to move to the next parameter.

The syntax of every SATELLITE command is checked. However, preprocessor can compensate for simple mistakes. Parameters can be edited freely since they are stored in editting buffers.

2.9.2 Loading a program from a file

To make the interpreter load a program from a file, the function **INLINE** is used. Its argument is the file name (it treats the file as the standard input). Each line of the program is processed one after another, similarly as in the case of the input from a terminal. It is also possible to process the program of another file from the one called. In fact, the **INLINE** is also processed in a syntactic mode and connects the standard input of the interpreter to the file. The limitation is given by the number of files that can be opened. If an error occurs while loading a file, the subsequent lines are not executed. The example of a program file with name `testsum.sl` is shown as follows:

```
psum = 0;
for( i = 1; i <= 10; i++ ) {
    sum = sum + i;
}
printf("sum = %d\n", sum);
```

Using **INLINE** the interpreter reads the above file.

```
[]SATELLITE[]~tom/rose:[14]% inline("testsum.sl") ↩
sum = 55
[]SATELLITE[]~tom/rose:[15]%
```

When required to read a file in another file, use **INLINE** in the file as follows:

```
sum = 0;
for( i = 1; i <= 10; i++ ) {
    sum = sum + i;
}
printf("sum = %d\n",sum);
inline("testsum2.sl");
```

The limit number of available file calls is 10.

Chapter 3

SYSTEM Module — SYSTEM

SYSTEM module is a gathering of basic functions for handling data. It includes the functions for extracting a subset of data, finding a maximum or minimum of a sequence, modifying data format, displaying header information of data files, etc. They are illustrated in the following subsections.

3.1 HELP — displaying a command manual

Display the on-line reference of SATELLITE commands.

usage : `help( "com_name" )`

`com_name` stands for a command name. It needs to be put in double quotation marks. For example, the explanation of **HELP** command is displayed by the following:

```
[]SATELLITE[]~tom/rose:[63]% help("help") ↩
```

3.2 HEADER — displaying or modifying the header information of a data file

This command is for confirmation or alteration of a data file header information (such as data format, index, etc.).

usage : `header( file_name, mode )`

`file_name` stands for a file name and `mode` is the integer that selects the mode (0: display, 1: modify). The following example displays information about the data file `test.dat` on a display.

```
[]SATELLITE[]~tom/rose:[64]% header("test.dat", 0) ↩
```

3.3 WAIT — interrupting the execution of a program

It pauses the batch processing until CR key is pressed.

usage : `wait()`

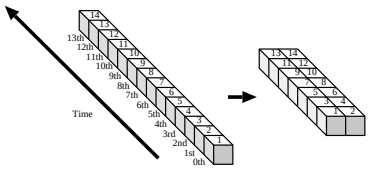


Figure 3.1: An example of using **REFORM**(1).

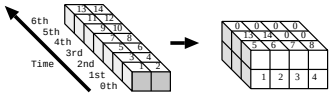


Figure 3.2: An example of using **REFORM**(2).

3.4 REFORM — changing the size or index of data

Command for the modification of an object format.

usage : `y = reform( x, index )`

`x` stands for an input object, `y` for output, and `index` for the index of `y`. As shown in Figure 3.1, for example, we can change a 1-dimensional Series object a to a 2-dimensional Series object b by the following:

```
[]SATELLITE[]~tom/rose:[65]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[66]% a ↩
[ 0]:%       1       2       3       4       5
[ 5]:%       6       7       8       9      10
[10]:%      11      12      13      14
[]SATELLITE[]~tom/rose:[67]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[68]% b ↩
[0]:[0]%       1       2
[1]:[0]%       3       4
[2]:[0]%       5       6
[3]:[0]%       7       8
[4]:[0]%       9      10
[5]:[0]%      11      12
[6]:[0]%      13      14
[]SATELLITE[]~tom/rose:[69]%
```

Conversion of 2-dimensional Series object b to 3-dimensional Series object c, shown in Figure 3.2, is performed as follows. If the specified index size is bigger than the input object's one, 0s are filled in the tail of data.

```
[]SATELLITE[]~tom/rose:[69]% c = reform(b,(3,2,4)) ↩
[]SATELLITE[]~tom/rose:[70]% c ↩
[0]:[0][0]%       1       2       3       4
[0]:[1][0]%       5       6       7       8
[1]:[0][0]%       9      10      11      12
[1]:[1][0]%      13      14       0       0
[2]:[0][0]%       0       0       0       0
[2]:[1][0]%       0       0       0       0
[]SATELLITE[]~tom/rose:[71]%
```

Similarly can be reformatted Snapshot objects.

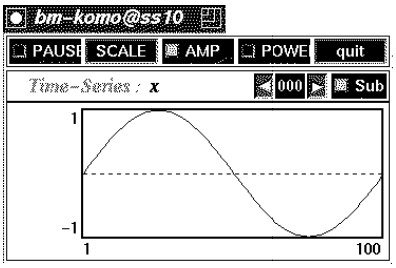


Figure 3.3: Buffer monitor.

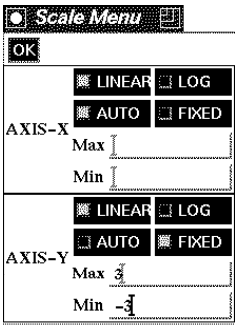


Figure 3.4: Window for setting up a range to draw.

3.5 BM — data monitoring

This command displays a window for monitoring objects simultaneously while processing other commands.

usage : `bm( x )`

`x` stands for an object to monitor. Example:

```
[]SATELLITE[]~tom/rose:[72]% bm(x) ↩
```

The example of the buffer monitor is in Figure 3.3. In this example, the object x has already been defined by the following:

```
[]SATELLITE[]~tom/rose:[70]% t = 0~99 ↩
[]SATELLITE[]~tom/rose:[71]% x = sin(2*PI*t/100) ↩
```

Another window can be opened by clicking on the `SCALE` button. One can adjust scaling of a chart. Figure 3.4 shows the window.

An example of 2-dimensional Series objects is given. First, we convert 1-dimensional Series object x to 2-dimensional Series object y by **REFORM** as follows:

```
[]SATELLITE[]~tom/rose:[73]% y = reform(x,(2,50)) ↩
```

If we want to monitor y, we can proceed similarly as in the previous example,

```
[]SATELLITE[]~tom/rose:[74]% bm(y) ↩
```

The buffer monitor window of this example is shown in Figure 3.5. By clicking on the button ▷, the chart is changed, as shown in Figure 3.6. Figure 3.5 is the chart of `y:[0]` and Figure 3.6 of `y:[1]`. That is, Figure 3.5 corresponds to the chart from `x:[0]` to `x:[49]` and Figure 3.6 from `x:[50]` to `x:[99]`.

3.6 SAM — sampling frequency setting

This command defines a sampling frequency.

usage : `sam( frequency )`

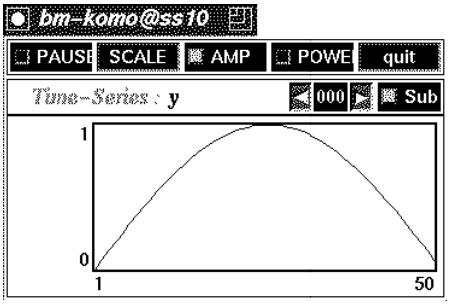


Figure 3.5: Window for monitoring `y:[0]`.

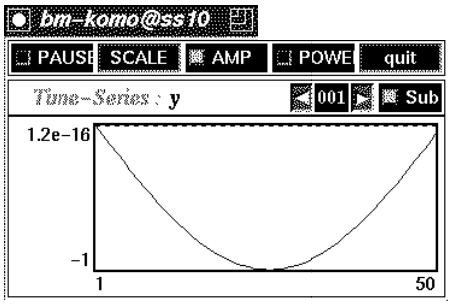


Figure 3.6: Window for monitoring `y:[1]`.

`frequency` is a sampling frequency. For example, define a Series object a as follows:

```
[]SATELLITE[]~tom/rose:[77]% a = 1~10 ↩
```

The chart of a, by using **WOPEN**, **GRAPH**, and **AXIS** commands, is shown in Figure 3.7. In this case, the default sampling frequency is 1000Hz. Figure 3.8 displays the chart of a after changing the sampling frequency as follows:

```
[]SATELLITE[]~tom/rose:[78]% sam(100) ↩
```

The sampling frequency set by **SAM** is referred in commands of ISPP module or **GRAPH** command of GPM module.

3.7 CUT — selecting a subset of data

This command allows selection of specified subset of data contained in an object.

usage : `y = cut( x, start, end )`

`x` is the original object, `y` is the object picked out, `start` is the starting point, and `end` is the end point. The following example selects a part of a 1-dimensional Series object a, as shown in Figure 3.9:

```
[]SATELLITE[]~tom/rose:[79]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[80]% a ↩
[0]:%      1      2      3      4      5
[5]:%      6      7
[]SATELLITE[]~tom/rose:[81]% b = cut(a,3,5) ↩
[]SATELLITE[]~tom/rose:[82]% b ↩
[0]:%      4      5      6
[]SATELLITE[]~tom/rose:[83]%
```

One cannot obtain the proper result if the start point is replaced with the end one as follows:

```
[]SATELLITE[]~tom/rose:[81]% b = cut(a,5,3) ↩
```

One can also select a part of the 2-dimensional Series object b by the following (see also Figure 3.10):

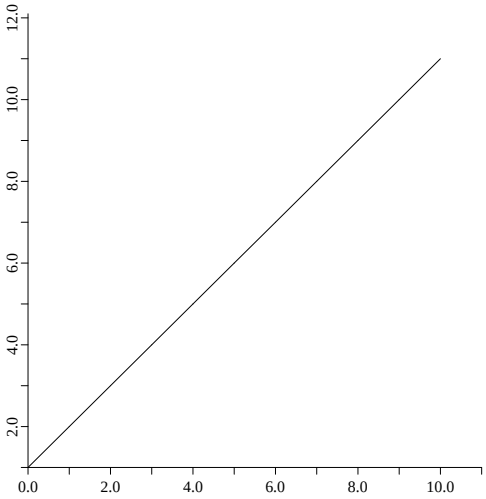


Figure 3.7: A graphic using the sampling frequency = 1000Hz (default).

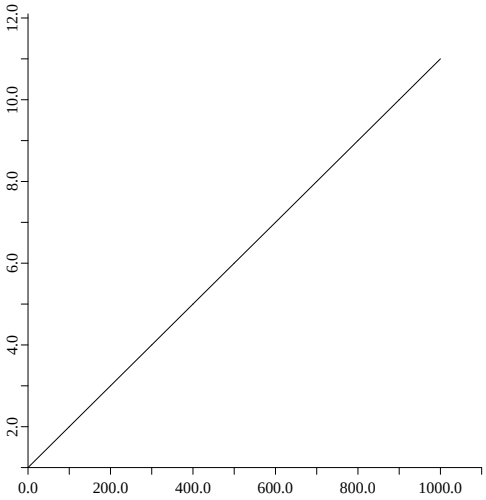


Figure 3.8: A graphic using the sampling frequency = 10Hz.

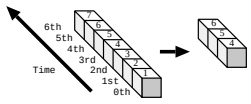


Figure 3.9: An example of using **CUT** on 1-dimensional Series object.

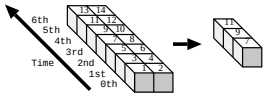


Figure 3.10: An example of using **CUT** on 2-dimensional Series object.

```
[]SATELLITE[]~tom/rose:[85]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[86]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[87]% c = cut(b,(3,0),(5,0)) ↩
[]SATELLITE[]~tom/rose:[88]% c ↩
[0]:[0]%      7
[1]:[0]%      9
[2]:[0]%     11
[]SATELLITE[]~tom/rose:[89]%
```

Similarly, selection can be performed on Snapshot objects.

3.8 PUT — replacing old data with new one

This command replaces a part of an object with another one.

usage : `z = put( x, y, index )`

`x` is the original object, `y` is the object to insert into `x`, `z` is the object after replacement, and `index` is the position where to put `y`. The size of the object `z` is the same as that of `x`. For example, as shown in Figure 3.11, replacement of a part of a 1-dimensional Series object a by b can be performed as follows:

```
[]SATELLITE[]~tom/rose:[89]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[90]% b = 11~17 ↩
[]SATELLITE[]~tom/rose:[91]% c = put(a,b,3) ↩
[]SATELLITE[]~tom/rose:[92]% c ↩
[0]:%      1      2      3     11     12
[5]:%     13     14
[]SATELLITE[]~tom/rose:[93]%
```

The next example is the case of 2-dimensional Series object replacement, as shown in Figure 3.12.

```
[]SATELLITE[]~tom/rose:[23]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[24]% b = 31~36 ↩
[]SATELLITE[]~tom/rose:[25]% ar = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[26]% br = reform(b,(3,2)) ↩
```

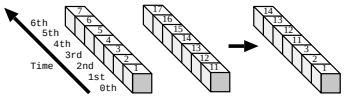


Figure 3.11: An example of using **PUT** on 1-dimensional Series object.

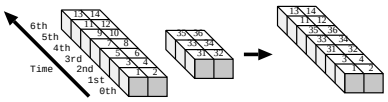


Figure 3.12: An example of using **PUT** on 2-dimensional Series object.

```
[]SATELLITE[]~tom/rose:[27]% c = put(ar,br,(2,0)) ↩
[]SATELLITE[]~tom/rose:[28]% c ↩
[0]:[0]%      1      2
[1]:[0]%      3      4
[2]:[0]%     30     31
[3]:[0]%     32     33
[4]:[0]%     34     35
[5]:[0]%     11     12
[6]:[0]%     13     14
[]SATELLITE[]~tom/rose:[29]%
```

Similarly, the operation can be performed on Snapshot objects.

3.9 MERGE — merging two data sets

This command merges two objects together.

usage : `z = merge( x, y )`

`x` and `y` are the objects to link, and `z` is the final object in which `y` is attached at the end `x`. The subindex of `x` must be equal to the `y`'s one in the case of multi-dimensional objects. The example of merging 2-dimensional Series objects *ar* and *br* is shown below and depicted Figure 3.13:

```
[]SATELLITE[]~tom/rose:[29]% a = 1~8 ↩
[]SATELLITE[]~tom/rose:[30]% b = 31~36 ↩
[]SATELLITE[]~tom/rose:[31]% ar = reform(a,(4,2)) ↩
[]SATELLITE[]~tom/rose:[32]% br = reform(b,(3,2)) ↩
[]SATELLITE[]~tom/rose:[33]% c = merge(ar,br) ↩
[]SATELLITE[]~tom/rose:[34]% c ↩
[0]:[0]%      1      2
[1]:[0]%      3      4
[2]:[0]%      5      6
[3]:[0]%      7      8
[4]:[0]%     30     31
```

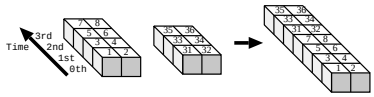


Figure 3.13: An example of using **MERGE** on 2-dimensional Series object.

```
[5]:[0]%      32      33
[6]:[0]%      34      35
[]SATELLITE[]~tom/rose:[35]%
```

Similarly Snapshot objects.

3.10 FILL — filling data with a specified value

This command fills a part of an object with a particular value.

usage : `y = fill( x, start, end, value )`

`x` is the original object, `y` is the final object, and `start` and `end` are the start and end points for filling the `value`. All range in `x` specified by `start` and `end` is filled with the same value `value`. If we want to fill a part of 1-dimensional Series object a with 20 as shown in Figure 3.14, we proceed as follows:

```
[]SATELLITE[]~tom/rose:[35]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[36]% b = fill(a,3,5,20) ↩
[]SATELLITE[]~tom/rose:[37]% b ↩
[0]:%       1       2       3      20      20
[5]:%      20       7
[]SATELLITE[]~tom/rose:[38]%
```

The example of filling 2-dimensional Series object follows (see also Figure 3.15):

```
[]SATELLITE[]~tom/rose:[38]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[39]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[40]% c = fill(b,(3,0),(5,0),30) ↩
[]SATELLITE[]~tom/rose:[41]% c ↩
[0]:[0]%       1       2
[1]:[0]%       3       4
[2]:[0]%       5       6
[3]:[0]%      30       8
[4]:[0]%      30      10
[5]:[0]%      30      12
[6]:[0]%      13      14
[]SATELLITE[]~tom/rose:[42]%
```

Similarly, the operation can be performed on Snapshot objects.

3.11 ZERO — filling data with 0

This command fills a part of an object with 0.

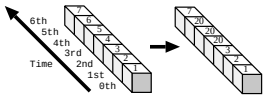


Figure 3.14: An example of using **FILL** on 1-dimensional Series object.

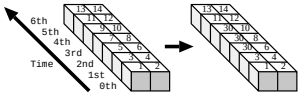


Figure 3.15: An example of using **FILL** on 2-dimensional Series object.

usage : `y = zero( x, start, end )`

`x` is the original object, `y` is the filled object, and `start` and `end` are the start and end points. The range in `x` specified by `start` and `end` is filled with 0. The following example is similar to the **FILL**'s one as shown in Figure 3.16, except the specified value 20 is replaced with 0:

```
[]SATELLITE[]~tom/rose:[42]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[43]% b = zero(a,3,5) ↩
[]SATELLITE[]~tom/rose:[44]% b ↩
[0]:%       1       2       3       0       0
[5]:%       0       7
[]SATELLITE[]~tom/rose:[45]%
```

In the case of 2-dimensional Series object, as shown in Figure 3.17, the following example is quite similar to previous one.

```
[]SATELLITE[]~tom/rose:[45]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[46]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[47]% c = zero(b,(3,0),(5,0)) ↩
[]SATELLITE[]~tom/rose:[48]% c ↩
[0]:[0]%       1       2
[1]:[0]%       3       4
[2]:[0]%       5       6
[3]:[0]%       0       8
[4]:[0]%       0      10
[5]:[0]%       0      12
[6]:[0]%      13      14
[]SATELLITE[]~tom/rose:[49]%
```

Similarly, the operation can be performed on Snapshot objects.

3.12 REVERSE — reversing the order of data

This command reverses the order of data in an object.

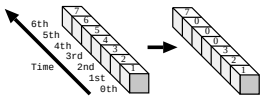


Figure 3.16: An example of using **ZERO** on 1-dimensional Series object.

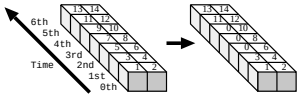


Figure 3.17: An example of using **ZERO** on 2-dimensional Series object.

usage : `y = reverse( x )`

`x` is the original object, and `y` is the reversed one. For example, the reversed 1-dimensional Series object a is obtained by the following:

```
[]SATELLITE[]~tom/rose:[49]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[50]% b = reverse(a) ↩
[]SATELLITE[]~tom/rose:[51]% a ↩
[0]:%      1      2      3      4      5
[5]:%      6      7
[]SATELLITE[]~tom/rose:[52]% b ↩
[0]:%      7      6      5      4      3
[5]:%      2      1
[]SATELLITE[]~tom/rose:[53]%
```

The case of 2-dimensional Series object (see also Figure 3.18):

```
[]SATELLITE[]~tom/rose:[54]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[55]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[56]% b ↩
[0]:[0]%      1      2
[1]:[0]%      3      4
[2]:[0]%      5      6
[3]:[0]%      7      8
[4]:[0]%      9     10
[5]:[0]%     11     12
[6]:[0]%     13     14
[]SATELLITE[]~tom/rose:[57]% c = reverse(b) ↩
[]SATELLITE[]~tom/rose:[58]% c ↩
[0]:[0]%     14     13
[1]:[0]%     12     11
[2]:[0]%     10      9
[3]:[0]%      8      7
[4]:[0]%      6      5
```

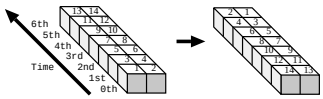


Figure 3.18: An example of using **REVERSE** on 2-dimensional Series object.

```
[5]:[0]%       4       3
[6]:[0]%       2       1
[]SATELLITE[]~tom/rose:[59]%
```

Similarly, the operation can be performed on Snapshot objects.

3.13 ROTATE — rotating data

This command moves the head pointer of an object to the specified position.

usage : `y = rotate( x, index )`

`x` is the original object, `y` is the rotated object, and `index` is the position of the front. An example is shown in Figure 3.19:

```
[]SATELLITE[]~tom/rose:[59]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[60]% a ↩
[0]:%       1       2       3       4       5
[5]:%       6       7
[]SATELLITE[]~tom/rose:[61]% b = rotate(a,3) ↩
[]SATELLITE[]~tom/rose:[62]% b ↩
[0]:%       4       5       6       7       1
[5]:%       2       3
[]SATELLITE[]~tom/rose:[63]%
```

The following example is for 2-dimensional Series object, as shown in Figure 3.20.

```
[]SATELLITE[]~tom/rose:[63]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[64]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[65]% b ↩
[0]:[0]%       1       2
[1]:[0]%       3       4
[2]:[0]%       5       6
[3]:[0]%       7       8
[4]:[0]%       9      10
[5]:[0]%      11      12
[6]:[0]%      13      14
[]SATELLITE[]~tom/rose:[66]% c = rotate(b,(3,0)) ↩
[]SATELLITE[]~tom/rose:[67]% c ↩
[0]:[0]%       7       8
[1]:[0]%       9      10
[2]:[0]%      11      12
```

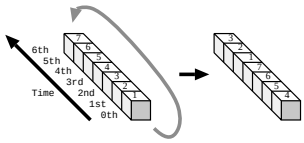


Figure 3.19: An example of using **ROTATE** on 1-dimensional Series object.

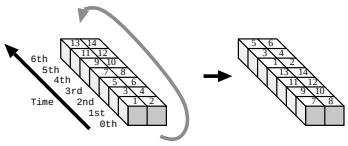


Figure 3.20: An example of using **ROTATE** on 2-dimensional Series object.

```
[3]:[0]%     13     14
[4]:[0]%      1      2
[5]:[0]%      3      4
[6]:[0]%      5      6
[]SATELLITE[]~tom/rose:[68]%
```

Similarly, the operation can be performed on Snapshot objects.

3.14 MABI — selecting the subsequence of data

This command selects from an object a subsequence of data specified by interval.

usage : `y = mabi( x, step )`

`x` is the original object, `y` is the resulting object, and `step` is the interval (at interval of `step` − 1 points). There is no difference between `x` and `y` in the case where `step` = 0 or 1. The following example, and Figure 3.21, shows **MABI** function on 1-dimensional Series object:

```
[]SATELLITE[]~tom/rose:[68]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[69]% b = mabi(a,2) ↩
[]SATELLITE[]~tom/rose:[70]% b ↩
[7]->[4]

[0]:%      1      3      5      7
[]SATELLITE[]~tom/rose:[71]%
```

Selecting 2-dimensional Series object at some intervals is shown in Figure 3.22. The commands are as follows:

```
[]SATELLITE[]~tom/rose:[71]% a = 1~21 ↩
[]SATELLITE[]~tom/rose:[72]% b = reform(a,(7,3)) ↩
[]SATELLITE[]~tom/rose:[73]% b ↩
```

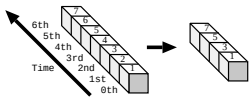


Figure 3.21: An example of using **MABI** on 1-dimensional Series object.

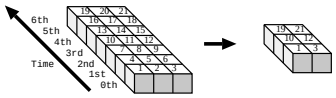


Figure 3.22: An example of using **MABI** on 2-dimensional Series object.

```
[0]:[0]%       1       2       3
[1]:[0]%       4       5       6
[2]:[0]%       7       8       9
[3]:[0]%      10      11      12
[4]:[0]%      13      14      15
[5]:[0]%      16      17      18
[6]:[0]%      19      20      21
[]SATELLITE[]~tom/rose:[74]% c = mabi(b,(3,2)) ↩
[]SATELLITE[]~tom/rose:[75]% c ↩
[7][3]->[3][2]

[0]:[0]%       1       3
[1]:[0]%      10      12
[2]:[0]%      19      21
[]SATELLITE[]~tom/rose:[76]%
```

Similarly, the operation can be performed on Snapshot objects.

3.15 GET — getting a value at the specified position of data

This function reads a value at the particular position of an object.

usage : `y = get( x, position )`

`x` is an object, and `y` is the value at `position`. A simple example is shown as follows (see also Figure 3.23):

```
[]SATELLITE[]~tom/rose:[77]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[78]% b = get(a,3) ↩
[]SATELLITE[]~tom/rose:[79]% b ↩
```

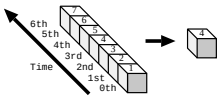


Figure 3.23: An example of using **GET** on 1-dimensional Series object.

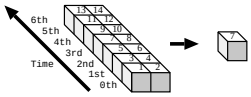


Figure 3.24: An example of using **GET** on 2-dimensional Series object.

```
4
[]SATELLITE[]~tom/rose:[80]%
```

In case of 2-dimensional Series object (as shown in Figure 3.24), we have

```
[]SATELLITE[]~tom/rose:[80]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[81]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[82]% c = get(b,(3,0)) ↩
[]SATELLITE[]~tom/rose:[83]% c ↩
7
[]SATELLITE[]~tom/rose:[84]%
```

Similarly, the operation can be performed on Snapshot objects.

3.16 MAXPOS — getting the position of the maximum in data

This command obtains the position of the maximum in a object.

usage : `y = maxpos( x, num )`

`x` is an object, `y` is the Series object, and `num` is the number of positions to consider. For example, as shown in Figure 3.25, if we need to obtain the position of the maximum in the 1-dimensional Series object a, then,

```
[]SATELLITE[]~tom/rose:[84]% a =(3,7,5,1,6,2,4) ↩
[]SATELLITE[]~tom/rose:[85]% c = maxpos(a,1) ↩
[]SATELLITE[]~tom/rose:[86]% c ↩
1
[]SATELLITE[]~tom/rose:[87]%
```

To get the positions of the 1st and 2nd maxima in a, as shown in Figure 3.26, is done by the following:

```
[]SATELLITE[]~tom/rose:[87]% c = maxpos(a,2) ↩
[]SATELLITE[]~tom/rose:[88]% c ↩
[0]:[0]%      1
```

```
[1]:[0]%      4
[]SATELLITE[]~tom/rose:[89]%
```

As shown in Figure 3.27, to get the position of the maximum in 2-dimensional Series object *b* proceed as follows:

```
[]SATELLITE[]~tom/rose:[18]% a = (7,13,1,3,12,6,11,4,14,2) ↩
[]SATELLITE[]~tom/rose:[19]% b = reform(a,(5,2)) ↩
[]SATELLITE[]~tom/rose:[20]% c = maxpos(b,1) ↩
[]SATELLITE[]~tom/rose:[21]% c ↩
[0]:[0]%      4      0
[]SATELLITE[]~tom/rose:[22]%
```

Similarly, the operation can be performed on Snapshot objects. There is a similar command for obtaining the position of the minimum; **MINPOS**.

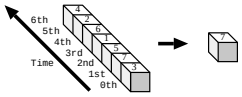


Figure 3.25: An example of using **MAXPOS** on 1-dimensional Series object(1).

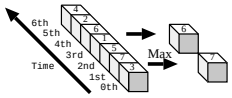


Figure 3.26: An example of using **MAXPOS** on 1-dimensional Series object(2).

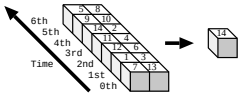


Figure 3.27: An example of using **MAXPOS** on 2-dimensional Series object.

3.17 MAX — getting the maximum of data

This command obtains the maximum value of an object.

usage : `y = max( x )`

`x` is the object, and `y` is the maximum value of it. In case of 1-dimensional Series object, the example follows:

```
[]SATELLITE[]~tom/rose:[23]% a =(3,7,5,1,6,2,4) ↩
[]SATELLITE[]~tom/rose:[24]% c = max(a) ↩
```

```
[]SATELLITE[]~tom/rose:[25]% c ↩
7
[]SATELLITE[]~tom/rose:[26]%
```

In case of a 2-dimensional Series object, the performance is similar.

```
[]SATELLITE[]~tom/rose:[26]% a = (7,13,1,3,12,6,11,4,14,2) ↩
[]SATELLITE[]~tom/rose:[27]% b = reform(a,(5,2)) ↩
[]SATELLITE[]~tom/rose:[28]% c = max(b) ↩
[]SATELLITE[]~tom/rose:[29]% c ↩
14
[]SATELLITE[]~tom/rose:[30]%
```

Similarly, the operation can be performed on Snapshot objects. There is a similar command for obtaining the minimum; **MIN**.

3.18 FIND — finding the value close to the specified one in data

This command obtains the nearest value to the specified one in an object.

usage : `ip = find( x, val, num )`

`x` is an object, `ip` is the returned value of the position of the nearest value, `val` is the value to locate, and `num` is the number of values to find. As shown in Figure 3.28, for example, we can obtain the first and second nearest values to the specified value 5.8 in a 1-dimensional Series object by the following:

```
[]SATELLITE[]~tom/rose:[30]% a = 1~7 ↩
[]SATELLITE[]~tom/rose:[31]% c = find(a, 5.8, 2) ↩
DATA[6] -- POINT:[5]
DATA[5] -- POINT:[4]
[]SATELLITE[]~tom/rose:[32]% c ↩
[0]:[0]%      5
[1]:[0]%      4
[]SATELLITE[]~tom/rose:[33]%
```

The following example demonstrates **FIND** on 2-dimensional Series object (see also Figure 3.29):

```
[]SATELLITE[]~tom/rose:[33]% a = 1~14 ↩
[]SATELLITE[]~tom/rose:[34]% b = reform(a,(7,2)) ↩
[]SATELLITE[]~tom/rose:[35]% c = find(b, 6.8, 2) ↩
DATA[7] -- POINT:[3][0]
DATA[6] -- POINT:[2][1]
[]SATELLITE[]~tom/rose:[36]% c ↩
[0]:[0]%      3      0
[1]:[0]%      2      1
[]SATELLITE[]~tom/rose:[37]%
```

Similarly, the operation can be performed on Snapshot objects.

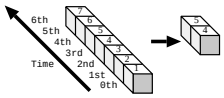


Figure 3.28: An example of using **FIND** on 1-dimensional Series object.

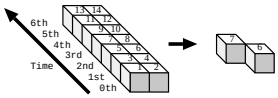


Figure 3.29: An example of using **FIND** on 2-dimensional Series object.

Chapter 4

Interactive Signal Processing Package — ISPP

ISPP is the core module of *SATELLITE*. A lot of processing functions are represented by commands, which cover the methodology of the digital signal processing such as the preprocessing by window functions, FFT, spectrum analysis by linear prediction model, filtering, cepstrum analysis, etc. All commands require to store data or data files. One can analyze data multilaterally using the signal processing or statistical techniques.

4.1 The command system of ISPP

The commands of ISPP are classified into the categories shown in Table 4.1 and 4.2. By combining the commands with fundamental functions, it is possible to carry out complicated analysis.

4.2 Examples to use

The fundamental use of ISPP is described, by referring to Fourier transform, filtering, and matrix operation.

4.2.1 Fourier transform

Fourier transform of a signal is shown. Signal is synthesized two sinusoidal waves overlapped by noise.

Generation of data

(1) Generation of a sinusoidal wave:

```
(1) t = 0~1999/2000;
```

Data is stored in the Series object `t`.

```
(2) a = 5*sin(2*PI*20*t) + 3;
    b = 3*sin(2*PI*50*t) + 3;
```

The sine waves with DC in which their frequencies and amplitude values are different from each other are stored in the Series objects `a` and `b`.

Table 4.1: ISPP commands (1).

Data generation	
`argen`	Data generation by AR model
`gauss2`	Generation of 2-dimensional Gaussian distribution function
`arand`	Generation of random data with optional probability distribution
`mnrand`	Generation of multi-dimensional Gaussian random data
`nrand`	Generation of Gaussian random data
`urand`	Generation of uniform random data
Data operation	
`dccut`	DC removal from data
`norm`	Data normalization
`shift`	Shifting the whole data so that the specified value is consistent with a specified element of the data
Data interpolation	
`interp`	Interpolation of 2-dimensional data
`akima`	Interpolation of 1-dimensional data by the Akima's method
`spline`	Interpolation of 1-dimensional data by the natural cubic spline
Arithmetic operation	
`average`	Calculation of the arithmetic mean of data
`integ`	Calculation of the sum of data
`det`	Calculation of the determinant
`eigen`	Calculation of eigenvalues and eigenvectors
`inv`	Calculation of the inverse matrix
`mul`	Calculation of the product of two matrices
`trans`	Calculation of the transposed matrix
`nmeq`	Solving the normal equation

Table 4.2: ISPP commands (2).

Data analysis	
`bpbtw`	Design of IIR-type band-pass filter with the Butterworth property
`burg`	Calculation of power spectra by the Burg method
`cep`	Calculation of complex cepstrum
`fftc`	Complex Fourier transform
`fftn`	Complex Fourier transform for multi-dimensional data
`fir`	Filtering by FIR-type filter
`firmake`	Design of FIR-type filter
`hil`	Hilbert transform
`hpbtw`	Design of IIR-type high-pass filter with the Butterworth property
`icep`	Inverse cepstrum analysis
`iir`	Filtering by IIR-type filter
`iircoef`	Calculation of the coefficients of IIR-type filter from zero points and poles
`levin`	Calculation of power spectra by the Levinson-Durbin's algorithm
`lpbtw`	Design of IIR-type low-pass filter with Butterworth property
`phase`	Calculation of the phase of a complex number
`pole`	Calculation of poles from AR coefficients
`power`	Calculation of the gain of a complex number
`rank`	Calculation of histogram and the Gaussian density function value from data
`spcf`	Calculation of power spectrum and phase of data
`window`	Window processing for data

(2) Selecting a part of data of 1024-point from the 0th point to the 1023rd point of a sinusoidal wave.

```
(3.1) acut =
      bcut =
```

Series objects which store picked data are set.

```
(3.2) acut = cut(a,
      bcut = cut(b,
```

Original objects are set.

```
(3.3) acut = cut(a,0
      bcut = cut(b,0
```

Each starting point is set.

```
(3.4) acut = cut(a,0,1023);
      bcut = cut(b,0,1023);
```

Each ending point is set.

By the above procedure, the selected data are stored in the Series objects `acut` and `bcut`.

(3) Generation of random numbers: We use **NRAND** command to generate the normal random numbers.

```
(4.1) nois =
```

The Series object that stores generated random numbers is set.

```
(4.2) nois = nrand(1024,
```

The number of datum point to generate is set.

```
(4.3) nois = nrand(1024,1
```

The initial value to generate random numbers is set (This must be an odd number).

```
(4.4) nois = nrand(1024,1,0
```

The mean value of random numbers is set.

```
(4.5) nois = nrand(1024,1,0,1);
```

The variance of the random number is set.

By the above procedure, 1024-point standard normal random number data are stored in the Series object `nois`. Furthermore, the **URAND** command is used for generating the uniform random numbers.

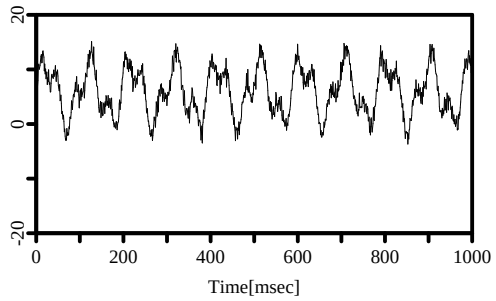


Figure 4.1: Waveform of the synthetic signal.

(4) Synthesis of signals: The signals obtained by the above procedures are synthesized as follows:

`(5.1) data =`

The Series object that stores the synthetic signal is set.

```
(5.2) data = acut + bcut + nois;
```

Signals are synthesized.

Mixture of two sine waves and normal random numbers is stored in the Series object `data`. The waveform of the synthetic signal is shown in Figure 4.1.

Preprocessing of data

The methods of DC removal and window processing are shown below.

(1) Removal of DC: The **DCCUT** command is used for removing the DC of data.

`(1.1) data1 =`

The Series object that stores the data after removing DC is set.

```
(1.2) data1 = dccut(data);
```

The original object is set.

By the above procedure, the data with removed DC is stored in the Series object `data1`. The signal waveform is shown in Figure 4.2.

(2) Window processing: We use the **WINDOW** command for the window processing.

`(2.1) data2 =`

The Series object that stores the data after the window processing.

```
(2.2) data2 = window(data1,
```

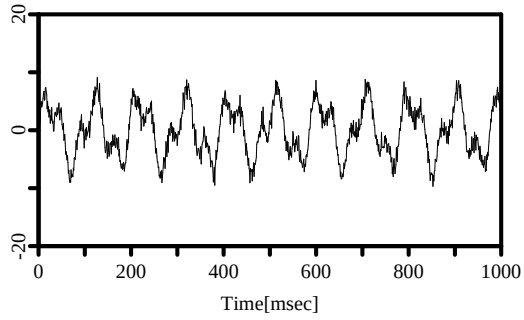


Figure 4.2: Signal waveform after the removal of DC.

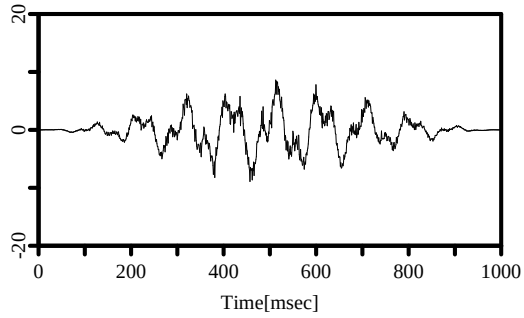


Figure 4.3: Signal waveform after the window processing.

The original object is set.

`(2.3) data2 = window(data1,1,`

The type of the window (1: Humming window, 2: Hanning window, 3: Blackman window, 4: Triangle window) is set.

`(2.4) data2 = window(data1,1,0);`

`1` is set if we want to correct data so that both integrated values of data before and after the window processing become equal, but `0` if not.

By the above procedure, the data after the window processing is performed is stored in the Series object `data2`. The signal waveform is shown in Figure 4.3.

Fourier transform

(1) Fourier transform: Using the **FFTC** command, it is possible to carry out Fourier transform and inverse Fourier transform for complex number data. Since the FFT algorithm is used for the Fourier transform, the number of data must be the power of 2.

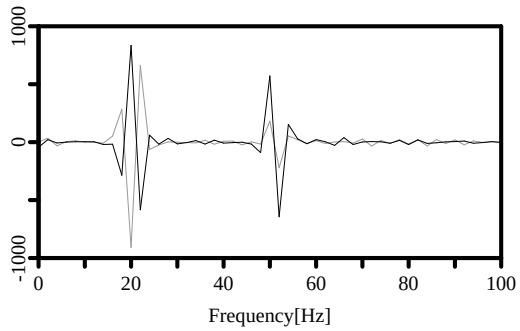


Figure 4.4: The signal waveform after Fourier transform (black line: the real parts of data, gray line: the imaginary parts of data).

```
(1) series Rout,Iout;
```

The Series object that stores the real part and the imaginary part of an output time series is defined.

```
(2) rei = 0~1023*0;
```

In the case where the imaginary part of the original signal does not exist, 1024 zeros are stored in the Series object `rei`.

```
(3.1) fftc(P,
```

The flag for calculation (`P`: Fourier transform, `I`: Inverse Fourier transform) is set.

```
(3.2) fftc(P,data2,
```

The real part of the original object is set.

```
(3.3) fftc(P,data2,rei,
```

The imaginary part of the original object is set.

```
(3.4) fftc(P,data2,rei,Rout,
```

The Series object that stores the real part of the data after Fourier transform is set.

```
(3.5) fftc(P,data2,rei,Rout,Iout);
```

The Series object that stores the imaginary part of the data after Fourier transform is set.

By the above procedure, the processed data is stored in the Series objects `Rout`, `Iout`. The signal waveform after Fourier transform is shown in Figure 4.4.

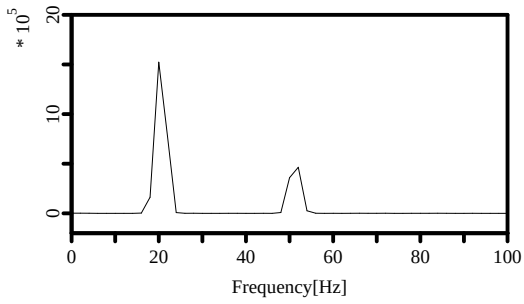


Figure 4.5: Power spectrum.

(2) Power spectra: The **POWER** command is used for adding two squared objects. Using this command, we can obtain the power spectrum of the original time series from the real part and the imaginary part of the data after the Fourier transform.

`(4.1) pw =`

The Series object that stores the obtained power spectrum is set.

`(4.2) pw = power(Rout,`

The real part of the data after Fourier transform is set.

`(4.3) pw = power(Rout,Iout);`

The imaginary part of the data after Fourier transform is set.

The power spectrum data is stored in the Series object `pw`, and shown in Figure 4.5.

(3) Phase property: The **PHASE** command is used for obtaining the phase of the original time series from the real part and the imaginary part of the data after the Fourier transform.

`(5.1) phs =`

The Series object that stores the obtained phase is set.

`(5.2) phs = phase(Rout,`

The real part of the data after Fourier transform is set.

`(5.3) phs = phase(Rout,Iout,`

The imaginary part of the data after Fourier transform is set.

`(5.4) phs = phase(Rout,Iout,D,`

The type of the output phase (`D`: degree, `O`: radian) is set.

`(5.5) phs = phase(Rout,Iout,D,U);`

`U` is set if we want to perform the phase rehydration, but `O` if not.

By the above procedure, the phase data is stored in the Series object `phs`.

Method for obtaining the power spectrum and the phase of the original data

Using the **SPCF** command, we can obtain both the power spectrum and the phase from an input time series. The procedure is shown below.

```
(1) series pw,phs;
```

The Series objects that store the power spectrum and the phase are defined.

```
(2.1) spcf(data2,
```

The original time series is set.

```
(2.2) spcf(data2,pw,
```

The Series object that stores the obtained power spectrum is set.

```
(2.3) spcf(data2,pw,phs);
```

The Series object that stores the obtained phase is set.

The power spectrum and the phase data are stored in the Series objects `pw` and `phs` by the above.

4.2.2 Filtering

MA filter

Using the moving average method, the procedure for smoothing the source signal is shown as follows.

```
(1) coef = (1/5, 1/5, 1/5, 1/5, 1/5);
```

The coefficient vector of the filter is set.

```
(2.1) output =
```

The object that stores the smoothed signal is set.

```
(2.2) output = fir(coef,
```

The source signal is smoothed by using the **FIR** command. First, the coefficient of the filter `coef` is set.

```
(2.3) output = fir(coef, input);
```

The original signal `input` is set.

By the above procedure, the smoothed data is stored in the Series object `output`. The **FIR** command carries out the processing shown in Figure 4.6. Therefore, the number of the filter coefficients (the order of the filter) must be the odd number (it is assumed that this value is equal to $2n + 1$). Besides, the original data form the $(n + 1)$-th point is used for filtering, because the data from the beginning to the n-th point is not possible to deal with precisely. Similarly the final data, the ones to the $(n + 1)$-th point from behind is ignored.

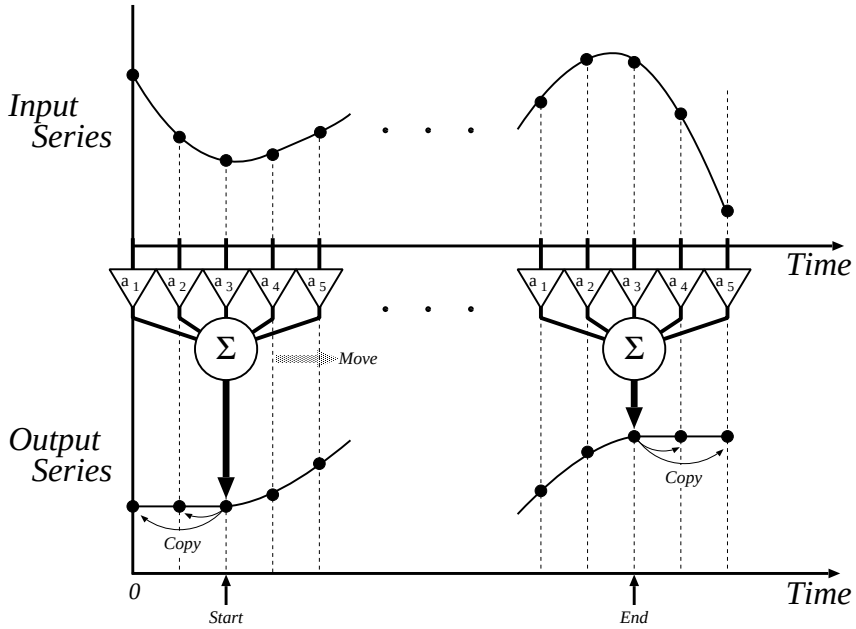


Figure 4.6: Filtering by the **FIR** command.
($a_1, a_2, \cdots, a_5$ are the filter coefficients)

FIR filter

When the FIR filter of the low-pass, high-pass or band-pass type is designed by the window function method, the filtering by **FIR** is carried out after the filter coefficient is obtained using the **FIRMAKE** command. The example of a low-pass filter is shown below.

```
(1) sam(1024);
```

The sampling frequency is set.

```
(2.1) coef =
```

The Series object for storing the filter coefficients is set.

```
(2.2) coef = firmake(1,
```

The filter is set to be the low-pass type (`1`: Low-pass, `2`: High-pass, `3`: Band-pass).

```
(2.3) coef = firmake(1,11,
```

The order of the filter is set. The value is the odd number used by the **FIR** command.

```
(2.4) coef = firmake(1,11,100,
```

The cut-off frequency is set.

```
(2.5) coef = firmake(1,11,100,3);
```

The type of the window function is set (`0`: Rectangle window, `1`: Hanning window, `2`: Humming window, `3`: Blackman window, `4`: Kayser window).

By the above procedure, the coefficients of the 11th-order FIR-type low-pass filter with the cut-off frequency 100Hz is stored in the Series object `coef`. Similarly can be obtained high-pass type filter:

```
coef = firmake(2,11,400,3);
```

In this example, the 11th-order FIR-type high-pass filter with the cut-off frequency 400Hz is designed. Band-pass filter with the cut-off frequencies 100Hz and 400Hz, and the order 11, for example, is obtained as follows:

```
coef = firmake(3,11,(100,400),3);
```

Then, filtering can be performed by the **FIR** command with the coefficients `coef` as shown below.

```
(3) output = fir(coef,input);
```

IIR filter

In order to design an IIR filter of the low-pass, high-pass or band-pass type with the Butterworth characteristics, it is first necessary to obtain zero points, poles, and gain of the transfer function using the **LPBTW**, **HPBTW**, or **BPBTW** command, respectively. Then, filtering is carried out by using **FIR** and **IIR**, after the zero points and poles are converted into the filter coefficients by the **IIRCOEF** command. The example of a low-pass filter is shown below.

```
(1) sam(1024);
```

The sampling frequency is set.

```
(2) series zr,zi,pr,pi;
```

The Series objects for storing the zero points and poles of the transfer function are defined.

```
(3.1) gain =
```

The Scalar object for storing the gain of the designed filter is set.

```
(3.2) gain = lpbtw(100,
```

The cut-off frequency is set.

```
(3.3) gain = lpbtw(100,13,
```

The order of the filter is set. This value must be odd number (the maximum is 101).

```
(3.4) gain = lpbtw(100,13,zr,zi,
```

The Series objects for storing the zero points (real part and imaginary part) of the transfer function are set.

```
(3.5) gain = lpbtw(100,13,zr,zi,pr,pi);
```

The Series objects for storing the poles (real part and imaginary part) of the transfer function are set.

By the above procedure, it is possible to obtain the zero points `zr` and `zi`, the poles `pr` and `pi`, and the gain `gain` of the transfer function of the 13th-order IIR-type low-pass filter with the cut-off frequency 100Hz, with the Butterworth characteristics. The high-pass filter can be set as follows:

```
gain = hpbtw(400,13,zr,zi,pr,pi);
```

In this example, the 13th-order IIR-type high-pass filter with the cut-off frequency 400Hz is designed. In case of band-pass type, two cut-off frequencies must be set. When the cut-off frequencies are 100Hz and 400Hz, and the order of the filter is 13, for example, the following is set:

```
gain = bpbtw(100,400,13,zr,zi,pr,pi);
```

Next, we calculate the filter coefficients from `zr`, `zi`, `pr`, and `pi` using the **IIRCOEF** command.

```
(4) series a,b;
```

The Series objects that store the coefficients of the denominator and numerator of the transfer function are defined.

```
(5.1) iircoef(zr,zi,pi,pr,
```

The zero points and poles of the transfer function are set.

```
(5.2) iircoef(zr,zi,pr,pi,a,
```

The Series object that stores the coefficients of the denominator of the transfer function is set.

```
(5.3) iircoef(zr,zi,pr,pi,a,b);
```

The Series object that stores the coefficients of the numerator of the transfer function is set.

By the above procedure, the obtained filter coefficients can be used in both **FIR** and **IIR**. Finally, filtering is carried out as follows.

```
(6) temp = fir(b,input);
```

The numerator of the transfer function is calculated.

```
(7) output = iir(a,temp)*gain;
```

The denominator of the transfer function is calculated, and the result of the filtering is obtained by gain multiplication.

The signal after filtering is stored in the Series object `output`.

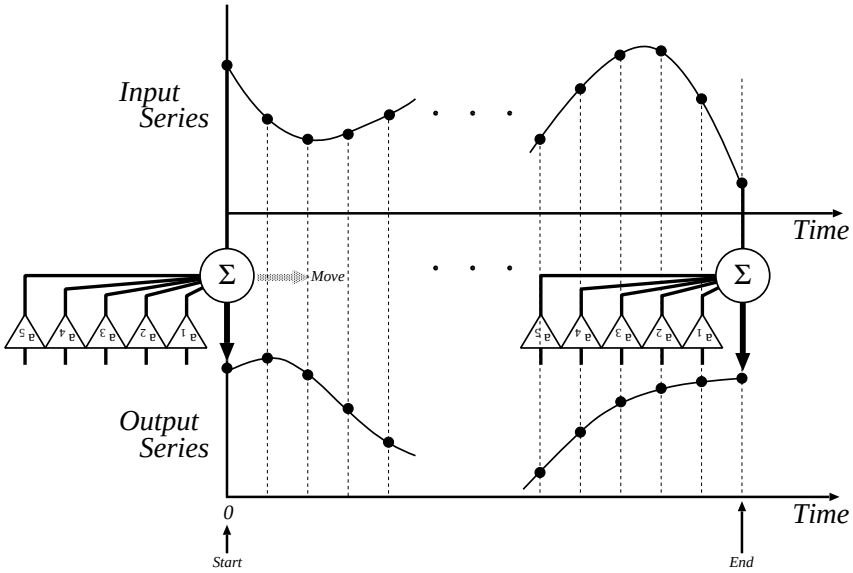


Figure 4.7: Filtering by the **IIR** command.
($a_1, a_2, \cdots, a_5$ are the filter coefficients)

Example

The design of the 13th-order IIR-type low-pass filter with the cut-off frequency 100Hz, and with the Butterworth characteristics is provided. The procedure is shown below.

```
(1) sam(512);
```

The sampling frequency is set.

```
(2) series zr,zi,pr,pi;
(3) series a,b;
(4) series u,v;
```

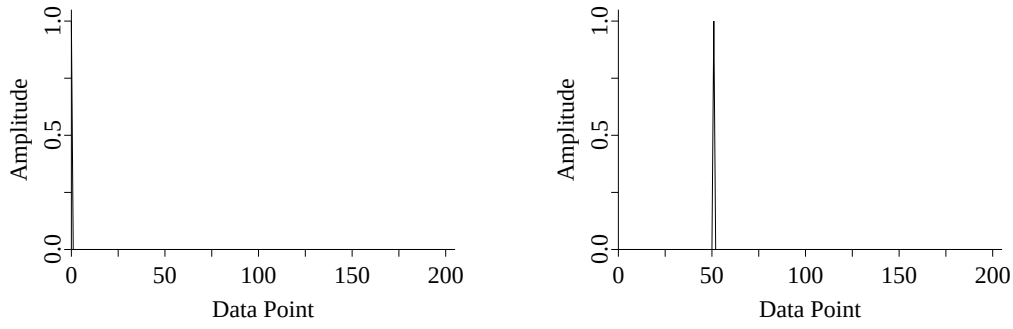
The Series objects used in **LPBTW**, **IIRCOEF**, and **SPCF** are defined.

```
(5) delay = 50;
(6) datp = 511;
(7) impulse = (1,(1~datp)*0);
(8) d_impulse = ((0~delay)*0,impulse);
```

The impulse signal and the signal that contains zeros for delay are generated.

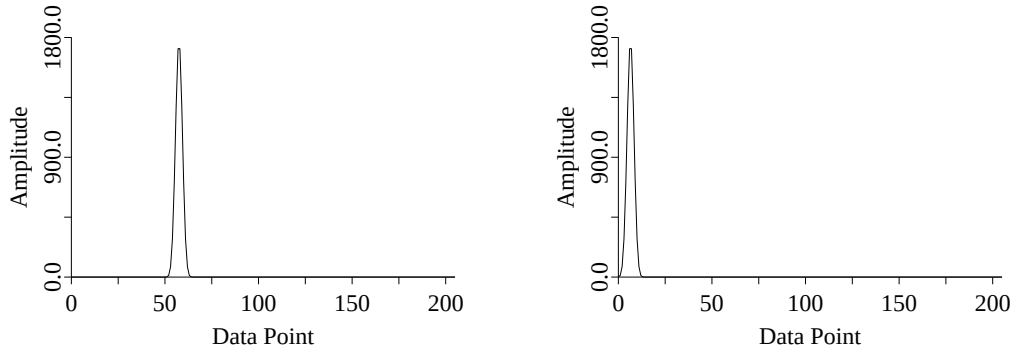
Since the output points within the filter order can not be calculated by the **FIR** command, the signal `d_impulse` is created as the union of *delay* 0s and `impulse` (Figure 4.8(a)), as shown in Figure 4.8(b). The impulse response is obtained by shifting the `delay` points (Figure 4.9(b)) after filtering of `d_impulse` is performed (Figure 4.9(a)).

FIR command uses the future input in order to obtain the present output, as it was shown in Figure 4.6. Since the causality is not satisfied, the **IIRCOEF** command outputs the coefficients by joining (*filter order* − 1) 0s to the coefficients of the numerator of the transfer function. Therefore, the data for



(a) inpulse (b) inpulse

Figure 4.8: Impulse signal.



(a) firtemp (b) firimp

Figure 4.9: Impulse response obtained by **FIR** command.

filtering has from $((2 \times \textit{filter order}) - 1)$ points. In this example, since $2 \times 13 - 1 = 25$, it is possible to obtain the accurate filtering result by defining `delay` as a value larger than 25, e.g., 50.

```
(9) gain = lpbtw(100,13,zr,zi,pr,pi);
(10) iircoef(zr,zi,pr,pi,a,b);
```

The filter is designed by obtaining the transfer function.

```
(11) firtemp = fir(b,d_impulse);
(12) firinp = cut(firtemp,delay+1,datp+delay+1);
```

By calculating the numerator part of the transfer function and removing 0s in `d_impulse`, the impulse response is shifted *delay* points.

```
(13) output = iir(a,firinp)*gain;
```

The part of the denominator of the transfer function is calculated, and the impulse response of the designed filter multiplied the gain is obtained (Figure 4.10).

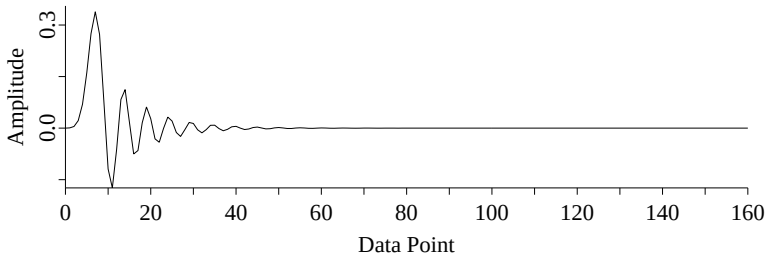


Figure 4.10: Impulse response of the designed filter.

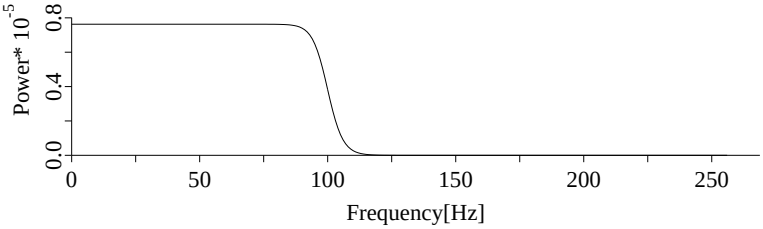


Figure 4.11: Amplitude chart of the designed filter.

```
(14) spcf(output,u,v);
```

By executing Fourier transform of the impulse response `output` and calculating power spectrum, we obtain the amplitude chart of the designed filter is obtained (Figure 4.11). We can confirms the Butterworth characteristics can be confirmed.

4.2.3 Matrix operation

Matrix operations are one of the features of ISPP. Here, as a practical example, we obtain the solution of a system of n linear equations.

$$\begin{aligned} x_{11}\theta_1 + \cdots + x_{1n}\theta_n &= y_1, \\ &\vdots \\ x_{m1}\theta_1 + \cdots + x_{mn}\theta_n &= y_m. \end{aligned}$$

System of equations can be written in the matrix form as follows:

$$\begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nn} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_n \end{pmatrix} = \begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix}. \tag{4.1}$$

$$\mathbf{X}\boldsymbol{\theta} = \mathbf{Y}. \tag{4.2}$$

The solution of Eq.(4.1) is as follows under the assumption that the matrix $\mathbf{X}$ is regular.

$$\boldsymbol{\theta} = \mathbf{X}^{-1}\mathbf{Y}, \tag{4.3}$$

The procedure to calculate Eq.(4.3) by ISPP is shown in the following:

$$\mathbf{X} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 2 & 1 & 3 \end{pmatrix}, \qquad \mathbf{Y} = \begin{pmatrix} 10 \\ 7 \\ 16 \end{pmatrix}, \qquad \boldsymbol{\theta} = \begin{pmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{pmatrix}.$$

In the ISPP Module, there are several matrix operation commands, such as **MUL** command (to get the product of two matrices), **INV** (to calculate the inverse matrix), etc.

```
(1) tempx = (1,1,1,1,2,1,2,1,3);
(2) x = reform(tempx,(3,3));
```

Matrix **X** is created.

```
(3) tempy = (10,7,16);
(4) y = reform(tempy,(3,1));
```

In the same way, matrix **Y** is formed.

```
(5) ix = inv(x);
```

The inverse matrix of **X** is calculated and stored in `ix`.

```
(6) theta = mul(ix,y);
```

By obtaining the product of **X**−1 and **Y**, the solution is obtained.

Moreover, the procedure from step `(5)` and `(6)` can be realized by setting commands as the arguments of other commands:

```
theta = mul(inv(x),y);
```

The result of the above operation is the solution of a system of linear equations.

$$\boldsymbol{\theta} = \begin{pmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{pmatrix} = \begin{pmatrix} 20 \\ -3 \\ -7 \end{pmatrix}.$$

Chapter 5

Graphic Package Module — GPM

5.1 Introduction

GPM is the module for visualization of the data processed or analyzed by modules ISPP, BPS, NCS, etc. in SATELLITE. From the standpoint of data analysis, visualization of data is much more important than numerical evaluation. The GPM module provides various graphic functions for making charts useful for writing articles or presentation.

The GPM module consists of about 30 commands, which are divided into the following two categories:

- Commands for drawing graphic charts.
- Parameter setting commands.

The main commands are described in Table 5.1. The commands for drawing can also be classified as follows:

- Commands for displaying 1-dimensional objects.
- Commands for displaying 2-dimensional objects, such as contour maps, bird's-eye pictures, etc.

Many parameters such as line type, width, color, etc. are needed in order to draw pictures. They can be set up by the commands such as **LTYPE**, **LWIDTH**, or **COLOR**. Even if one do not know how to use GPM commands exactly, it is possible to make beautiful charts by using the online message function (see §**2.9.1**). The parameters related to drawing are initialized to default values at the time of starting SATELLITE.

5.2 Drawing and Printing

WOPEN command is used for opening a window for drawing figures or charts. Conversely, the command for closing it is **WCLOSE**. Many windows can be opened. **CHWIN** specifies the target window. It is not allowed to draw charts on two or more windows simultaneously. **WE** is the command for erasing graphics in the window.

After making the charts by GPM commands, they can be preserved as files or printed. In order to print graphics in a window, proceed as follows:

```
% gpm2ps GPMDVIFILE1 > filename.ps
% lpr -Pxxx filename.ps
```

Table 5.1: Commands in GPM module.

Related to X-windows	
`wopen`	Open a window
`wclose`	Close a window
`we`	Erase pictures in a window
`newpage`	Renew a window
`chwin`	Change a target window to draw
Related to charts	
`graph`	Draw a chart
`axis`	Draw the coordinate axes
`frame`	Draw a frame
`draw`	Draw a line with specified level
`line`	Draw a line (or a rectangle)
`label`	Draw labels
Related to 2-dimensional graphics	
`cont`	Draw a contour map
`gsolm`	Draw a bird's-eye picture
`map`	Draw a color map
Setting parameters	
`color`	Set colors for charts and frames
`factor`	Set magnification for charts
`font`	Set character font
`ltype`	Set line type
`lwidth`	Set line width
`origin`	Set the origin of the coordinate axes
`scale`	Set a range of drawing
`size`	Set a size of charts
`title`	Set labels of the coordinate axes
Others	
`ginit`	Initialize the parameters for drawing
`gstat`	Check the current status of parameters

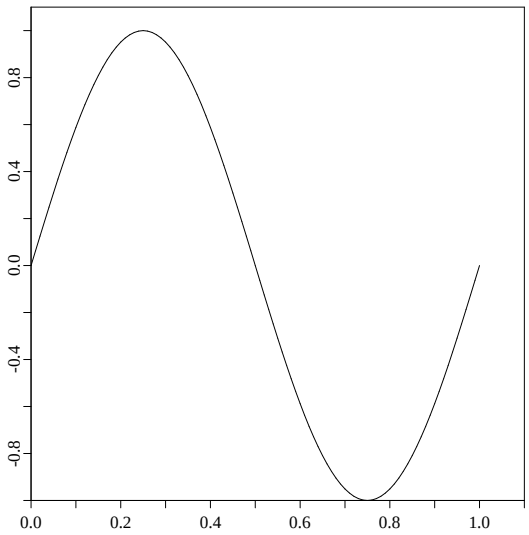


Figure 5.1: A sinusoidal curve.

`GPMDVIFILE1` is the middle file generated by GPM, and `xxx` is a printer name. **GPM2PS** command converts the file `GPMDVIFILE1` to the PostScript (PS) file `filename.ps`. Encapsulated PostScript (EPS) file for LaTeX, PowerPoint, or tgif, can be made as follows:

```
% gpm2eps GPMDVIFILE1 > filename.eps
```

5.3 Examples

The followings are examples showing the use of GPM commands. See also the Command Reference for further details.

5.3.1 Displaying 1-dimensional objects

Example 1 — displaying a sinusoidal curve.

Program from the line editor, and also file can be processed by using the **INLINE** command (see §**2.9.2**). Figure 5.1 shows the chart drawn by the following:

```
wopen(1,"A4",0,1);      #Open a window (A4-size).
t = (0~100) / 100;      #Substitute numerical values
                        # from 0 to 1 for the Series object t.
y = sin(2 * PI * t);    #Calculate the sinusoidal function.
scale("N","A","N","A"); #Set the range of drawing.
graph(y,t,0,0,0,0,0);   #Draw the chart
frame();                #Draw frame.
axis(1,1,"XY","XY",3.5,0,0,0,0,0);
                        #Draw the coordinate axes.
```

All the beginning, it is required to open a drawing window. The first line command, **WOPEN**, does it. The last argument should be set to `1` if we want to print the picture, otherwise `0` is the default value.

Table 5.2: Colors for drawing

Number	Color
0	black
1	blue
2	red
3	magenta
4	green
5	cyan
6	yellow
7	white

The type and range of the coordinate axes is defined in the fourth line. The axis type can be `"N"` (linear), or `"L"` (logarithmic). We choose `"N"` for both X- and Y-axis. The argument `"A"` in **SCALE** means that the range is set automatically. This is default if we do not use the **SCALE** command. In order to specify the range, we need to set the argument to `"F"`, and set the minimum and maximum values for X- and/or Y-axis as the fifth and sixth arguments. If we omit those, SATELLITE presses us to set (see §**2.9.1**). The chart is drawn by the commands in the fifth line. Sixth and Seventh lines display the frame and the coordinate axes.

In this example, the color of the chart is white by default. To specify the color, use **COLOR** command before **GRAPH** command. There are 8 possible colors to display for both charts and frames, as shown in Table 5.2. Although the numbers (0 to 7) are usually used for specification of colors, one can write the name of the color instead of number. Mix capital letters with small letters for describing colors is not allowed.

Example 2 — displaying two sinusoidal curves with different amplitude and frequency.

```
wopen(1,"A4",0,1);
origin(40,40);          #Set the origin of the coordinate axes.
size(80,80);            #Set the size of the chart.
title(1,"time","f(t)"); #Set the labels of X-axis and Y-axis.
t = (0~100) / 100;
y1 = sin(PI * 5 * t);
y2 = 0.5 * sin(2 * PI * 5 * t);
scale("N","F","N","F",0.0,1.0,-1.2,1.2);
lwidth(1,2);            #Set the width of the lines.
graph(y1,t,0,0,0,0,0);
lwidth(2,2);
graph(y2,t,0,0,0,0,0);
axis(1,1,"XY","XY",4,0,0,0,0,0);
lwidth(1,2);
ltype(1,2);             #Set the dashed line type.
draw("Y",0);            #Draw a line such that Y = 0.
ltype(1,1);
frame();
```

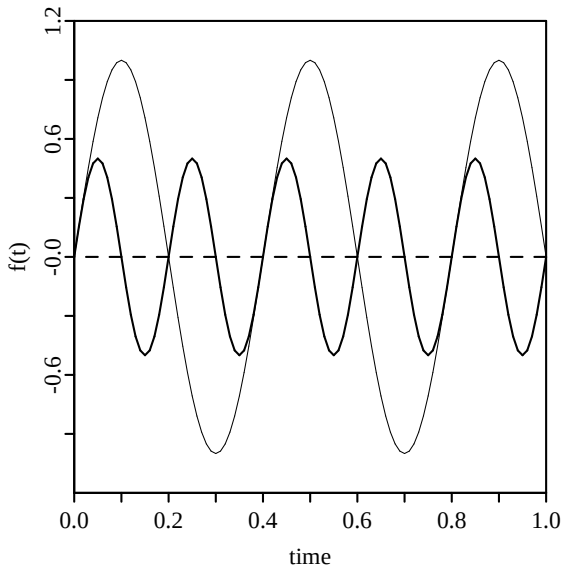


Figure 5.2: Two sinusoidal curves with different amplitude and frequency.

The result is shown in Figure 5.2. The origin of the coordinate axes (second line), the size of the chart (third line), the labels of X- and Y-axis (fourth line), and the width of lines (ninth, eleventh, and fourteenth lines) were set. The argument values of **ORIGIN** command should be the absolute coordinate values from the bottom-left corner of a window. They can be displayed by moving a mouse cursor in the window.

In order to draw two curves in one chart, the range of drawing should be fixed by setting the second and fourth arguments in **SCALE** to `"F"`. If they are set to `"A"`, the range can be adjusted by setting the second and fourth arguments in **SCALE** to `"D"` before the **GRAPH** command (twelfth line). In the fifteenth line, the command **LTYPE** changes the line type. The dashed line $y = 0$ is drawn by **DRAW** in the sixteenth line.

Example 3 — Displaying time series.

One of the merits of SATELLITE (for analysis of biological data) is efficient time series manipulation. Here, the example of a Gaussian noise sequence (time series):

```
x = nrand(1000,1,0,1); #Generate a Gaussian noise sequence.
wopen(1,"A4",0,1);
sam(10000);            #Set the sampling frequency.
size(80,80);
origin(20,200);
title(1,"time[msec]","value");
scale("N","A","N","A");
graph(x,"T",0,0,0,0,0);           #Draw time series.
axis(1,1,"XY","XY",3.5,0,0,0,0,0);
frame();
label("I",20,70,5.0,0,"example4"); #Display labels.
```

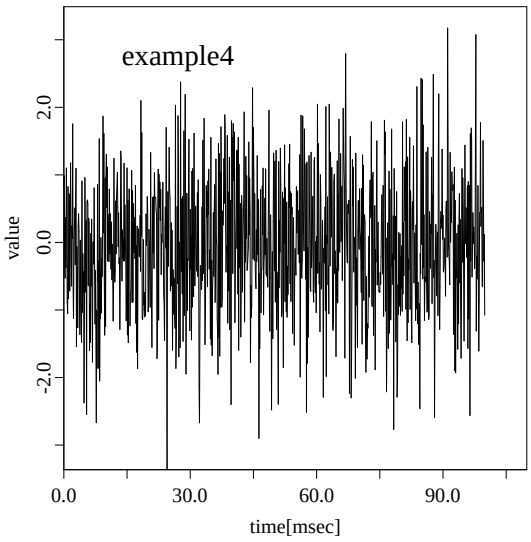


Figure 5.3: A Gaussian noise sequence.

The result of display is shown in Figure 5.3.

We generated 1000 Gaussian random values. The **SAM** command in the third line sets the sampling frequency to 10000Hz in order to consider them as a time series with the range 0.1sec (the default is 1000Hz). The argument related to the X-axis in the eighth line is `"T"`. It means that the horizontal axis corresponds to time. If it is set to `"D"`, then X-axis corresponds to data points. In the eleventh line, the **LABEL** command displays labels. The specified coordinates are relative values from the origin defined by **ORIGIN**. The **FONT** command can set the font type of characters displayed by **LABEL**.

5.3.2 Displaying 2-dimensional objects

Example 4 — displaying 2-dimensional random values

The following examples show a bird's-eye view, a contour map, and a color map of 2-dimensional Series object.

```
wopen(1,"A4",0,1);
size(80,80);
x = nrand(128,1,0,1);   #Generate Gaussian noise sequence
y = reform(x,(16,8));   #Convert 1-D Series to 2-D
origin(20,200);
gsolm(y,0.3,0.4,0,0,0,4,0,1,1,"X",1,0); #Draw bird's-eye picture
origin(20,100);
cont(y,.5,"X",1,0);     #Draw contour map
origin(120,200);
map(y,"X",1,0,1);       #Draw color map (Type 1)
origin(120,100);
map(y,"X",0,0,1);       #Draw color map (Type 2)
```

The result of the above command sequence is shown in Figure 5.4.

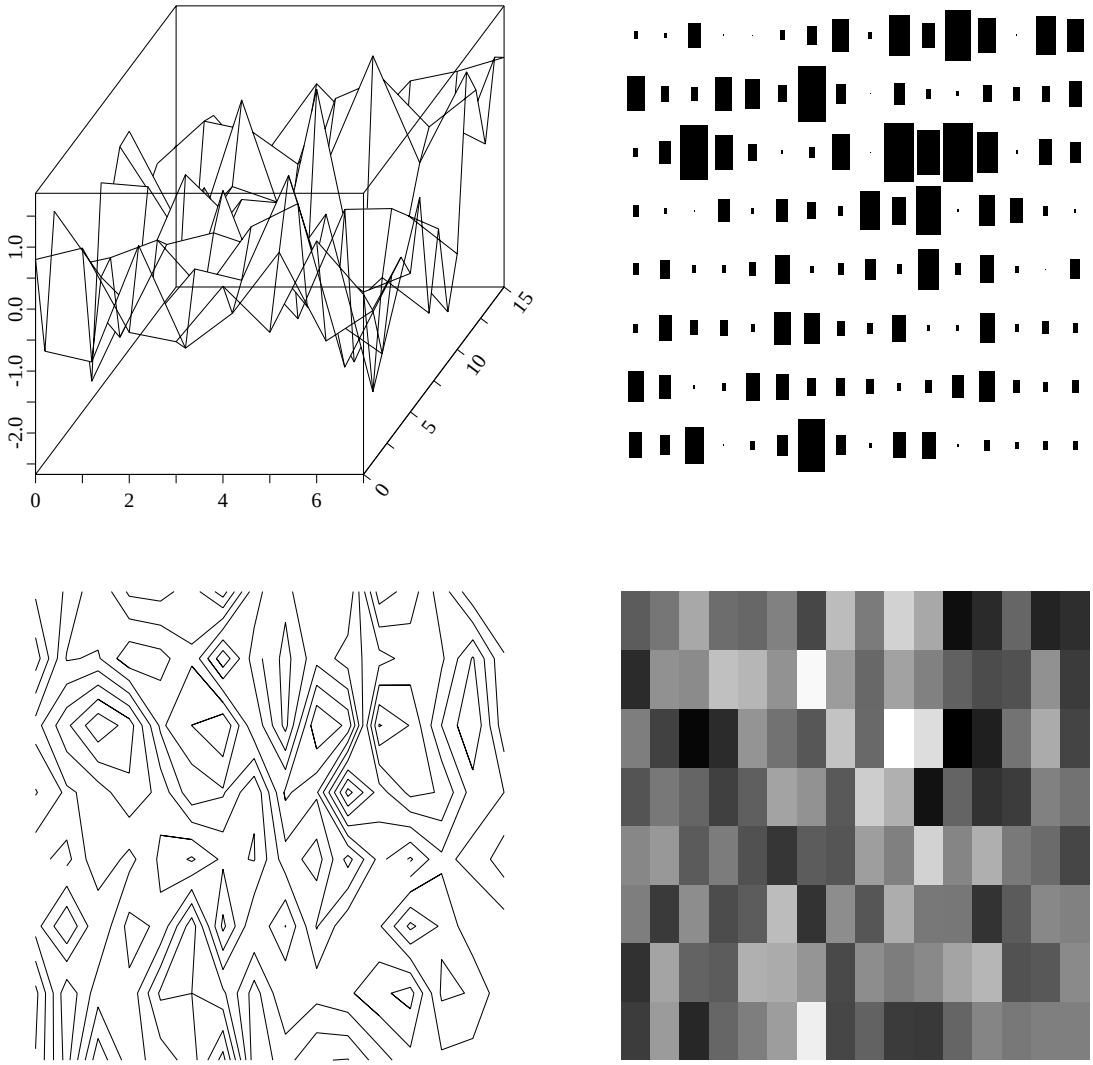


Figure 5.4: Various kinds of displays for 2-dimensional Gaussian noise sequence.

The command converting a 1-dimensional Series object to 2-dimensional one is **REFORM** (fourth line). It changes 128-point object to 16×8 object.

In the sixth line, the object is displayed as a bird's-eye picture, in which the hidden-line elimination is done. The contour map is drawn in the eighth line. The tenth and twelfth lines are displaying color maps. There are two sorts of displays for color maps: The first, normalized numerical values (according to min/max range) correspond to the rectangle size. The second, normalized numerical values correspond to colors.

Chapter 6

Back-Propagation Simulator — BPS

6.1 Introduction

BPS is one of the system modules of SATELLITE. It consists of the functions and procedures for simulating a multi-layered perceptron model (MLP). It is possible to use the error back-propagation method (BP) and its five accelerated modifications as the learning algorithms. A little background about MLP and its learning algorithm is required for using BPS module.

Followings are the features of BPS:

- Using the SATELLITE interactive programming environment, it is possible to define the structure of MLP easily. Setting, changing the parameters (connection weights) of MLP, and execution of simulations can also be done easily.
- Using the **INLINE** command, it is possible to batch-process setting of parameters and the network structure, learning, testing, the trace of internal weight representation, etc.
- Using the buffer monitoring function **BM**, it is possible to monitor the real-time change of the error during learning. It is also possible to display the simulation results easily by the GPM module in SATELLITE.
- Using the ISPP module of SATELLITE, we can carry out the multilateral and detailed analysis of MLP.

6.2 The file types used in BPS

In BPS, the exchange of data during learning or testing of MLP is carried out through files. There are seven file types, as shown in Table 6.1. Although all file formats are in conformity to SATELLITE ones, each type is different (see below for further details). There is another type of files, the parameter file (ASCII file), which is for preserving the parameters of network structure, learning conditions, the management of data, etc.

6.3 BPS use example

In the following, the use of BPS is explained on the concrete examples of the MLP simulation. The example is XOR (Exclusive OR) problem. There are two input variables and one output variable (Table

Table 6.1: File types for the BPS module.

File type	Contents	Commands
Input data file	Input data for learning	`teach`*, `setrec`*
Teaching data file	Teaching data for learning	`teach`*
Initial weight File	Initial weight values	`walgo`*, `winit`**, `weight`*
Weight history file	The weight values during learning	`weight`*, `setrec`*, `learn`**, `wgtload`*, `errfunc`*, `rvmap`*, `sigmoid`*
Error history file	The error during leaning	`error`*, `learn`**, `errload`*
Test data file	Input data for testing	`setrec`*
Test result file	Output results for testing	`setrec`*, `rec`**, `actload`*

* : Using the file for input
** : Using the file for output

Table 6.2: The XOR problem.

Inputs		Output
0	0	0
0	1	1
1	0	1
1	1	0

6.2).

6.3.1 Preparation of "input", "teach", and "test" data files

In order to learn MLP, "input" and "teach" data files must be made. The record direction corresponds to the patterns and the data-point direction to the input (or output) units, as shown in Figure 6.1. The test result files generated by the **REC** command also take this form. There is no limitation in the number of patterns and the number of units.

The number of input units and output units are 2 and 1, respectively. The number of patterns is 4 in case of the XOR problem. The type of data is given as Series type or Snapshot type. Suppose that the names of objects for the "input" and "teach" data are `in` and `out`, respectively. The substitution of each object is as follows:

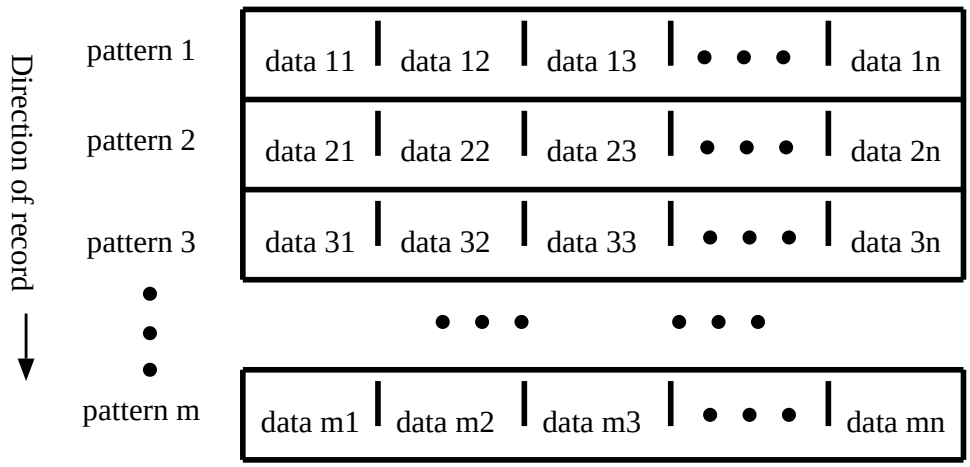


Figure 6.1: Format of input data, teach data, test data, and test result files.

Series objects

```
series in[2], out[1];
#
in:[0] = (0,0);
in:[1] = (0,1);
in:[2] = (1,0);
in:[3] = (1,1);
#
out:[0] = 0;
out:[1] = 1;
out:[2] = 1;
out:[3] = 0;
```

Snapshot objects

```
snapshot in[4][2], out[4];
#
in[0][0] = 0; in[0][1] = 0;
in[1][0] = 0; in[1][1] = 1;
in[2][0] = 1; in[2][1] = 0;
in[3][0] = 1; in[3][1] = 1;
#
out[0] = 0;
out[1] = 1;
out[2] = 1;
out[3] = 0;
```

"Input" and "teach" data are stored in files as follows:

```
$"in.dat" = in;
$"out.dat" = out;
```

In this example, `in.dat` and `out.dat` are "input" data and "teach" data files respectively.

The test data file is required when performing the test of MLP. If one wants to observe the MLP's output on the same input data used during learning, the input data file can be used as a test data file.

6.3.2 Setting learning parameters

Some parameters must be set before the learning and testing of MLP are executed. There are four types of parameters:

- MLP's structure parameters.
- Parameters for generating the initial values of connection weights
- Learning parameters.
- Testing parameters.

It is possible to store the parameters using the **BPSAVE** command to a parameter file. The parameters can be read from the parameter file by the **BPLOAD** command. Since the parameter file is the ASCII type, another simulation under the different conditions can be carried out easily by changing the parameters using an editor. The content of the parameter file is shown in the following.

Contents of the learning parameter file:

⋆ number of layers
⋆ number of cells in each layer
⋆ status of activation functions and bias units
⋆ weight initialization algorithm
⋆ initial weight file name stored by **WINIT**
⋆ seed of random number generator for weight initialization
⋆ maximum for initial weights
⋆ minimum for initial weights
⋆ initial weight file name loaded by **LEARN**
⋆ weight history file name
⋆ interval to store weight history
⋆ mode to store weight history
⋆ error history file name
⋆ interval to store error history
⋆ direction to store error history
⋆ mode to store error history
⋆ input data file name for learning
⋆ teaching data file name for learning
⋆ first pattern number for learning
⋆ last pattern number for learning
⋆ learning mode
⋆ learning algorithm
⋆ learning rate
⋆ momentum
⋆ increasing factor for learning rate
⋆ reduction factor for learning rate
⋆ threshold for Vogl's method
⋆ factor for Ochiai's method
⋆ minimum error to stop learning
⋆ maximum steps to stop learning
⋆ interval to display comments
⋆ comment
⋆ weight file name for testing
⋆ weight history number for testing
⋆ test data file name
⋆ first pattern number for testing
⋆ last pattern number for testing
⋆ input layer number for testing

⋆ output layer number for testing
⋆ test result file name

MLP structure parameters

The structure parameters for MLP, namely the number of layers, the number of units in each layer, and the type of activation functions, must be set in all cases of generating the initial values of connection weights, learning, testing, tracing, etc. The parameters are set by the **LAYER** and **FUNCTION** commands. The activation functions of units in the input layer (the 0th layer) are linear. **FUNCTION** has to be executed after the number of layers is set by **LAYER**.

In the XOR problem, the number of output units is 1 and the number of input units is 2. The hidden layer is composed of 2 units with sigmoidal activation functions. The activation function of the output unit is linear, and each unit in the hidden and output layers has the threshold. Then, setting parameters for the MLP is carried out as follows (see also the Command Reference Manual) :

```
layer(3,2,2,1);
function("LN","SA","LA");
```

Weight initialization parameters

The initial weight file which stores the initial values of connection weights is generated by the **WINIT** command. **WINIT** requires several parameters. They specify the algorithm for generating initial values, the name of the initial weight file (details are described later), the seed for generating random numbers, and the maximum and minimum of initial values. There are two methods for generating initial weight value; using random numbers generated from a given seed (`R`) and the Jia's algorithm (`J`). When the Jia's algorithm is used, the bias unit must be added in each layer. These parameters are set using the **WALGO** command.

In the XOR problem, for example, the parameters for the initial values of connection weights are set by the following:

```
walgo(R,"initwf",1,1.0,-1.0);
winit();
```

Learning parameters

The **WEIGHT**, **ERROR**, **TEACH**, **LALGO**, **LEND**, and **DISP** commands are used to set the parameters for learning.

The **WEIGHT** command sets the following: The name of the initial weight file (the initial values of connection weights are read from this file), the name of the weight history file (the histories of connection weights), the interval for storing weights, and the mode for storing weights (there are two kinds of storing methods; append `"A"` or overwrite `"O"`). It is also possible to set the generated weight file. In this case, the final history written to the file is used for setting of initial values. If it is not necessary to store the history, the mode should be "overwrite". The details on weight history file format and the mode for storing are described later.

The **ERROR** command is for setting the name of the error history file (storing the histories of the sum of square error) and the interval, the direction (record direction `"R"` or data-point direction `"D"`), and the mode for storing error. When the direction for storing error is set to the record direction, the error of each output unit and the sum of them are stored. However, if the direction is set to "data point", only the sum of error is stored. The details on the error history file are described later.

In the **TEACH** command, the following are set: Input data file name, teach data file name, the number of patterns (the beginning and end points of the input and teach data). When the numbers are set from the 0th to the 0th, all patterns are used for learning.

The **LALGO** command sets the mode for learning (on-line learning `"P"`, or batch-learning `"S"`), the learning algorithm (six methods; steepest descent method, conjugate gradient method, etc.), the learning rate and the necessary parameters for each algorithm.

In the **LEND** command, the maximum number of iterations and the tolerance are set as the termination conditions for learning.

In the **DISP** command, the followings are set : The interval to display the number of iterations and the square error value, and a comment sentence.

The example of setting the learning parameters for the XOR problem is shown:

```
weight("initwf","wgt",200,"A");
error("err",200,"D");
teach("in","out",0,0);
lalgo("S","6",0.005,0.6,0.0003,0.75,0.6);
lend(0.0,5000);
disp(200,"I'M LEARNING!");
```

Testing parameters

The parameters for testing MLP are the weight file name (the weight values of MLP after learning), the weight history number to use, the test data file name, the pattern numbers to use, the input layer and output layer numbers, and the test result file name. If the pattern numbers are set from the 0th to the 0th, all patterns are used for testing. These parameters are set by the **SETREC** command.

```
setrec("wgt",0,"in",0,0,0,2,"res");
```

6.3.3 Initialization of weights

An initial weight file is necessary in order to carry out learning. However, there is no necessity of executing the **WINIT** command when the history stored in the weight history file, generated during previous learning, is utilized as the initial weight files.

The example of the **WINIT** command execution is shown in Figure 6.2. The followings are displayed: The MLP's structure and the parameter values for generating the initial values of connection weights. If the initial weight file with given name does not exist, the message that a new file has been created is displayed. The following confirmation message is shown:

```
*** File [ filename ] already exists.  ***
Overwrite ?  ( y/n ) :
```

If `y`, the following message is displayed:

```
File [ filename ] has been overwritten.
```

If `n` is chosen, the error message is shown. In this case, the file name has to be reset.

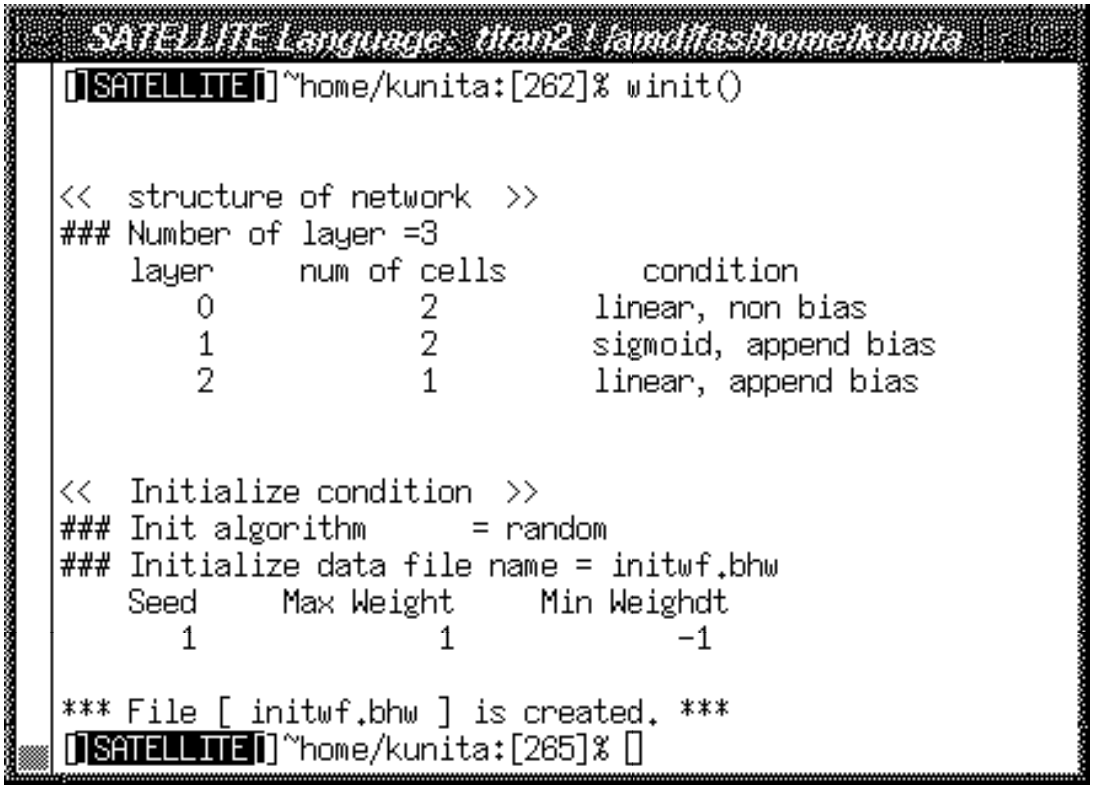


Figure 6.2: Execution of **WINIT**.

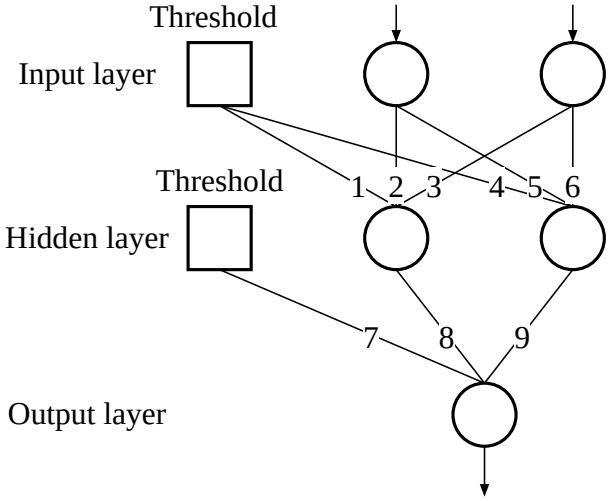


Figure 6.3: The example of an MLP's structure.

6.3.4 Learning

Learning of MLP is carried out by the **LEARN** command. **LEARN** reads "input" data, "teach" data, and initial values of connection weights from files. It writes the history of connection weights and square errors during learning.

It is also possible to store the sum of errors at each iteration, by giving a Series (or Snapshot) object as an argument to **LEARN**. The real-time buffer monitoring function **BM** can be used. For example,

```
series x; or snapshot x[lc]
bm(x);
learn(x);
```

`lc` stands for the number of iterations. If the sum of errors does not have to be stored, set `learn(0)`.

The connection weight history during learning is stored to the weight history file, and the square error values to the error history file. There are 2 kinds of storing modes for the weight history file: "Append mode" in which the history is added in order of storing, and "Overwrite mode" in which the history is overwritten.

The MLP (Figure 6.3) is used to illustrate usage of **LEARN**. MLP consists of 3 layers. The number of units is 2, 2, and 1 for the input, hidden, and output layers, respectively. The hidden layer and the output layer have the bias terms. In Figure 6.3, the circles and the squares stand for units and bias units, respectively. The number on each weight corresponds to the order of storing in the file. The weights are stored as shown in Figure 6.4.

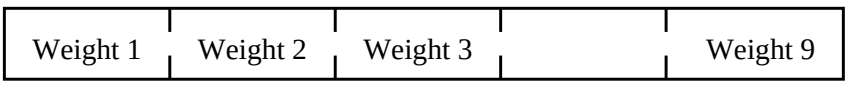


Figure 6.4: Format for storing connection weights.

For the interruption/restart of learning, the revised values of the connection weights 1 step before are

stored at the end of the connection weight data file, as shown in Figure 6.5. In the initial weight file, all of the values are 0. In Figure 6.5, m records from record n, or m records from record $n+m+1$, correspond to 1 data block. The **WINIT** command creates 2 data blocks that consist of the initial connection weight values and the 0 values. The **LEARN** command reads the last 2 data blocks in the initial weight file, and carries out the processing. In this way, it is possible to perform the learning process by continuing from the point where the learning was interrupted or terminated.

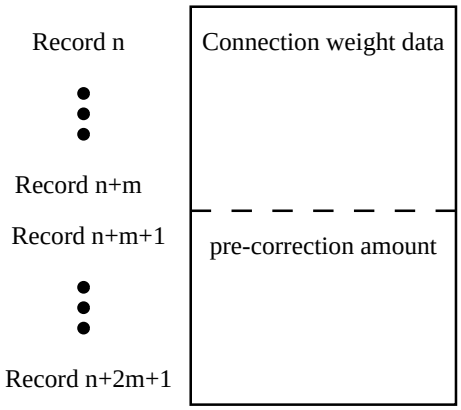


Figure 6.5: Format of a weight history file.

Append mode and Overwrite mode are explained next. The Append mode is the mode where the weight values and previous revisions are stored in 1 data block after the last "history", as shown in Figure 6.6. By utilizing this storing method, it is possible to put the latest data at the end of the file, and leave the history from the start point to the end point of learning.

The Overwrite mode is the mode where the weight data are overwritten to the initial values, as shown in Figure 6.7. This mode is useful in the cases where the scale of the MLP's structure is large and there are many weights, or it is not required to observe the history of the connection weights.

There are 2 kinds of methods for storing the error history; record direction and data-point direction. Moreover, Append mode and Overwrite mode are provided. Record direction storing is the method for storing error of each unit in the output layer and totals, as shown in 6.8. The data length of 1 block is equal to $(number\ of\ output\ units) + 1$.

Figure 6.9 shows the execution of **LEARN**. The MLP's structure and the learning parameters are displayed. The message that new files are created is displayed if the specified weight history file and error history file do not exist. When either of them exists, the notifying message is displayed, and it is storing mode confirmed (Append or Overwrite). In the case the mode is Overwrite, the mode is reconfirmed by pressing `y`. If `n` is pressed , the command is terminated and the file name must be reset. In the case the mode is Append, no message is displayed but the mode is set by pressing `y`. The input "`n`" means that the mode is changed to Overwrite, with the message on display.

When the learning is in progress, the number of iterations, the sum of square errors, the difference from previous error value, and comments are displayed. Assume that the number of output units is N. Then the squared error e_i for each pattern is as follows:

$$e_i = \sum_{j=1}^{N} (t_{ij} - o_{ij})^2,$$

where t_{ij} is teaching data and o_{ij} is output data of MLP. Assume that the number of all patterns is M.

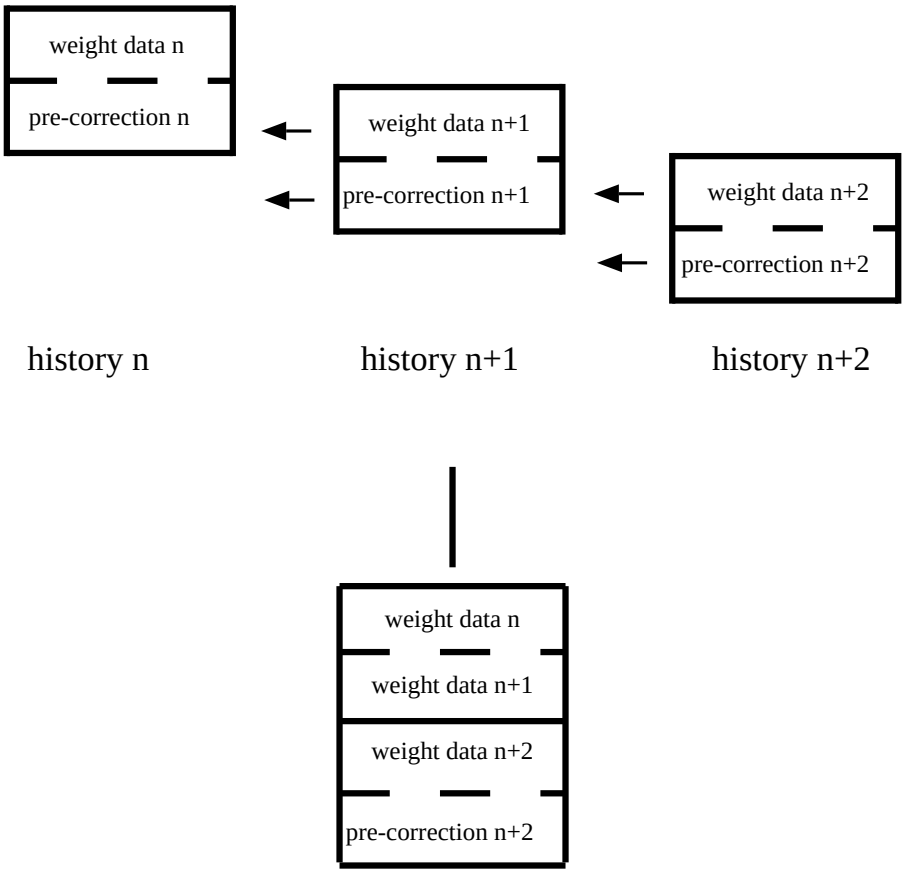


Figure 6.6: Weight history file format in Append mode.

Then the sum of them is given by the following equation:

$$E = \sum_{i=1}^{M} e_i^2.$$

The initial value of error is the difference between the teaching data and the output of MLP with the initial weight values.

Learning is terminated if the sum of errors is less than the set tolerance, or the number of iterations reaches the maximum. At that time, the following message is displayed:

```
*** Learning is done !  ***
```

6.3.5 MLP testing

MLP is tested by the **REC** command. **REC** reads the test data and the connection weights from files, and writes the output results to a file. It is possible to show the activity of units by change of a square size or color in the display of the structure of MLP. In that case, it is required to open a graphic window by the **WOPEN** command. Using **SIZE**, **ORIGIN**, and **COLOR** in the GPM module, we can set the size, position, and color of the connection weights of MLP, respectively.

Figure 6.10 is the picture while executing **REC**. The MLP structure and the test parameters are displayed during the execution. The message that a new file is created is displayed, when designated test

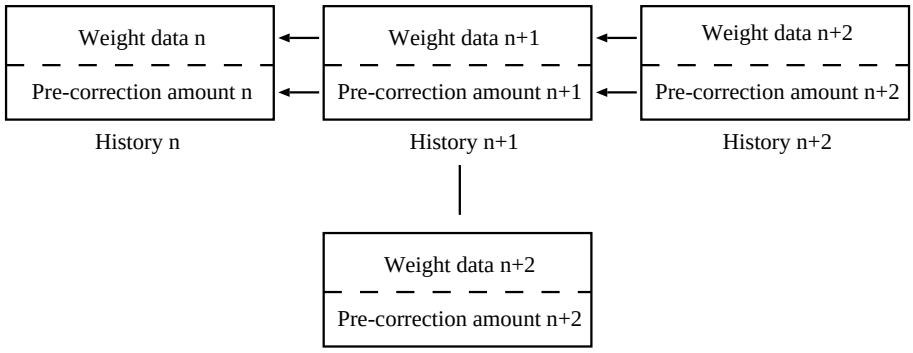


Figure 6.7: Weight history file format in Overwrite mode.

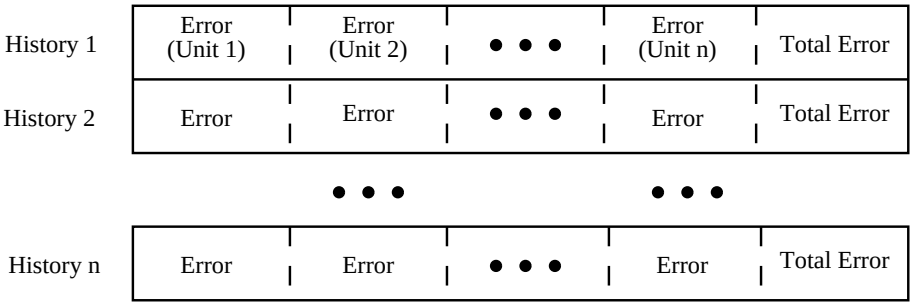


Figure 6.8: Format of error history file (Record direction mode).

result file does not exist. If the file exists, the mode of overwriting is confirmed. The message that the overwriting has been performed is displayed if `y` is pressed. The command will be terminated and the file name must be reset, when `n` is chosen.

6.3.6 Tracing connection weights and errors

By combining the commands of BPS with the GPM's ones, the trace of the internal parameters of MLP can be performed. The data sets which are necessary for tracing are read from the weight history file, the error history file, and the test result file generated during the learning and testing of MLP using the following commands:

`errload :` Data are read from the error history file.

`wgtload :` Data are read from the weight history file.

`actload :` Data are read from the test result file.

As previously mentioned, the **WOPEN** command is used for opening graphic windows. By using GPM commands such as **CONT**, **GRAPH**, **GSOLM**, and **MAP**, it is possible to display the data in buffers.

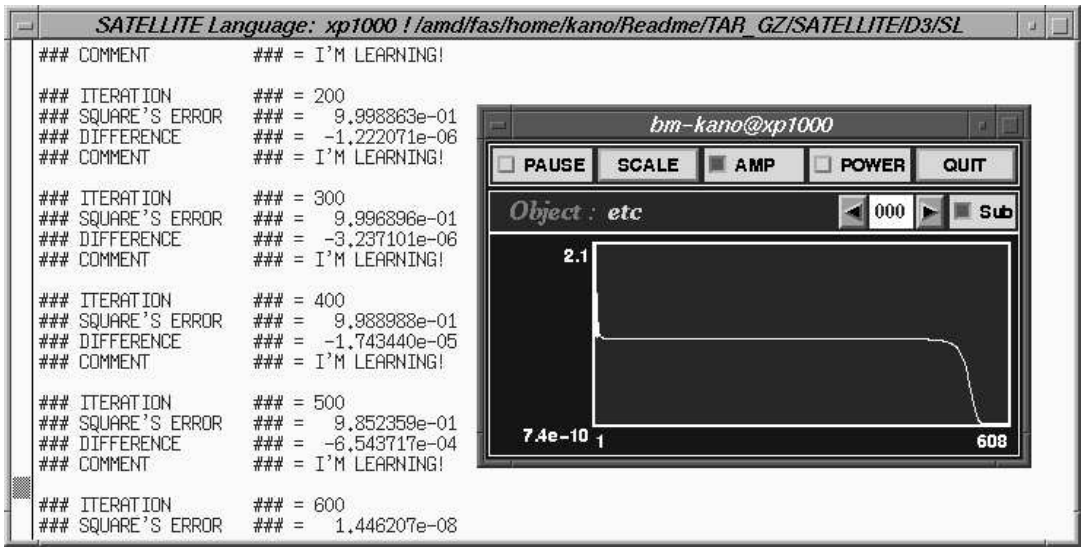


Figure 6.9: Execution of **LEARN**.

6.3.7 Internal representation analysis of MLP

Even if the ISPP commands are used, we can carry out the analysis of the internal state of MLP. The following commands have been implemented into BPS commands for it: **RVMAP**, **SIGMOID**, **ERRFUNC**, and **COR**.

`rvmap :` The inverse projection operation is carried out for the connection weights, and the results are stored to 2-dimensional objects. They can be displayed by using GPM commands.

`sigmoid :` This command tests MLP with the test parameters. The total input value and activation value of the unit are displayed in the quadrature axis and the vertical line, respectively. Furthermore, the activation values of some inputs can be plotted on the curve. It is also possible to show the histogram of input values.

`errfunc :` Two connection weights between optional units are chosen and the values of the weights change a little, when the other weight values are fixed. Then, the data are presented to MLP, the square errors of the outputs are calculated. Since they are stored to the object, it is possible to display them using GPM commands.

`cor :` The command for obtaining the correlation matrix of objects. Data are read from the weight history file to the object using the **WGTLOAD** command.

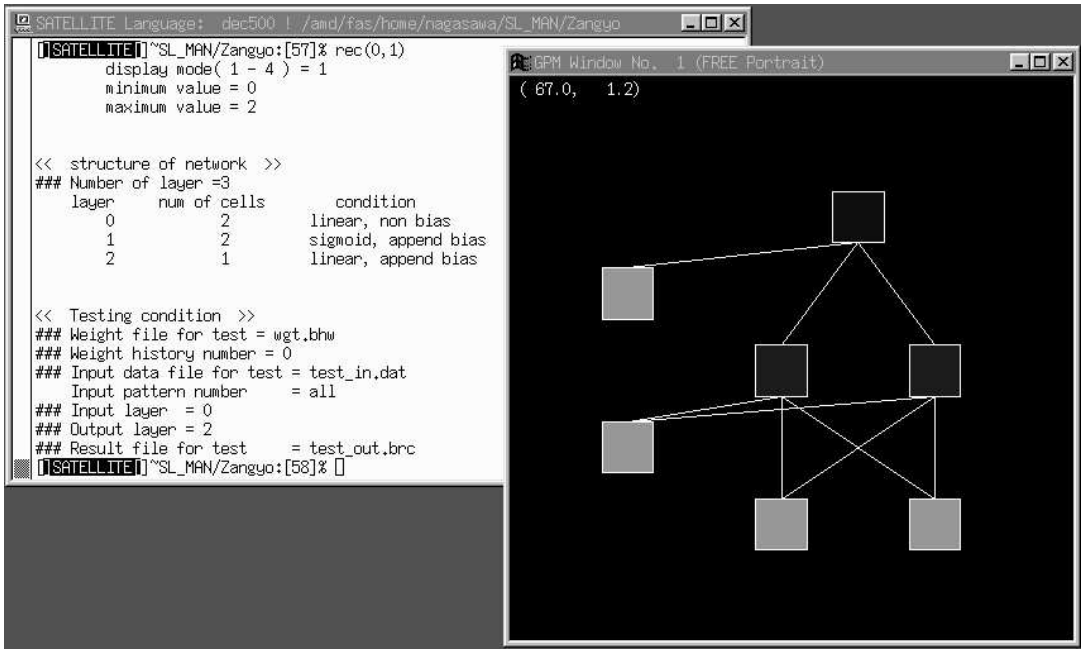


Figure 6.10: Example of **REC** execution.

Chapter 7

Neural Circuit Simulator — NCS

7.1 Introduction

The information processing mechanism in the brain and nervous system of human is described mathematically based on the results of physiological experiments. Generally, mathematical models are described by nonlinear multi-dimensional simultaneous differential equations, and the solutions are obtained by the numerical calculations. Simulation programs are coded by general-purposive programming languages.

The Neural Circuit Simulator (NCS) has been developed as a software system supporting research. In NCS, characteristics or connecting states of cells are described using the NCS language which is the exclusive model description language. It is possible to efficiently carry out the simulations under various conditions without rewriting the model description. Followings are the features of NCS:

- It is possible to perform the large-scale neural circuit model simulation based on a physiological knowledge.
- It is possible to handle not only the model with faithful physiological evidence, but also the general continuous system model.
- Programming, except the mathematical model construction, is unnecessary.
- Simulations are possible without recompiling if the conditions are changed.

7.1.1 Basic specifications

The NCS system structure is shown in Figure 7.1. The NCS consists of three components: NCS preprocessor, NCS library, and a command group for setting conditions. NCS preprocessor converts a neural circuit model described in the NCS language into a simulation program and a simulation condition file group coded in C language. The simulation program compiled by the C compiler becomes a simulation execution file by linking the NCS library. The NCS library is aggregate of the basic programs for executing the simulation, including the processing before the simulation starts, numerical integration routines, etc. The simulation condition file group is the assembly of the files containing information on the execution of the simulation, such as outside stimulation conditions, model parameters, signal delay information, etc. The simulation is carried out using the condition file group and the execution file.

7.1.2 Concept of modularization

The relationships between the type, module, and component in NCS are shown in Figure 7.2 and Figure 7.3.

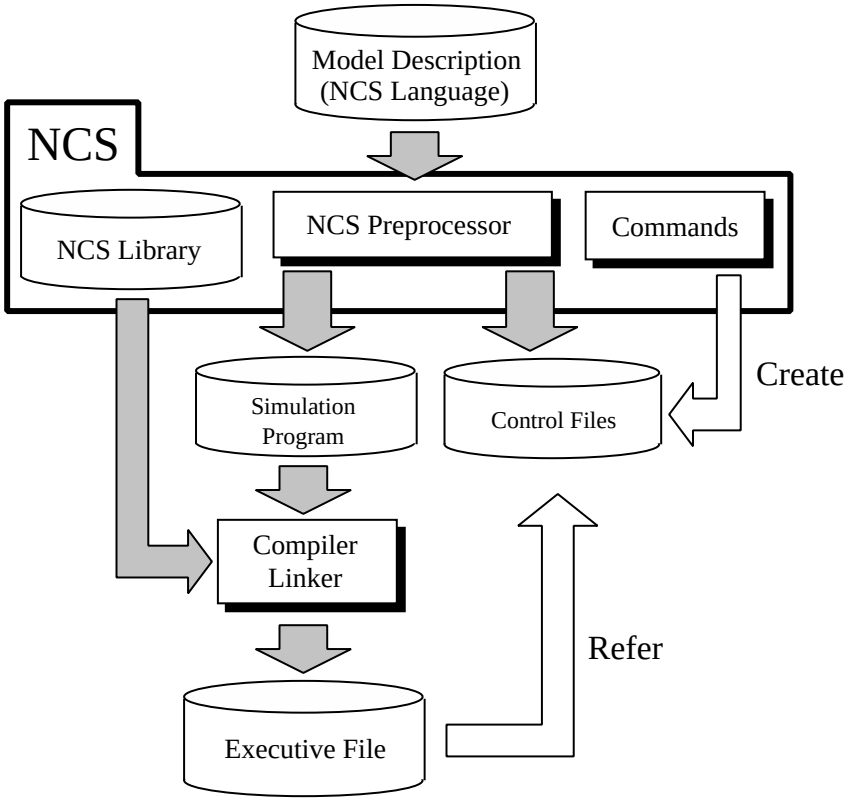


Figure 7.1: Composition of NCS.

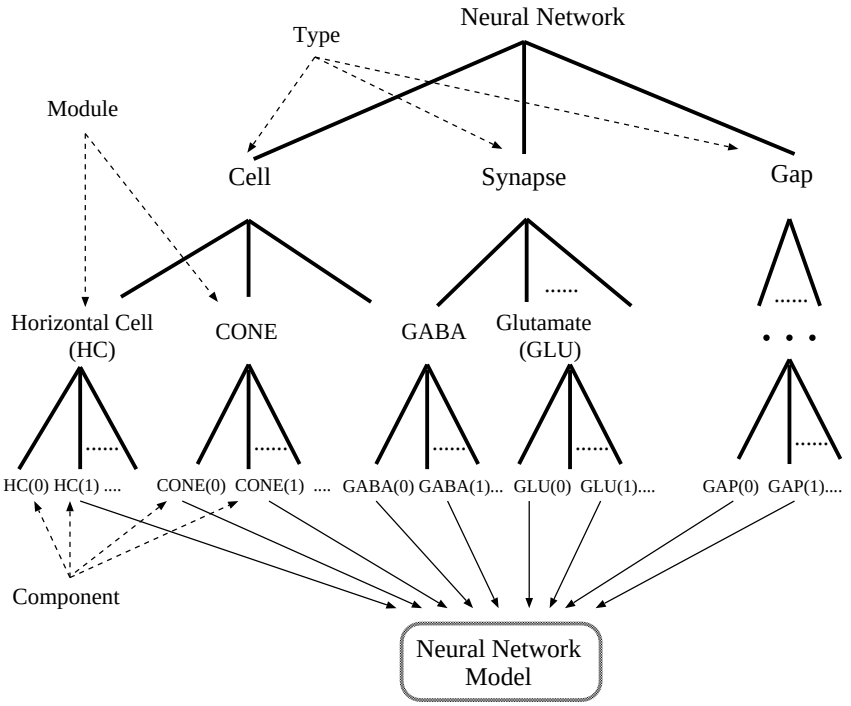


Figure 7.2: Neural circuit elements and the model structure in NCS.

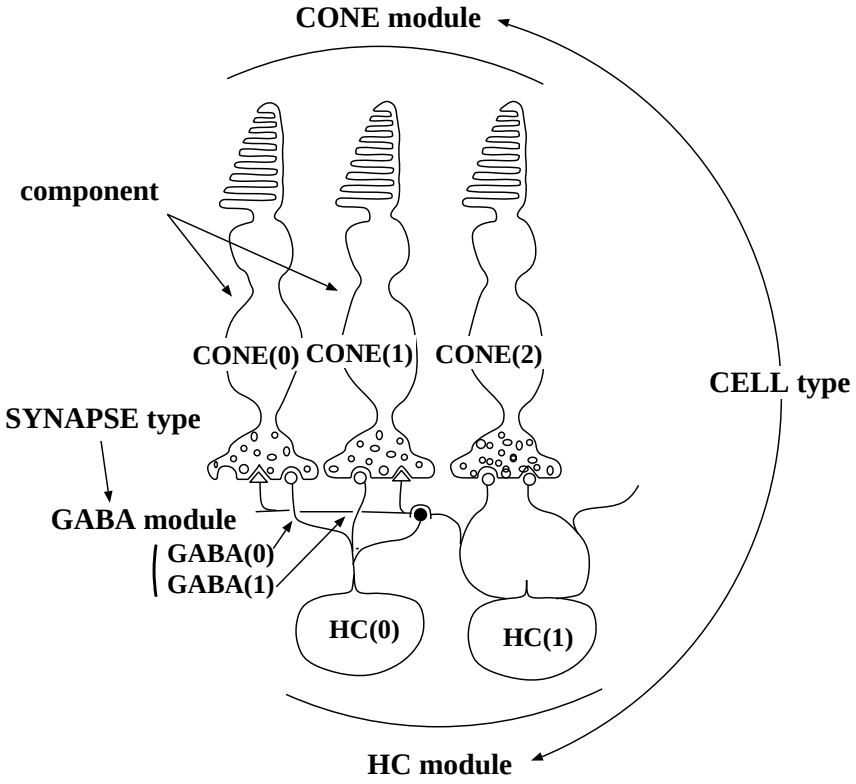


Figure 7.3: Correspondence to the real neural circuit.

A neural circuit consists of large number of neurons combined by chemical synapses and electric synapses (gap junctions). The elements constituting the neural circuit are: electric synapse, chemical synapse, and neuron. All neural circuits are made of the combination of these elements, and each of them has the specific function in the neural circuit. In the model description by NCS, they are regarded as "type". Neural circuit is classified into 3 types: cell type (neuron) , synapse type (chemical synapse), and gap type (electric synapse). By using the notation of the set theory, it can be described as follows:

$$\text{Elements in a neural network} = \{\text{cell type} ,\ \text{synapse type} ,\ \text{gap type}\}.$$

Although the type is a cluster of all elements with the identical function, it can be subdivided into "modules". In case of retina, for example, there are some cell-type modules, namely the cone photoreceptor (CONE) which receives the light, and the horizontal cell (HC) which controls and modifies visual information. Their characteristics are different each other. Every element with different characteristics is divided and defined as a module in NCS. The cell type is,

$$\text{cell type} = \{\text{HC module} ,\ \text{CONE module} ,\ \cdots\},$$

and similarly other types. The expression for the HC module is as follows:

$$\text{HC module} = \{\text{HC}[0], \text{HC}[1], \cdots\}.$$

The element in the module is called "component". It corresponds to the substance of the elements which are parts of the neural network. The component is indicated by index which is attached to the module name, as follows:

$$\text{HC}[0], \text{HC}[1], \cdots,$$

A module name and a suffix specify one element.

7.2 NCS Language

Language called the NCS language is used to describe a model. User can construct various models by describing the model for each module and changing its description if needed. Moreover, some special descriptions are used in order to deal with large-scale models. The NCS language has been composed of reserved words, NCS library functions, sentences and special descriptions. For example, the neural circuit model (Figure 7.4) in which the Hodgkin-Huxley (H-H) model (Table 7.1) is connected in series by resistances can be described as shown in Listing 1.

From the 2nd to the 12th line: A network description.

It is certainly necessary for model files. The connected form in Figure 7.4 is defined.

From the 14th to the 47th line: The description of the H-H model.

The membrane potential V is the input of the gap current I_g. The simultaneous differential equations in Table 7.1 are described in the function sentence.

From the 49th to the 56th line: The description of electric synapses.

The current outputs in proportion to the membrane potential.

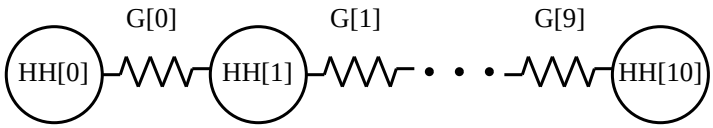


Figure 7.4: Example of a neural circuit model.

The descriptions by the NCS language can be divided roughly into the module description using differential equations (from the 14th to the 62nd line) and the network description which shows the connected modules (from the 2nd to the 12th line). As mentioned in §**7.1.2**, three types of module descriptions are provided: electric synapse, chemical synapse, and cell. In the listing, lines from the 14th to the 52nd line correspond to the cell-type module, and lines from the 54th to the 62nd line describe the electric-synapse-type module.

Details of reserved words, NCS library functions, sentences, and special descriptions used in the NCS language are explained next.

7.2.1 Reserved words

The following 5 words are defined as the reserved words by the system:

1. `TIME`

   The simulation time. It can be used for all modules.

2. `CN`

   The component number. It can be used for all modules.

3. `PRECN`

   The cell module that is the input value to the chemical/electrical synapse is called "presynaptic cell module" of the synapse. `PRECN` holds its component number. It can be used for chemical and electrical synapse modules.

4. `POSTCN`

   The cell module that is the output value from chemical/electrical synapse is called "postsynaptic cell module" of the synapse.

   POSTCN holds its component number. It can be used for chemical and electrical synapse modules.

5. `POSOUT`

   The output value from the postsynaptic cell module. It can be used for chemical and electrical synapse modules.

7.2.2 Library functions

The following 5 kinds of functions have been implemented. Mathematical library functions of C language can be also used, as shown in Table 7.2.

Table 7.1: The Hodgkin-Huxley model.

Membrane potential

$$C_m \frac{dV}{dt} = I - I_{Na} - I_K - I_L$$

V : membrane potential[mV]
C_m : membrane capacity[μF/cm^2]
I : total membrane current[μA/cm^2]

Sodium current

$$I_{Na} = \bar{g}_{Na} \cdot m^3 \cdot h(V - E_{Na})$$
$$\frac{dm}{dt} = \alpha_m(1-m) - \beta_m \cdot m$$
$$\alpha_m = \frac{0.1(25-V)}{\exp[(25-V)/10] - 1}$$
$$\beta_m = 4\exp\left(-\frac{V}{18}\right)$$
$$\frac{dh}{dt} = \alpha_h(1-h) - \beta_h \cdot h$$
$$\alpha_h = 0.07\exp\left(-\frac{V}{20}\right)$$
$$\beta_h = \frac{1}{\exp[(30-V)/10] + 1}$$

I_{Na} : sodium current[μA/cm^2]
$\bar{g}_{Na}$: membrane conductance 120[mS/cm^2]
E_{Na} : reversal potential 115[mV]

Potassium current

$$I_K = \bar{g}_K \cdot n^4(V - E_K)$$
$$\frac{dn}{dt} = \alpha_n(1-n) - \beta_n \cdot n$$
$$\alpha_n = \frac{0.01(10-V)}{\exp[(10-V)/10] - 1}$$
$$\beta_n = 0.125\exp\left(-\frac{V}{80}\right)$$

I_K : potassium current[μA/cm^2]
$\bar{g}_K$: membrane conductance 36[mS/cm^2]
E_K : reversal potential -12[mV]

Leak current

$$I_L = \bar{g}_L(V - E_L)$$

$\bar{g}_L$: membrane conductance 0.3[mS/cm^2]
E_L : reversal potential 10.6[mV]

Table 7.2: Mathematical library functions of C language that can be used in NCS.

Function	Description	Definition
exp	$y = \exp(x)$	$y = e^x$
pow	$y = \mathrm{pow}(x, a)$	$y = x^a$
sin	$y = \sin(x)$	$y = \sin(x)$
cos	$y = \cos(x)$	$y = \cos(x)$
tan	$y = \tan(x)$	$y = \tan(x)$

```
 1  /*              Hodgkin-Huxley's cell model           */
 2  type:           NETWORK;
 3  module:           SQUID;
 4  cell:           HH[11];
 5  gap:            G[10];
 6  connection:
 7                  HH[0] < ( G[0] < HH[1]  );
 8                  for( n = 1; n <= 9; n++ ){
 9                       HH[n] < ( G[n-1] < HH[n-1] + G[n] < HH[n+1] );
10                      }
11                  HH[10] < ( G[9] < HH[9] );
12                  end;
13  /*              HH module              */
14  type:           CELL;
15  module:         HH;
16  exinput:        Iex;
17  input:          Ig;
18  output:         V;
19  observable:     INa, IK, Il, Ig;
20  constant:       VNa = 115.0, VK = -12.0, Vl = 10.6;
21  parameter:      Cm = 1.0, mNa0 = 0.05293, GNa =120.0, GK = 36.0,
22                  Gl = 0.3, hNa0 = 0.5961, nK0 = 0.3177, V0 = 0.;
23  function:
24                  if( V != 25. ){                /* sodium current */
25                        am = 0.1*(25.-V)/(exp((25.-V)/10.)-1.); }
26                   else{
27                        am = 0.1*10.; }
28                  bm = 4.*exp(-V/18.);
29                  dmNa = am*(1. - mNa) - bm*mNa;
30                  mNa = integral(mNa0, dmNa);
31                  ah = 0.07*exp(-V/20.);
32                  bh = 1./(exp((30.-V)/10.)+1.);
33                  dhNa = ah*(1. - hNa) -bh*hNa;
34                  hNa = integral(hNa0, dhNa);
35                  INa = GNa*pow(mNa,3.0)*hNa*(V-VNa);
36                  if( V != 10. ){                /* potassium current */
37                        an = 0.01*(10.-V)/(exp((10.-V)/10.)-1.);}
38                   else{
39                        an = 0.01*10.; }
40                  bn = 0.125*exp(-V/80.);
41                  dnK = an*(1. - nK) - bn*nK;
42                  nK = integral(nK0, dnK);
43                  IK = GK*pow( nK, 4.0 )*(V-VK);
44                  Il = Gl*(V-Vl);               /* leakage current */
45                  Iall = Iex - INa - IK - Il + Ig;
46                  dV = Iall/Cm;
47                  V = integral(V0, dV);
48                  end;
49  /*              G module              */
50  type:           GAP;
51  module:         G;
52  input:          VOP(0.1,0);
53  output:         Ig;
54  parameter:      GL = 5.0;
55  function:
56                  Ig = GL * ( VOP - POSOUT );
57  end;
```

List 1: Description of the Hodgkin-Huxley model by the NCS Language.

- **PULSE**

  Description : $y = \text{pulse}(a, b, c, d, e)$
  Arguments :
  1. a : Starting time for input
  2. b : Initial input value
  3. c : Pulse height
  4. d : Time width
  5. e : Time period

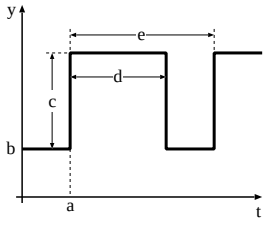


Figure 7.5: **Pulse.**

- **RAMP**

  Decription : $y = \text{ramp}(a, b, c)$
  Arguments :
  1. a : Starting time for input
  2. b : Initial input value
  3. c : slope

- **INTEGRAL**

  Description : $y = \text{integral}(A, P)$
  Definition : $y(t) = \int_t P dt, y(0) = A$

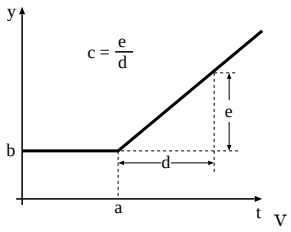


Figure 7.6: **Ramp.**

- **SIGMOID**

  Description : $y = \text{sigmoid}(-x)$
  Definition : $y = \dfrac{1}{1 + \exp(x)}$

- **RCASB**

  Description : $y = \text{rcasb}(V, a, b, c, d, e, f, g)$
  Definition : $y = \dfrac{a \cdot \exp\{b \cdot (V + c)\} + d \cdot (V + e)}{\exp\{f \cdot (V + c)\} + g}$

7.2.3 Description of modules

Each module is described using the "sentences" explained in the next subsection. The combination of these sentences depends on types. The details of sentences and different-type description methods are shown in the following.

Sentence

Each sentence should be started with the definition that specifies what is described, and completed with a semicolon. The contents are divided by colons, as follows:

```
Definition :  contentA, contentB, ...  contentZ ;
```

1. **type**

   It defines the type of the module. There are 3 types:

   CELL Cell type

   SYNAPSE Chemical synapse type

   GAP Electrical synapse type

   The combination of them:

   ```
   type :  NETWORK;
   ```

   Example:

```
/*   Definition of the network type   */
type : NETWORK;

/*   Definition of the cell type   */
type : CELL;
```

2. **module**

   It defines the module name. Use letters of alphabet for the beginning of a module name.

   Example:

   ```
   /*   Setting the module name "HH"   */
   module : HH;
   ```

3. **cell**

   In the network description, the cell module used in a model is defined by this. The module name and the number of components are required. In order to set two or more cell modules, we use commas to link them.

   Example:

   ```
   /* Definition of the cell module with 11 components,
      with name "HH"                                    */
   cell : HH[11];
   ```

4. **synapse**

   In the network description, the chemical synapse module used in a model is defined by this. The module name and the number of components are required. In order to set two or more cell modules, we use commas to link them.

   Example:

   ```
   /* Definition of the chemical synapse module
      with 5 components, with name "SYN"        */
   synapse : SYN[5];
   ```

5. **gap**

   In the network description, the electrical synapse module used in a model is defined by this. The module name and the number of components are required. In order to set two or more cell modules, we use commas to link them.

   Example:

   ```
   /* Definition of the electric synapse module
      with 10 components, with name "G"         */
   gap : G[10];
   ```

6. **exinput**

   It defines the name of an external input variable in a cell module. The number of external input variables is just one.

   Example:

```
/* Definition of "Iex" as an external input variable */
exinput : Iex;
```

7. **input**

   It defines the name of an input variable in a module. The number and description order of input variables in the cell module should correspond to the descriptions in the **connection** sentences. The number of input variables in the chemical or electrical synapse module is one. In order to set two or more cell modules, use commas to link them. Moreover, it is possible to add delay information to the **input** sentence for the chemical and electrical synapse. The delay information is described by the following:

   `input :` *name_of_a_variable* (*delay_time*, *initial_value*);

   initial_value is output in the interval from 0 to *delay_time*.

   Example:

```
/* Definition of "Ig" as an input variable */
input : Ig;
/* Definition of "VOP" as an input variable
   with the delay = 0.1 and the initial value = 0.0 */
input : VOP( 0.1, 0 );
```

8. **output**

   It defines the name of an output variable in a module. The number of output variables is one.

   Example:

```
/* Definition of "V" as an output variable */
output : V;
```

9. **observable**

   It defines the name of the variable of which value is to be observed (used in the **function** sentence). Specify the output by the **NOUT** command. The value of the defined variable can be observed while the simulation is running.

   Example:

```
/* Definitions of "INa", "IK", "Il", "Ig"
   as the variables to observe            */
observable : INa, IK, Il, Ig;
```

10. **constant**

    It defines the name and value of a constant used in the **function** sentence. Use the "double" notation for constants even if they are integers[1].

    Example:

```
/* Definition of "VNa", "VK", "Vl" as constants
   with the values 115, -12, 10.6, respectively */
constant : VNa = 115.0, VK = -12.0, Vl = 10.6;
```

[1]The variables become double type when the NCS program is converted into C language through the NCS preprocessor. Therefore, it would happen that the desirable values are not substituted if we used an old compiler of C language.

11. **parameter**

    It defines parameter variables. The parameters defined here are registered in a simulation condition file, and can be changed using the **NPARA** command. Use the "double" notation for parameters even if they are integers.

    Example:

```
/* Definitions of "Cm", "mNa0", "GNa", "GK", "Gl"
   as parameters with values 1.0, 0.05293, 120,
   36, 0.3, respectively                          */
parameter : Cm = 1.0, mNa0 = 0.05293, GNa =120.0,
            GK = 36.0, Gl = 0.3;
```

12. **connection**

    It defines the relationship of between two or more components. It is called a relative expression. "<" in the relative expression stands for the composition in which the the output of the right-hand side is input of the left-hand side. Each input is in parentheses. For example,

```
mdl[i] < ( input1 )( input2 );
```

    `input1` and `input2` are substituted for the first and the second inputs of the i-th component of the module `mdl`. As mentioned before, the number of input variables in the **input** sentence should be equal to the relative expression's one. That is, two input variables have to be defined for the description of `mdl` as follows:

```
input :  V1, V2;
```

    In this case, the outputs from `input1` and `input2` are substituted for `V1` and `V2`, respectively.

    If the module does not have any inputs, that is, there is no **input** sentence, the relative expression for such a module is given as follows:

```
mdl[i] < ();
```

    The input of the cell module must be inputted through the components of the chemical or electrical synapse modules. For example, the description that the output from the j-th component of the module `mdl` is substituted for the first input of its i-th component through the k-th component of the chemical (or electric) synapse is

```
mdl[i] < ( syn[k] < mdl[j] )( input2 );
```

    It is also possible to designate the result of adding the outputs of components of modules to the input of the component of each module. In this case, we use "+" to link them. For example, the second input of the i-th component of the cell module `mdl` is the sum of the output of the n-th component of `mdl` through the m-th component of the synaptic module `syn` and the output of the l-th component of `mdl` through the o-th component of `syn`:

```
mdl[i] < ( input1 )( syn[m] < mdl[n] + syn[o] < mdl[l] );
```

    The component of a cell module, which appears in the right-hand side of a relative expression, should be presented in the most left-hand side of the different relative expression. Note that we

never use the components of chemical or electrical synapse modules. They necessarily have the components of cell modules on the input and output sides.

Examples:

```
connection:
/* Input the output from the 1st component of the
   cell module "HH" to the 0th component of "HH"
   through the 0th component of the synapse
   module "G"                                      */

HH[0] < ( G[0] < HH[1]  );

/* Input the sum of the output from the 4th
   component of the cell module "HH" through
   the 4th component of the synapse module "G"
   and the output from the 6th component of
   "HH" through the 5th component of "G" to
   the 5th component of "HH"                   */

HH[5] < ( G[4] < HH[4] + G[5] < HH[6] );

/* 2 inputs to the 10th component of the cell
   module "HH":
   The 1st input is the output from the 9th
   component of "HH" through the 9th component
   of the synapse module "G"
   The 2nd input is the output from the 0th
   component of "CA" through the 0th component
   of the synapse module "SYN"                 */

HH[10] < ( G[9] < HH[9] )( SYN[0] < CA[0] );
```

13. **function**

Characteristics of the module are described by using mathematical expressions. The values of parameters should be preset before they are used. The mathematical expressions are divided by semicolons.

IF sentences can be used in **function** sentences.

`if ( `*condition*` ) { `*sentence1*` }` [`else { `*sentence2*` }`]

If the expression *condition* is true, then *sentence1* is executed. Otherwise, *sentence2* is performed. Relative operators for conditional expressions are shown in Table 7.3.

Examples:

```
/* Descriptions of "INa" and "IK" */
function :
INa = GNa * ( V - VNa );
```

Table 7.3: Operators for conditional expressions

Operation	Operator
parity	=
disparity	<>
comparison	<, >, <=, >=
logical OR	.OR.
logical AND	.AND.
negation	.NOT.

```
if( V > 10 ){
  IK = GK * ( V - VK );
  }
else{
  IK = 0.;
  }
```

14. **Comment**

    The part contained in "`/*`" and "`*/`" is a comment sentence. It is possible to use it anywhere and exceed two or more lines.

Description of cell type modules

The cell can be described using a membrane model based on the ionic currents. The sentences used in the cell type module and their order are as follows:

1. **type** sentence
2. **module** sentence
3. **exinput** sentence
4. **input** sentence
5. **output** sentence
6. **observable** sentence
7. **constant** sentence
8. **parameter** sentence
9. **function** sentence

Although it is possible to omit some sentences, their order cannot be changed. See the previous section for the details on each sentence. The "`end;`" word is required at the end of the module description.

Example:

```
/*        cell type module          */
type:        CELL;
module:      CL;
exinput:     Iex;
input:       Ig;
output:      V;
```

```
observable:  IK, Il, Ig, nK;
constant:    VK = -12.0, Vl = 10.6;
parameter:   Cm = 1.0, GK = 36.0, Gl = 0.3;
function:
if( V!=10.){
  an = 0.01*(10.-V)/(exp((10.-V)/10.)-1);
  }else{
  an = 0.01*10.;
  }
bn = 0.125*exp( -V / 80. );
dnK = an*( 1.- nK ) - bn * nK;
nk = integral( 0.3177, dnK );
IK = GK * pow( nK, 4. ) * ( V - VK ); /* Potassium Current */
Il = Gl * ( V - Vl );                 /* Leak Current */
Iall = Iex - IK - Il + Ig;
dV = Iall/Cm;
V = integral( 0., dV );              /* Membrane Potential */
end;
```

Description of chemical synapse type modules

The chemical synapse type module is the module with one input and one output. It can combines two or more cell type modules. In the description, there is no difference between the chemical synapse type and the electrical synapse type. The sentences used in the chemical synapse type module and their order are shown in the following:

1. **type** sentence
2. **module** sentence
3. **input** sentence
4. **output** sentence
5. **observable** sentence
6. **constant** sentence
7. **parameter** sentence
8. **initial** sentence
9. **function** sentence

Although it is possible to omit some sentences, their order cannot be changed. See the previous section for the details on each sentence. The "`end;`" word is required at the end of the module description.

Example:

```
/*           synapse type module           */
type:        SYNAPSE;
module:      GABA;
input:       PO( 0.1, 0 );
output:      Tr;
parameter:   FB = 0.01;
```

```
function:
Tr = P0 /( FB + P0 );
end;
```

Description of electrical synapse type modules

The electrical synapse type module is the module with one input and one output. It can combines two or more cell type modules. The sentences used in the electrical synapse type module and their order are shown in the following:

1. **type** sentence
2. **module** sentence
3. **input** sentence
4. **output** sentence
5. **observable** sentence
6. **constant** sentence
7. **parameter** sentence
8. **function** sentence

Although it is possible to omit some sentences, their order cannot be changed. See the previous section for the details on each sentence. Put "`end;`" word at the end of the module description.

Example:

```
/*         gap type module           */
type:        GAP;
module:      G;
input:       VOP( 0.1, 0 );
output:      Ig;
parameter:   GL = 5.0;
function:
Ig = GL * ( VOP - POSOUT );
end;
```

Network description

The modules used in the model are defined, and the properties of each component are described using mathematical expressions. The sentences used in the network type and their order are shown in the following:

1. **type** sentence
2. **module** sentence
3. **cell** sentence
4. **synapse** sentence
5. **gap** sentence
6. **connection** sentence

Although it is possible to omit some sentences, their order cannot be changed. See the previous section for the details on each sentence. Put "`end;`" word at the end of the module description.

FOR sentences can be used in order to incorporate loops. The format of the **FOR** sentence is shown in the following:

```
for ( expr1 ; expr2 ; expr3 ) {
    sentences
}
```

The expressions, such as substitution, relative operator, and so on, can take the place of *expr1*, *expr2*, and *expr3*. *expr1* is an expression for initializing the loop. *sentence* is executed if the result of *expr2* is true. Relative operators shown in Table 7.3 can be used in *expr2*. *expr3* is evaluated at the end of every iteration. In the **FOR** sentence, the parentheses "`{`", "`}`" are necessary.

Example:

```
/*          Hodgkin-Huxley's cell model          */
type:       NETWORK;
module:     SQUID;
cell:       HH[11];
gap:        G[10];
connection:
HH[0] < ( G[0] < HH[1] );
for( n = 1; n <= 10; n++ ){
  HH[n] < (G[n-1] < HH[n-1] + G[n] < HH[n+1] );
  }
HH[10] < ( G[9] < HH[9] );
end;
```

The description of networks must be at the beginning of the model description file.

7.2.4 Example — Hodgkin-Huxley model

In this section, the programming by the NCS language is explained using a real model. It is the network model connecting the Hodgkin-Huxley (H-H) models (Table 7.1), as in Figure 7.4.

The sodium current of the H-H model is shown in the following equation.

$$I_{Na} = \bar{g}_{Na} \cdot m^3 \cdot h(V - E_{Na}) \tag{7.1}$$

$$\frac{dm}{dt} = \alpha_m(1-m) - \beta_m \cdot m \tag{7.2}$$

$$\alpha_m = \frac{0.1(25-V)}{\exp[(25-V)/10]-1} \tag{7.3}$$

$$\beta_m = 4\exp\Big(-\frac{V}{18}\Big) \tag{7.4}$$

$$\frac{dh}{dt} = \alpha_h(1-h) - \beta_h \cdot h \tag{7.5}$$

$$\alpha_h = 0.07\exp\Big(-\frac{V}{20}\Big) \tag{7.6}$$

$$\beta_h = \frac{1}{\exp[(30-V)/10]+1} \tag{7.7}$$

$\bar{g}_{Na}$: Sodium membrane conductance, 120 [mS/cm^2]
E_{Na} : Sodium reversal potential, 115 [mV]

By using the NCS language, Eq.(7.3) and Eq.(7.4) are described as follows:

```
am = 0.1*(25.-V)/(exp((25.-V)/10.)-1);
bm = 4.*exp(-V/18.);
```

The value $V = 25$ [mV]. However, α_m has to be rewritten as follows:

```
if( V != 25. ){
    am = 0.1*(25.-V)/(exp((25.-V)/10.)-1);
   }else{
    am = 0.1 * 10.;
   }
```

The gating variable m of the sodium channel is expressed by a differential equation. It can be described by the following:

```
dmNa = am * ( 1. - mNa ) - bm * mNa;
mNa = integral( mNa0, dmNa );
```

Similarly h can be described as follows, from Eq.(7.5), Eq.(7.6), and Eq.(7.7):

```
ah = 0.07 * exp( -V / 20. );
bh = 1. / ( exp( ( 30.-V )/10. ) + 1. );
dhNa = ah * ( 1. - hNa ) - bh * hNa;
hNa = integral( hNa0, dhNa );
```

From Eq.(7.1), the sodium current I_{Na} is given by the following:

```
INa = GNa * pow( mNa, 3.0 ) * hNa * ( V - VNa );
```

The potassium current is described by following equations:

$$I_K = \bar{g}_K \cdot n^4 (V - E_K) \tag{7.8}$$

$$\frac{dn}{dt} = \alpha_n (1 - n) - \beta_n \cdot n \tag{7.9}$$

$$\alpha_n = \frac{0.01(10 - V)}{\exp[(10 - V)/10] - 1} \tag{7.10}$$

$$\beta_n = 0.125 \exp\Big(-\frac{V}{80}\Big) \tag{7.11}$$

$\bar{g}_K$: Potassium membrane conductance, 36 [mS/cm^2]
E_K : Potassium reversal potential, -12l [mV]

From Eq.(7.9), Eq.(7.10), and Eq.(7.11), the gating variable n of potassium channel is described in the same way as the sodium current:

```
if( V != 10.){
    an = 0.01 * ( 10. - V ) / ( exp( ( 10. - V ) / 10. ) - 1. );
   }else{
    an = 0.01 * 10;
   }
bn = 0.125 * exp( -V / 80. );
dnK = an * ( 1 - nK ) - bn * nK;
nK = integral( nK0, dnK );
```

From Eq.(7.8), the potassium current I_K is given by the following:

```
IK = GK * pow( nK, 4.0 ) * ( V - VK );
```

The leak current is defined by the following equation:

$$I_L = \bar{g}_L(V - E_L) \tag{7.12}$$

$\bar{g}_L$: Leak-current membrane conductance, 0.3 [mS/cm^2]
E_L : Leak-current reversal potential, 10.6 [mV]

From the above equation, the description of the leak current is as follows:

```
Il = Gl * ( V - Vl );
```

The current which crosses a membrane I is given by the following equation:

$$C_m \frac{dV}{dt} = I - I_{Na} - I_K - I_L \tag{7.13}$$

From Figure 7.4, the total current I is the sum of currents from the neighboring cells through the electrical synapse I_g and the injection current I_{ex}:

$$I = I_{ex} - I_{Na} - I_K - I_L + I_g \tag{7.14}$$

Eq.(7.13) can be transformed as follows:

$$\frac{dV}{dt} = \frac{I}{C_m} \tag{7.15}$$

From the above, the description in the NCS language is given by the following:

```
Iall = Iex - INa - IK - Il + Ig;
dV = Iall / Cm;
V = integral( V0, dV );
```

The module with the above characteristics is described next. Assume that the "type" is the cell type and the name is "HH".

```
type:       CELL;
module:     HH;
```

The external input is the injection current I_{ex}, the input is the current from the adjoining cell I_g, and the output is the membrane potential V.

```
exinput:    Iex;
input:      Ig;
output:     V;
```

The following are observed: Sodium current I_{Na}, potassium current I_K, leak current I_L, and the current from the adjoining cell I_g.

```
observable: INa, IK, Il, Ig;
```

The reversal potential of each ion current, E_{Na}, E_K, and E_L, is defined as a constant.

```
constant:   VNa = 115.0, VK = -12.0, Vl = 10.6;
```

The followings are defined as parameters: membrane capacitance C_m, the initial value of an integration constant, membrane conductance of each ion $\bar{g}_{Na}$, $\bar{g}_K$, $\bar{g}_L$.

```
parameter:  Cm = 1.0, mNa0 = 0.05293, GNa = 120., GK = 36.,
            Gl = 0.3, hNa0 = 0.5961, nK0 = 0.3177, V0 = 0.;
```

Above-mentioned descriptions are used for **function** sentences.

The description of the electrical synapse type module for connecting two cells is shown in the following; the name is "G":

```
type:       GAP;
module:     G;
```

Its input is the voltage and its output is the current. The initial value of the voltage is 0 with the delay time 0.1[s].

```
input:      VOP( 0.1, 0 );
output:     Ig;
```

The conductance of the electric synapse is defined as a parameter.

```
parameter:  GL = 5.0;
```

From Figure 7.4, the output current I_g is given by following equation:

$$I_g \quad = \quad g \times (V_1 - V_2), \tag{7.16}$$

where V_1 and V_2 are the voltages at both ends of the electric synapse. Thus, the **function** sentence is described as follows:

```
function:
           Ig = GL * ( VOP - POSOUT );
```

Finally, consider the network description. The name of this module is "SQUID".

```
type:     NETWORK;
module:   SQUID;
```

As shown in Figure 7.4, 11 "HH" cells and 10 "G" synapses are necessary. They are defined as follows:

```
cell:     HH[11];
gap:      G[10];
```

Relationship is described using the **FOR** sentence.

```
connection:
          HH[0] < ( G[0] < HH[0] );
          for( n = 1; n <= 10; n++ ){
              HH[n] < ( G[n-1] < H[n-1] + G[n] < HH[n+1] );
             }
          HH[10] < ( G[9] < HH[9] );
```

The description using the NCS language shown in Listing 1 is completed.

7.3 How to use NCS

This system is implemented in SATELLITE. Batch processing using the batch file or interactive processing are possible. Refer to the SATELLITE language command reference manual for the details of commands.

The procedure for doing simulations using NCS is as follows:

1. Preparation of a model file.

   The file that describes a model using the NCS language should be made. See §**7.2** for further details of the description method by the NCS language.

2. Registration of a model file.

   The name of a model description file for simulation should be defined. After the definition, NCS carries out the processing.

3. Preparation of an execution and a simulation condition file.

   After starting the preprocessor and linking the registered model file, the execution file and the simulation condition file group are created.

4. Setting simulation conditions.

   The followings are set for the simulation: The simulation time, the external input variables, output variables, etc.

5. Execution of the simulation.

   The simulation is executed.

6. Display and analysis of the simulation results.

   The results obtained by the simulation are graphically displayed.

By referring to the simulation using the model description shown in Listing 1, the detail of this procedure are described in the next subsections.

7.3.1 Preparation of a model file

We can describe a model file with the specifications of the NCS language. "`.mdl`" should be the end of the name of the model file. Using the **NE** command, an editor is executed for the model file which is registered by the **NASSIGN** command (see §**7.3.2**). The default is "vi" editor. It can be changed by setting the environmental variable EDITOR of UNIX.

7.3.2 Registration of a model file

Starting the preprocessor by the **NPP** command (see §**7.3.3**) and execution file by the **NLINK** command are done for the model file registered in the work area of SATELLITE. The model must be registered in order to carry out the simulation using the NCS. The registration is made by the **NASSIGN** command or the **NPP** command (see §**7.3.3**). The **NASSIGN** command takes the model file name as its argument, and registers the model file with the given name. In the model file name, there is no need to add "`.mdl`".

```
[]SATELLITE[]~tom/rose:[50]% nassign("hhmodel") ↩
```

In the above example, "`hhmodel.mdl`" is registered as a model file.

7.3.3 Preparation of an execution and a simulation condition file

After the execution of the **NPP** command, the preprocessor is started, and the model file described in the NCS language is converted into the source file of C language including the simulation condition file group.

```
[]SATELLITE[]~tom/rose:[51]% npp() ↩
```

The **NPP** command can take the model file name as its argument, even if it is not registered by **NASSIGN**. There is no necessity to add "`.mdl`" in this case. "`hhmodel.mdl`" is registered as a model file and the preprocessor is started by the following:

```
[]SATELLITE[]~tom/rose:[51]% npp("hhmodel") ↩
```

After executing **NPP**, the execution file is made by the **NLINK** command for compiling the source file of C language and linking it with the library in NCS.

```
[]SATELLITE[]~tom/rose:[52]% nlink("-O2") ↩
```

The argument of **NLINK** "`-O2`" is the optimization level for compilation. The cc command of UNIX is used for compiling and linking. Refer to the manual of UNIX for further details.

7.3.4 Setting simulation conditions

Several conditions necessary for carrying out the simulation are required to set. Some of them are already set in the model file at the point when the **NPP** command is executed.

The commands for the simulation conditions described in the following overwrite the simulation condition file, which is generated by **NPP**. That is, **NPP** must be executed before the execution of simulation condition commands. If the simulation condition commands are not executed before **NPP**, the following error message is displayed:

```
sl: Error [<NCS:nout> No.1] :
              Improper Model File Name in near line <n>
```

The conditions are initialized when **NPP** is executed again.

Simulation time conditions

Simulation time conditions are set by the **NTIME** command. The format of **NTIME** is as follows:

Description) `ntime( last, cal, str, itv )`
Arguments)
1. `last` : Simulation time
2. `cal` : Calculation intervals
3. `str` : Sampling intervals
4. `itv` : Storing intervals

`last` is the time when the simulation ends. `cal` is the time interval used for numerical calculation. Since the error, convergence speed, and the execution time of the simulation depend on this value , it should be set to the appropriate value. `str` is the time interval for monitoring the calculation results. `itv` is the time interval for storing the execution results to the buffer designated by the **NOUT** command. The simulation time is dramatically prolonged when this value is too small. The unit of each argument is [msec]. For example, to set the simulation time to 10[msec], the interval of calculation to 0.001[msec], the interval of sampling to 0.01[msec], and the interval of storing to 1[msec], the following is required:

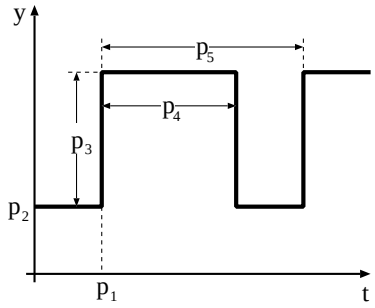


Figure 7.7: Pulse function.

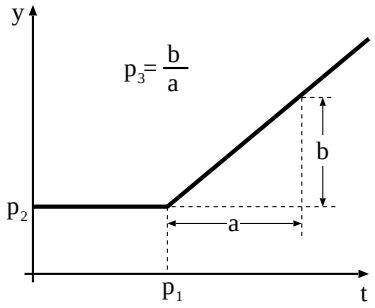


Figure 7.8: Ramp function.

```
[]SATELLITE[]~tom/rose:[53]% ntime( 10, 0.001, 0.01, 1 ) ↩
```

The simulation time conditions can be displayed by setting "T" as the argument of the **NSCLIST** command.

```
[]SATELLITE[]~tom/rose:[54]% nsclist(T) ↩

TIMER

  Last  Time =       10
  Calc. Step =    0.001
  Store Step =     0.01
  BufferStep =        1
```

External input conditions

Conditions for the external input are set by the **NSTIM** command. **NSTIM** has the format that requires the module name, the component number, and the input waveform. The followings are prepared for the input waveform: Pulse function, ramp function, optional function from a file, and a function from a buffer. The format is shown in the following:

Description) `nstim( mdul, com, type, p1[, p2, p3, p4, p5] )`
Arguments)
1. `mdul` : Module name
2. `com` : Component number
3. `type` : Function type for input
   - `P` — Pulse function
   - `R` — Ramp function
   - `F` — Input from a file
   - `B` — Input from a buffer
4. `p1 ... p5` : parameters (depending on `type`)

type	p1	p2	p3	p4	p5
P	Start time	Initial value	Height	Width	Period
R	Start time	Initial value	Steepness		
F	File name	Buffer no.			
B	Buffer name				

The module with the name specified by this command must have the description of the external input (using the **exinput** sentence). Setting to input pulse function of the 0th component of the module with the name "HH" is carried out by the following:

```
[]SATELLITE[]~tom/rose:[55]% nstim("HH",0,P,1,0,100,3,999) ↩
```

The conditions on the external input can be displayed by setting "S" as the argument of the **NSCLIST** command.

```
[]SATELLITE[]~tom/rose:[56]% nsclist(S) ↩

EXINPUT

EXTERNAL INPUTS
  Data No.      Component     Function Data No.
   1              HH(  0)            1

No. 1  Function  start_tm init_out  height    width   period
      <   PULSE> [     1] [     0] [   100] [     3] [   999]
```

Output conditions

The output conditions are set by the **NOUT** command. **NOUT** has the buffer name which stores output values, the module name, the component number, and the attributes of output as the arguments. If the output attribute is the internal variable, its name must be set as the argument. The format of **NOUT** is shown in the following:

Description) `nout( buff, mdl, com, type [, val] )`
Arguments)
1. `buff` : Buffer name for storing output values
2. `mdl` : Module name
3. `com` : Component number
4. `type` : Attribute of output
   `1` — Output value
   `2` — Input value
   `3` — Internal variable's value
5. `val` : Variable name if type = 3

"Output value" is the value of the variable designated in the **output** sentence in the description of the module with the name "`mdl`". The value of the variable in the **exinput** sentence is "input value". For example, to set the input value of the 0th component of the module with the name "`HH`" as an output to the buffer `Iin` is done as follows:

```
[]SATELLITE[]~tom/rose:[58]% nout(Iin,"HH",0,2) ↩
```

To set the output value of the 0th component of the module "`HH`" as an output to the buffer `V` is carried out as follows:

```
[]SATELLITE[]~tom/rose:[59]% nout(V,"HH",0,1) ↩
```

To set the value of the internal variable `INa` of the 0th component of the module "`HH`" as an output to the buffer `INa0` is done by the following:

```
[]SATELLITE[]~tom/rose:[60]% nout(INa0,"HH",0,3,"INa") ↩
```

The buffer which stores output values must be defined as Series type before the execution of the **NOUT** command. For example, the buffers `Iin`, `V`, `INa0` should be defined as follows:

```
[]SATELLITE[]~tom/rose:[57]% series Iin, V, INa0 ↩
```

The conditions on the output can be displayed by setting "0" as the argument of the **NSCLIST** command.

```
[]SATELLITE[]~tom/rose:[61]% nsclist(0) ↩

OUTPUT
        Variable(Num) [index]  OUTPUT VARIABLE
             Iin( 84) [  0  ] EX.INPUT OF HH(0)
               V( 83) [  0  ] OUTPUT   OF HH(0)
            INa0( 87) [  0  ] INa      OF HH(0)
```

Change of the parameter values

The parameter values can be changed by the **NPARA** command. The format of **NPARA** is shown in the following:

Description) `npara( mdl, var, num )`
Arguments)
1. `mdl` : Module name
2. `var` : Parameter name
3. `num` : Parameter value to set

For execution of the **NPARA** command, it is required to define the variable `var` of the module `mdl` in the description of the model file by the **parameter** sentence.

```
[]SATELLITE[]~tom/rose:[62]% npara( "HH", "Cm", 1.2 ) ↩
```

The values that are changed by **NPARA** command are available until the simulation condition file is initialized by command such as **NPP**.

It is possible to display the present parameter values by the **NLIST** command.

```
[]SATELLITE[]~tom/rose:[63]% nlist("HH") ↩

Parameter List

Module name : HH
  Cm        = [     1.2]
  mNa0      = [ 0.05293]
  GNa       = [     120]
  GK        = [      36]
  Gl        = [     0.3]
```

NLIST has the module name as its argument, and the parameter values of the module are displayed. When "-ALL" is set as the argument, the parameter values of all modules are shown, as follows:

```
[]SATELLITE[]~tom/rose:[64]% nlist("-ALL") ↩

Parameter List

Module name : HH
  Cm        = [     1.2]
  mNa0      = [ 0.05293]
  GNa       = [     120]
```

```
  GK        = [      36]
  Gl        = [     0.3]

Module name : G
  GL        = [       5]
```

Change of the delay

We can change the delay by the **NDELAY** command. The format of **NDELAY** is shown in the following:

Description) `ndelay( mdl, var, dt [, init ] )`
Arguments)
1. `mdl` : Module name
2. `var` : Internal variable's name
3. `dt` : Delay time
2. `init` : Initial value of output

The delay of the internal variable `VOP` of a module with the name "`G`" is changed by the following:

```
[]SATELLITE[]~tom/rose:[65]% ndelay(G,VOP,0.25) ↩
```

If the delay is added to the electrical/chemical synapse module, it is impossible to use the integration with adaptive calculation steps, which is the default of integration in NCS. Therefore, we have to choose another integration algorithm by **NINTEG** command.

The delay condition can be displayed by setting "`D`" as the argument of the **NSCLIST** command as follows:

```
[]SATELLITE[]~tom/rose:[66]% nsclist(D) ↩

DELAY

DELAY INFORMATION
 Data No.,       Input Name,     Delay Time,  Initial Output
   1             G(     VOP)        0.25           0
```

Selection of the numerical integration algorithm

The algorithm with adaptive calculation steps is used for numerical integration. NCS provides also Runge-Kutta and Euler methods. They can be used by the **NINTEG** command . The format is shown in the following:

Description) `ninteg( type [, mcell, relerr ] )`
Arguments)
1. `type` : Integration algorithm
   `F` — With adaptive calculation steps
   `R` — Runge-Kutta method
   `E` — Euler method
2. `mcell` : Maximum number of cells
3. `relerr` : Relative accuracy of integration

If the delay condition is added to the electrical/chemical synapse module, it is impossible to use the integration with adaptive calculation steps, which is the default of integration in NCS. Therefore, we have to choose another integration algorithm in this case, that is, Runge-Kutta or Euler.

```
[]SATELLITE[]~tom/rose:[67]% ninteg( R ) ↩
```

7.3.5 Execution of simulation

The simulation is executed by the **NCAL** command, after the simulation conditions are set.

```
[]SATELLITE[]~tom/rose:[11]% ncal() ↩
```

The following message is displayed when **NCAL** is executed:

```
## NCS Ver.6.8.3 SIMULATION PROGRAM on Sun ##
>>NOW CALCULATING...WAIT FOR A TIME, PLEASE!! <<   0.0% done.
```

`0.0%` stands for the percentage of the completed calculation. If it reaches 100%, the following message is displayed:

```
## NCS Ver.6.8.3 SIMULATION PROGRAM on Sun ##
>>THE CALCULATION HAS FINISHED.............!! << 100.0% done.
[]SATELLITE[]~tom/rose:[12]%
```

The simulation finished and the shell is waiting for another command.

7.3.6 Use of batch file

The above procedure can be described in a batch file. We can execute it by using the **INLINE** command:

`inline("`*batch_file_name*`")`

The example of the batch file for the simulation using the model file `hhmodel.mdl` is shown in List 2. When the name of this file is set to be "`hhmodel.sl`", the execution of the simulation can be performed as follows:

```
[]SATELLITE[]~tom/rose:[13]% inline("hhmodel.sl") ↩
```

```
 1  series V, Iin, INa0;

 2  nassign("hhmodel");                  # assign model file
 3  npp();                               # run the preprosessor
 4  nlink("-O2");                        # making simulation program

 5  ntime(10,0.001,0.01,1);              # set simulation time
 6  nstim("HH",0,"P",1,0,100,3,999);     # set external input variable
 7  nout(Iin,"HH",0,2);                  # set output variable
 8  nout(V,"HH",0,1);
 9  nout(INa0,"HH",0,3, "INa");
10  ninteg("R");                         # set integral method

11  ncal();                              # run simulation program
```

List 2: Example of the simulation batch file.

7.3.7 Display and analysis of simulation results

The calculation results are stored in the buffers specified by the **NOUT** command. The other system modules of SATELLITE can carry out the graphical representation and analysis.

For example, the simulation results from `hhmodel.sl` are displayed as a graph using the system module GPM (see Chapter 4), as follows:

```
[]SATELLITE[]~tom/rose:[14]% wopen(1,"A4",0,0) ↩
[]SATELLITE[]~tom/rose:[15]% graph(V,"T",0,0,0,0,0) ↩
[]SATELLITE[]~tom/rose:[16]% axis(1,1,"XY","XY",3.5,0,0,0,0,0) ↩
```

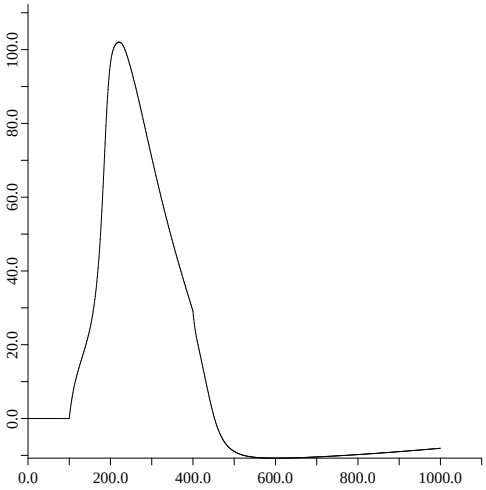


Figure 7.9: Example of a simulation result.