GNU MDK

GNU MIX Development Kit
Edition 1.2.11, for GNU MDK Version 1.2.11
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This manual is for GNU MDK (version 1.2.11, October, 2020), a set of utilities for developing programs using Donald Knuth's MIX mythical computer and MIXAL, its assembly language.

Short Contents

Table of Contents

Introduction

In his book series *The Art of Computer Programming* (published by Addison Wesley), D. Knuth uses an imaginary computer, the MIX, and its associated machine-code and assembly languages to illustrate the concepts and algorithms as they are presented.

The MIX's architecture is a simplified version of those found in real CISC CPUs, and the MIX assembly language (MIXAL) provides a set of primitives that will be very familiar to any person with a minimum experience in assembly programming. The MIX/MIXAL definition is powerful and complete enough to provide a virtual development platform for writing quite complex programs, and close enough to real computers to be worth using when learning programming techniques. At any rate, if you want to learn or improve your programming skills, a MIX development environment would come in handy.

The MDK package aims at providing such virtual development environment on a GNU box. Thus, MDK offers you a set of utilities to simulate the MIX computer and to write, compile, run and debug MIXAL programs. As of version 1.2.11, MDK includes the following programs:

`mixasm`
: MIXAL assembler. Assembler which translates MIXAL source files into programs that can be run (and debugged) by `mixvm`, `mixguile` or `gmixvm`.

`mixvm`
: MIX virtual machine. Emulation of the MIX computer with a CLI.

`gmixvm`
: A GTK+ GUI for the MIX virtual machine. Provides all of `mixvm` functionality accessible through a graphical interface.

`mixguile`
: A Guile shell, with an embedded MIX virtual machine and built-in commands to manipulate it using Scheme.

`mixal-mode.el`
: An Emacs major mode for MIXAL source files editing, providing syntax highlighting, documentation lookup and invocation of `mixvm` within Emacs.

`mixvm.el`
: This elisp program allows running `mixvm` inside an Emacs GUD buffer, providing concurrent edition and debugging of MIXAL programs.

`mixvm` and `gmixvm` implement a simulator of the MIX computer, giving you a virtual machine for executing and debugging MIX programs. These binary programs could be written by hand, but it is easier to produce them compiling MIXAL source files, using the MIXAL assembler `mixasm`. On the other hand, `mixguile` offers you the possibility of manipulating a MIX virtual machine through a set of Scheme functions, so that you can use this programming language to interact with the virtual machine. In addition, `mixvm` and `gmixvm` are also able to interpret Scheme scripts (using an embedded Guile interpreter), that is, you can use Scheme as an extension language to add new functionalities to these programs.

This manual gives you a tutorial of MIX and MIXAL, and a thorough description of the use of the MDK utilities.

Acknowledgements

Many people have further contributed to MDK by reporting problems, suggesting various improvements, or submitting actual code. Here is a list of these people. Please, help me keep it complete and exempt of errors.

- Philip Ellis King provided MIXAL test programs pinpointing bugs in the first MDK release, and useful discussions as well. Philip has also contributed with the Emacs port of `mixvm` and influenced the `gmixvm` GUI design with insightful comments and prototypes.
- Aleix Conchillo has been following MDK's development for many years, indefatigably chasing and fixing bugs, and suggesting many improvements. He's also the original author of the Fink and Macports ports.
- Pieter E J Pareit is the author of the Emacs MIXAL mode, and has also contributed many bug fixes.
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- Eric S. Raymond contributed the documentation file `MIX.DOC` and the samples `elevator.mixal` and `mistery.mixal` from his MIXAL package.
- Nelson H. F. Beebe has tested MDK in a lot of Unix platforms, suggesting portability enhancements to the source code.
- Ryan Schmidt, Agustin Navarro, Ying-Chieh Liao, Adrian Bunk, Baruch Even, and Ronald Cole ported MDK to different platforms, and created and/or maintain packages for it.
- Jason Uhlenkott, Andrew Hood, Radu Butnaru, Ruslan Batdalov, WeiZheng, Sascha Wilde, Michael Vernov and Xiaofeng Zhao reported bugs and suggested fixes to them.
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- Christoph von Nathusius, Stephen Ramsay and Johan Swanljung tested MDK on different platforms, and helped fixing the configuration process in them.
- Richard Stallman suggested various improvements to the documentation and has always kept an eye on each MDK release.
- MDK was inspired by Darius Bacon's MIXAL program (`http://www.accesscom.com/~darius/`).

1 Installing MDK

1.1 Download the source tarball

GNU MDK is distributed as a source tarball available for download in the following URLs:

- `ftp://ftp.gnu.org/pub/gnu/mdk`
- GNU mirrors (`http://www.gnu.org/prep/ftp.html`)

The above sites contain the latest stable releases of MDK. The development branch is available as a Git (`http://git-scm.com/`) repository located at[1]

- `git://git.savannah.gnu.org/mdk.git`

After you have downloaded the source tarball, unpack it in a directory of your choice using the command:

```
tar xfvz mdk-X.Y.tar.gz
```

where *X.Y* stands for the downloaded version (the current stable release being version 1.2.11).

1.2 Requirements

In order to build and install MDK, you will need the following libraries installed in your system:

- GLIB 2.16.0 (`http://www.gtk.org`) (required)
- GNU Flex 2.5 (`http://www.gnu.org/software/flex/flex.html`) (required)
- GTK 2.16.0 (`http://www.gtk.org`) (optional)
- Libglade 2.6.0 (`http://ftp.gnome.org/pub/GNOME/sources/libglade/2.6/`) (optional)
- GNU Readline (`http://cnswww.cns.cwru.edu/php/chet/readline/rltop.html`) (optional)
- GNU Libguile 2.0 (`http://www.gnu.org/software/guile`) (optional)

If present, readline and history are used to provide command completion and history management to the command line MIX virtual machine, `mixvm`. GTK+ and libglade are needed if you want to build the graphical interface to the MIX virtual machine, `gmixvm`. Finally, if libguile is found, the MDK utilities will be compiled with Guile support and will be extensible using Scheme.

Please note: you need both the libraries *and* the headers; this means both the library package and the `-dev` package if you do not compile your libraries yourself (ex: installing `libgtk2.0-0` and `libgtk2.0-0-dev` on Debian).

[1] See MDK's Git page (`https://savannah.gnu.org/git/?group=mdk`) for more information on using the unstable source tree. Note, however, that the rest of this manual is about the *stable* release.

1.3 Basic installation

MDK uses GNU Autoconf and Automake tools, and, therefore, should be built and installed without hassle using the following commands inside the source directory:

```
./configure
make
make install
```

where the last one must be run as root.

The first command, `configure`, will setup the makefiles for your system. In particular, `configure` will look for GTK+ and libglade, and, if they are present, will generate the appropriate makefiles for building the `gmixvm` graphical user interface. Upon completion, you should see a message with the configuration results like the following:

```
*** GNU MDK 1.2.11 has been successfully configured. ***

Type 'make' to build the following utilities:
    - mixasm (MIX assembler)
    - mixvm (MIX virtual machine, with readline support,
             with guile support)
    - gmixvm (mixvm GTK+ GUI, with guile support)
    - mixguile (the mixvm guile shell)
```

where the last lines may be missing if you lack the above mentioned libraries.

The next command, `make`, will actually build the MDK programs in the following locations:

- `mixutils/mixasm`
- `mixutils/mixvm`
- `mixgtk/gmixvm`
- `mixguile/mixguile`

You can run these programs from within their directories, but I recommend you to install them in proper locations using `make install` from a root shell.

1.4 Emacs support

MDK includes extensive support for Emacs. Upon installation, all the elisp code is installed in `PREFIX/share/mdk`, where `PREFIX` stands for your installation root directory (e.g. `/usr/local`). You can copy the elisp files to a directory that is in your load-path, or you can add the above directory to it. Assuming that the installing prefix is `/usr/local`, you can do it by adding to your `.emacs` file the following line:

```
(setq load-path (cons "/usr/local/share/mdk" load-path))
```

`MIXAL` programs can be written using Emacs and the elisp program `share/mdk/mixal-mode.el`, contributed by Pieter E. J. Pareit. It provides font locking, interactive help, compiling assistance and invocation of the `MIX` virtual machine via a new major mode called `mixal-mode`. To start `mixal-mode` automatically whenever you edit a `MIXAL` source file, add the following lines to your `.emacs` file:

```
(autoload 'mixal-mode "mixal-mode" t)
```

```
(add-to-list 'auto-mode-alist '("\\.mixal\\'" . mixal-mode))
```

In addition, `mixvm` can be run within an Emacs GUD buffer using the elisp program `share/mdk/mixvm.el`, contributed by Philip E. King. `mixvm.el` provides an interface between MDK's `mixvm` and Emacs, via GUD. Place this file in your load-path, optionally adding the following line to your `.emacs` file:

```
(autoload 'mixvm "mixvm" "mixvm/gud interaction" t)
```

1.5 Special configure flags

You can fine-tune the configuration process using the following switches with configure:

`--enable-gui[=yes|no]` [User Option]
`--disable-gui` [User Option]

Enables/disables the build of the MIX virtual machine GUI (`gmixvm`). If the required libraries are missing (see Section 1.2 [Requirements], page 5) the configure script with automatically disable this feature.

`--with-guile[=yes|no]` [User Option]
`--without-guile` [User Option]

Enables/disables the Guile support for `mixvm` and `gmixvm`, and the build of `mixguile`. If the required libraries are missing (see Section 1.2 [Requirements], page 5) the configure script with automatically disable this feature.

`--with-readline[=yes|no]` [User Option]
`--without-readline` [User Option]

Enables/disables the GNU Readline support for `mixvm`. If the required libraries are missing (see Section 1.2 [Requirements], page 5) the configure script with automatically disable this feature.

For additional, boilerplate configure options, see the `INSTALL` file, or run

```
configure --help
```

1.6 Supported platforms

GNU MDK has been tested in the following platforms:

- Debian GNU/Linux 2.2, 2.3, 3.0, 3.1, 3.2, 4.0, 5.0, 6.0, sid
- Redhat GNU/Linux 8.0 (Ronald Cole), 7.0 (Agustin Navarro), 6.2 (Roberto Ferrero)
- Mandrake 8.0 (Agustin Navarro)
- FreeBSD 4.2, 4.3, 4.4, 4.5 (Ying-Chieh Liao), 5.2
- Solaris 2.8/gcc 2.95.3 (Stephen Ramsay)
- MS Windows 98 SE/Cygwin 1.1.8-2 (Christoph von Nathusius)[2]
- Mac OS X 10.1.2 (Johan Swanljung), Mac OS X 10.4.x, 10.5 (Darwin Port by Aleix Conchillo).

[2] Caveats: Christoph has only tested `mixvm` and `mixasm` on this platform, using `gcc` 2.95.3-2, `GLIB` 1.2.10 and `GNU readline` 4.1-2. He has reported missing history functionalities on a first try. If you find problems with history/readline functionality, please try a newer/manually installed readline version.

- AMD Athlon, GNU/Linux version 2.4.2-2smp (Red Hat 7.1 (Seawolf)) (N. H. F. Beebe)
- Apple PowerPC G3, GNU/Linux 2.2.18-4hpmac (Red Hat Linux/PPC 2000 Q4) (N. H. F. Beebe)
- DEC Alpha, GNU/Linux 2.2.19-6.2.1 (Red Hat 6.2) (N. H. F. Beebe)
- Compaq/DEC Alpha OSF/1 4.0F [ONLY after adding rsync's snprintf() implementation] (N. H. F. Beebe)
- IBM PowerPC AIX 4.2 (N. H. F. Beebe)
- Intel Pentium III, GNU/Linux 2.4.9-31smp (Red Hat 7.2 (Enigma)) (N. H. F. Beebe)
- SGI Origin 200, IRIX 6.5 (N. H. F. Beebe)
- Sun SPARC, GNU/Linux 2.2.19-6.2.1 (Red Hat 6.2) (N. H. F. Beebe)
- Sun SPARC, Solaris 2.8 (N. H. F. Beebe)

MDK will probably work on any GNU/Linux or BSD platform. If you try it in a platform not listed above, please send a mail to the author.

2 MIX and MIXAL tutorial

In the book series *The Art of Computer Programming*, by D. Knuth, a virtual computer, the MIX, is used by the author (together with the set of binary instructions that the virtual CPU accepts) to illustrate the algorithms and skills that every serious programmer should master. Like any other real computer, there is a symbolic assembler language that can be used to program the MIX: the MIX assembly language, or MIXAL for short. In the following subsections you will find a tutorial on these topics, which will teach you the basics of the MIX architecture and how to program a MIX computer using MIXAL.

2.1 The MIX computer

In this section, you will find a description of the MIX computer, its components and instruction set.

2.1.1 MIX architecture

The basic information storage unit in the MIX computer is the *byte*, which stores positive values in the range 0-63 . Note that a MIX byte can be then represented as 6 bits, instead of the common 8 bits for a *regular* byte. Unless otherwise stated, we shall use the word *byte* to refer to a MIX 6-bit byte.

A MIX *word* is defined as a set of 5 bytes plus a sign. The bytes within a word are numbered from 1 to 5, being byte number one the most significant one. The sign is denoted by index 0. Graphically,

```
 -----------------------------------------------
|   0   |   1   |   2   |   3   |   4   |   5   |
 -----------------------------------------------
|  +/-  | byte  | byte  | byte  | byte  | byte  |
 -----------------------------------------------
```

Sample MIX words are '`- 12 00 11 01 63`' and '`+ 12 11 34 43 00`'.

You can refer to subfields within a word using a *field specification* or *fspec* of the form "(L:R)", where L denotes the first byte, and R the last byte of the subfield. When L is zero, the subfield includes the word's sign. An fspec can also be represented as a single value `F`, given by `F = 8*L + R` (thus the fspec '`(1:3)`', denoting the first three bytes of a word, is represented by the integer 11).

The MIX computer stores information in *registers*, that can store either a word or two bytes and sign (see below), and *memory cells*, each one containing a word. Specifically, the MIX computer has 4000 memory cells with addresses 0 to 3999 (i.e., two bytes are enough to address a memory cell) and the following registers:

`rA` A register. General purpose register holding a word. Usually its contents serves as the operand of arithmetic and storing instructions.

`rX` X register. General purpose register holding a word. Often it acts as an extension or a replacement of '`rA`'.

`rJ` J (jump) register. This register stores positive two-byte values, usually representing a jump address.

`rI1`, `rI2`, `rI3`, `rI4`, `rI5`, `rI6`
: Index registers. These six registers can store a signed two-byte value. Their contents are used as indexing values for the computation of effective memory addresses.

In addition, the MIX computer contains:

- An *overflow toggle* (a single bit with values *on* or *off*). In this manual, this toggle is denoted OV.
- A *comparison indicator* (having three values: *EQUAL*, *GREATER* or *LESS*). In this manual, this indicator is denoted CM, and its possible values are abbreviated as *E*, *G* and *L*.
- Input-output block devices. Each device is labelled as `un`, where `n` runs from 0 to 20. In Knuth's definition, `u0` through `u7` are magnetic tape units, `u8` through `15` are disks and drums, `u16` is a card reader, `u17` is a card writer, `u18` is a line printer and, `u19` is a typewriter terminal, and `u20`, a paper tape. Our implementation maps these devices to disk files, except for `u19`, which represents the standard output.

As noted above, the MIX computer communicates with the external world by a set of input-output devices which can be "connected" to it. The computer interchanges information using blocks of words whose length depends on the device at hand (see Section 6.3 [Devices], page 57). These words are interpreted by the device either as binary information (for devices 0-16), or as representing printable characters (devices 17-20). In the last case, each MIX byte is mapped onto a character according to the following table:

00		01	A	02	B	03	C
04	D	05	E	06	F	07	G
08	H	09	I	10	~	11	J
12	K	13	L	14	M	15	N
16	O	17	P	18	Q	19	R
20	[	21	#	22	S	23	T
24	U	25	V	26	W	27	X
28	Y	29	Z	30	0	31	1
32	2	33	3	34	4	35	5
36	6	37	7	38	8	39	9
40	.	41	,	42	(	43	)
44	+	45	-	46	*	47	/
48	=	49	$	50	<	51	>
52	@	53	;	54	:	55	'

The value 0 represents a whitespace. The characters `~`, `[` and `#` correspond to symbols not representable as ASCII characters (uppercase delta, sigma and gamma, respectively), and byte values 56-63 have no associated character.

Finally, the MIX computer features a virtual CPU which controls the above components, and which is able to execute a rich set of instructions (constituting its machine language, similar to those commonly found in real CPUs), including arithmetic, logical, storing, comparison and jump instructions. Being a typical von Neumann computer, the MIX CPU fetches binary instructions from memory sequentially (unless a jump instruction is found), and stores the address of the next instruction to be executed in an internal register called *location counter* (also known as program counter in other architectures).

The next section, See Section 2.1.2 [MIX instruction set], page 11, gives a complete description of the available MIX binary instructions.

2.1.2 MIX instruction set

The following subsections fully describe the instruction set of the MIX computer. We begin with a description of the structure of binary instructions and the notation used to refer to their subfields. The remaining subsections are devoted to describing the actual instructions available to the MIX programmer.

2.1.2.1 Instruction structure

MIX *instructions* are codified as words with the following subfield structure:

Subfield	*fspec*	*Description*
ADDRESS	(0:2)	The first two bytes plus sign are the *address* field. Combined with the INDEX field, denotes the memory address to be used by the instruction.
INDEX	(3:3)	The third byte is the *index*, normally used for indexing the address[1].
MOD	(4:4)	Byte four is used either as an operation code modifier or as a field specification.
OPCODE	(5:5)	The last (least significant) byte in the word denotes the operation code.

or, graphically,

```
 ------------------------------------------------
|   0   |   1   |   2   |   3   |   4   |   5    |
 ------------------------------------------------
|        ADDRESS        | INDEX |  MOD  | OPCODE |
 ------------------------------------------------
```

For a given instruction, '`M`' stands for the memory address obtained after indexing the ADDRESS subfield (using its INDEX byte), and '`V`' is the contents of the subfield indicated by MOD of the memory cell with address '`M`'. For instance, suppose that we have the following contents of MIX registers and memory cells:

```
[rI2] = + 00 63
[31] = - 10 11 00 11 22
```

where '`[n]`' denotes the contents of the nth memory cell and '`[rI2]`' the contents of register '`rI2`'[2]. Let us consider the binary instruction '`I = - 00 32 02 11 10`'. For this instruction we have:

```
ADDRESS = - 00 32 = -32
INDEX = 02 = 2
MOD = 11 = (1:3)
OPCODE = 10
```

---

[1] The actual memory address the instruction refers to, is obtained by adding to ADDRESS the value of the '`rI`' register denoted by INDEX.

[2] In general, '`[X]`' will denote the contents of entity '`X`'; thus, by definition, '`V = [M](MOD)`'.

```
M = ADDRESS + [rI2] = -32 + 63 = 31
V = [M](MOD) = (- 10 11 00 11 22)(1:3) = + 00 00 10 11 00
```

Note that, when computing 'V' using a word and an fspec, we apply a left padding to the bytes selected by 'MOD' to obtain a complete word as the result.

In the following subsections, we will assign to each MIX instruction a mnemonic, or symbolic name. For instance, the mnemonic of 'OPCODE' 10 is 'LD2'. Thus we can rewrite the above instruction as

```
LD2  -32,2(1:3)
```

or, for a generic instruction:

```
MNEMONIC  ADDRESS,INDEX(MOD)
```

Some instructions are identified by both the OPCODE and the MOD fields. In these cases, the MOD will not appear in the above symbolic representation. Also when ADDRESS or INDEX are zero, they can be omitted. Finally, MOD defaults to (0:5) (meaning the whole word).

2.1.2.2 Loading operators

The following instructions are used to load memory contents into a register.

`LDA` Put in rA the contents of cell no. M. OPCODE = 8, MOD = fspec. `rA <- V`.

`LDX` Put in rX the contents of cell no. M. OPCODE = 15, MOD = fspec. `rX <- V`.

`LDi` Put in rIi the contents of cell no. M. OPCODE = 8 + i, MOD = fspec. `rIi <- V`.

`LDAN` Put in rA the contents of cell no. M, with opposite sign. OPCODE = 16, MOD = fspec. `rA <- -V`.

`LDXN` Put in rX the contents of cell no. M, with opposite sign. OPCODE = 23, MOD = fspec. `rX <- -V`.

`LDiN` Put in rIi the contents of cell no. M, with opposite sign. OPCODE = 16 + i, MOD = fspec. `rIi <- -V`.

In all the above load instructions the 'MOD' field selects the bytes of the memory cell with address 'M' which are loaded into the requisite register (indicated by the 'OPCODE'). For instance, the word '+ 00 13 01 27 11' represents the instruction

```
LD3    13,1(3:3)
 ^      ^ ^  ^
 |      | |  |
 |      | |   --- MOD = 27 = 3*8 + 3
 |      |  --- INDEX = 1
 |       --- ADDRESS = 00 13
  --- OPCODE = 11
```

Let us suppose that, prior to this instruction execution, the state of the MIX computer is the following:

```
[rI1] = - 00 01
[rI3] = + 24 12
[12] = - 01 02 03 04 05
```

As, in this case, '`M = 13 + [rI1] = 12`', we have

```
V = [M](3:3) = (- 01 02 03 04 05)(3:3)
  = + 00 00 00 00 03
```

(note that the specified subfield is left-padded with null bytes to complete a word). Hence, the MIX state, after the instruction execution, will be

```
[rI1] = - 00 01
[rI3] = + 00 03
[12] = - 01 02 03 04 05
```

To further illustrate loading operators, the following table shows the contents of '`rX`' after different '`LDX`' instructions:

'`LDX 12(0:0) [rX] = - 00 00 00 00 00`'
'`LDX 12(0:1) [rX] = - 00 00 00 00 01`'
'`LDX 12(3:5) [rX] = + 00 00 03 04 05`'
'`LDX 12(3:4) [rX] = + 00 00 00 03 04`'
'`LDX 12(0:5) [rX] = - 01 02 03 04 05`'

2.1.2.3 Storing operators

The following instructions are the inverse of the load operations: they are used to store a subfield of a register into a memory location. Here, MOD represents the subfield of the memory cell that is to be overwritten with bytes from a register. These bytes are taken beginning by the rightmost side of the register.

`STA` Store rA. OPCODE = 24, MOD = fspec. `V <- rA`.

`STX` Store rX. OPCODE = 31, MOD = fspec. `V <- rX`.

`STi` Store rIi. OPCODE = 24 + i, MOD = fspec. `V <- rIi`.

`STJ` Store rJ. OPCODE = 32, MOD = fspec. `V <- rJ`.

`STZ` Store zero. OPCODE = 33, MOD = fspec. `V <- 0`.

By way of example, consider the instruction '`STA 1200(2:3)`'. It causes the MIX to fetch bytes no. 4 and 5 of register A and copy them to bytes 2 and 3 of memory cell no. 1200 (remember that, for these instructions, MOD specifies a subfield of *the memory address*). The other bytes of the memory cell retain their values. Thus, if prior to the instruction execution we have

```
[1200] = - 20 21 22 23 24
[rA] = + 01 02 03 04 05
```

we will end up with

```
[1200] = - 20 04 05 23 24
[rA] = + 01 02 03 04 05
```

As a second example, '`ST2 1000(0)`' will set the sign of '`[1000]`' to that of '`[rI2]`'.

2.1.2.4 Arithmetic operators

The following instructions perform arithmetic operations between rA and rX register and memory contents.

`ADD` Add and set OV if overflow. OPCODE = 1, MOD = fspec. `rA <- rA +V`.

`SUB` Sub and set OV if overflow. OPCODE = 2, MOD = fspec. `rA <- rA - V`.

`MUL` Multiply V times rA and store the 10-bytes product in rAX. OPCODE = 3, MOD = fspec. `rAX <- rA x V`.

`DIV` rAX is considered a 10-bytes number, and it is divided by V. OPCODE = 4, MOD = fspec. `rA <- rAX / V`, `rX <-` reminder.

In all the above instructions, '`[rA]`' is one of the operands of the binary arithmetic operation, the other being '`V`' (that is, the specified subfield of the memory cell with address '`M`'), padded with zero bytes on its left-side to complete a word. In multiplication and division, the register '`X`' comes into play as a right-extension of the register '`A`', so that we are able to handle 10-byte numbers whose more significant bytes are those of '`rA`' (the sign of this 10-byte number is that of '`rA`': '`rX`''s sign is ignored).

Addition and subtraction of MIX words can give rise to overflows, since the result is stored in a register with room to only 5 bytes (plus sign). When this occurs, the operation result modulo 1,073,741,823 (the maximum value storable in a MIX word) is stored in '`rA`', and the overflow toggle is set to TRUE.

2.1.2.5 Address transfer operators

In these instructions, '`M`' (the address of the instruction after indexing) is used as a number instead of as the address of a memory cell. Consequently, '`M`' can have any valid word value (i.e., it's not limited to the 0-3999 range of a memory address).

`ENTA` Enter '`M`' in [rA]. OPCODE = 48, MOD = 2. `rA <- M`.

`ENTX` Enter '`M`' in [rX]. OPCODE = 55, MOD = 2. `rX <- M`.

`ENTi` Enter '`M`' in [rIi]. OPCODE = 48 + i, MOD = 2. `rIi <- M`.

`ENNA` Enter '`-M`' in [rA]. OPCODE = 48, MOD = 3. `rA <- -M`.

`ENNX` Enter '`-M`' in [rX]. OPCODE = 55, MOD = 3. `rX <- -M`.

`ENNi` Enter '`-M`' in [rIi]. OPCODE = 48 + i, MOD = 3. `rIi <- -M`.

`INCA` Increase [rA] by '`M`'. OPCODE = 48, MOD = 0. `rA <- rA + M`.

`INCX` Increase [rX] by '`M`'. OPCODE = 55, MOD = 0. `rX <- rX + M`.

`INCi` Increase [rIi] by '`M`'. OPCODE = 48 + i, MOD = 0. `rIi <- rIi + M`.

`DECA` Decrease [rA] by '`M`'. OPCODE = 48, MOD = 1. `rA <- rA - M`.

`DECX` Decrease [rX] by '`M`'. OPCODE = 55, MOD = 1. `rX <- rX - M`.

`DECi` Decrease [rIi] by '`M`'. OPCODE = 48 + i, MaOD = 0. `rIi <- rIi - M`.

In the above instructions, the subfield '`ADDRESS`' acts as an immediate (indexed) operand, and allow us to set directly the contents of the MIX registers without an indirection to the memory cells (in a real CPU this would mean that they are faster that the previously discussed instructions, whose operands are fetched from memory). So, if you want to store in '`rA`' the value -2000 (- 00 00 00 31 16), you can use the binary instruction + 31 16 00 03 48, or, symbolically,

```
ENNA 2000
```

Used in conjunction with the store operations ('STA', 'STX', etc.), these instructions also allow you to set memory cells contents to concrete values.

Note that in these address transfer operators, the 'MOD' field is not a subfield specificator, but serves to define (together with 'OPCODE') the concrete operation to be performed.

2.1.2.6 Comparison operators

So far, we have learned how to move values around between the MIX registers and its memory cells, and also how to perform arithmetic operations using these values. But, in order to write non-trivial programs, other functionalities are needed. One of the most common is the ability to compare two values, which, combined with jumps, will allow the execution of conditional statements. The following instructions compare the value of a register with 'V', and set the CM indicator to the result of the comparison (i.e. to 'E', 'G' or 'L', equal, greater or lesser respectively).

`CMPA` Compare [rA] with V. OPCODE = 56, MOD = fspec.

`CMPX` Compare [rX] with V. OPCODE = 63, MOD = fspec.

`CMPi` Compare [rIi] with V. OPCODE = 56 + i, MOD = fspec.

As explained above, these instructions modify the value of the MIX comparison indicator; but maybe you are asking yourself how do you use this value: enter jump operators, in the next subsection.

2.1.2.7 Jump operators

The MIX computer has an internal register, called the *location counter*, which stores the address of the next instruction to be fetched and executed by the virtual CPU. You cannot directly modify the contents of this internal register with a load instruction: after fetching the current instruction from memory, it is automatically increased in one unit by the MIX. However, there is a set of instructions (which we call jump instructions) which can alter the contents of the location counter provided some condition is met. When this occurs, the value of the next instruction address that would have been fetched in the absence of the jump is stored in 'rJ' (except for JSJ), and the location counter is set to the value of 'M' (so that the next instruction is fetched from this new address). Later on, you can return to the point when the jump occurred reading the address stored in 'rJ'.

The MIX computer provides the following jump instructions: With these instructions you force a jump to the specified address. Use 'JSJ' if you do not care about the return address.

`JMP` Unconditional jump. OPCODE = 39, MOD = 0.

`JSJ` Unconditional jump, but rJ is not modified. OPCODE = 39, MOD = 1.

These instructions check the overflow toggle to decide whether to jump or not.

`JOV` Jump if OV is set (and turn it off). OPCODE = 39, MOD = 2.

`JNOV` Jump if OV is not set (and turn it off). OPCODE = 39, MOD = 3.

In the following instructions, the jump is conditioned to the contents of the comparison flag:

`JL` Jump if `[CM] = L`. OPCODE = 39, MOD = 4.

`JE` Jump if `[CM]` `=` `E`. OPCODE = 39, MOD = 5.

`JG` Jump if `[CM]` `=` `G`. OPCODE = 39, MOD = 6.

`JGE` Jump if `[CM]` does not equal `L`. OPCODE = 39, MOD = 7.

`JNE` Jump if `[CM]` does not equal `E`. OPCODE = 39, MOD = 8.

`JLE` Jump if `[CM]` does not equal `G`. OPCODE = 39, MOD = 9.

You can also jump conditioned to the value stored in the MIX registers, using the following instructions:

`JAN`
`JAZ`
`JAP`
`JANN`
`JANZ`
`JANP`
`JAE`
`JAO` Jump if the content of rA is, respectively, negative, zero, positive, non-negative, non-zero, non-positive, even or odd. OPCODE = 40, MOD = 0, 1, 2, 3, 4, 5, 6, 7.

`JXN`
`JXZ`
`JXP`
`JXNN`
`JXNZ`
`JXNP`
`JXE`
`JXO` Jump if the content of rX is, respectively, negative, zero, positive, non-negative, non-zero, non-positive, even or odd. OPCODE = 47, MOD = 0, 1, 2, 3, 4, 5, 6, 7.

`JiN`
`JiZ`
`JiP`
`JiNN`
`JiNZ`
`JiNP` Jump if the content of rIi is, respectively, negative, zero, positive, non-negative, non-zero or non-positive. OPCODE = 40 `+` i, MOD = 0, 1, 2, 3, 4, 5.

2.1.2.8 Input-output operators

As explained in previous sections (see Section 2.1.1 [MIX architecture], page 9), the MIX computer can interact with a series of block devices. To that end, you have at your disposal the following instructions:

`IN` Transfer a block of words from the specified unit to memory, starting at address M. OPCODE = 36, MOD = I/O unit.

`OUT` Transfer a block of words from memory (starting at address M) to the specified unit. OPCODE = 37, MOD = I/O unit.

`IOC` Perform a control operation (given by M) on the specified unit. OPCODE = 35, MOD = I/O unit.

`JRED` Jump to M if the specified unit is ready. OPCODE = 38, MOD = I/O unit.

`JBUS` Jump to M if the specified unit is busy. OPCODE = 34, MOD = I/O unit.

In all the above instructions, the '`MOD`' subfile must be in the range 0-20, since it denotes the operation's target device. The '`IOC`' instruction makes sense for magnetic tape devices ('`MOD`' = 0-7): it shifts the read/write pointer by the number of blocks given by '`M`' (if it equals zero, the tape is rewound), paper tape devices ('`MOD`' = 20): '`M`' should be 0, the tape is rewound, and disk/drum devices ('`MOD`' = 8-15): it moves the read/write pointer to the block specified in rX and '`M`' should be 0[3].

2.1.2.9 Conversion operators

The following instructions convert between numerical values and their character representations.

`NUM` Convert rAX, assumed to contain a character representation of a number, to its numerical value and store it in rA. OPCODE = 5, MOD = 0.

`CHAR` Convert the number stored in rA to a character representation and store it in rAX. OPCODE = 5, MOD = 1.

Digits are represented in MIX by the range of values 30-39 (digits 0-9). Thus, if the contents of '`rA`' and '`rX`' are, for instance,

```
[rA] = + 30 30 31 32 33
[rX] = + 31 35 39 30 34
```

the represented number is 0012315904, and '`NUM`' will store this value in '`rA`' (i.e., we end up with '`[rA]`' = `+` 0 46 62 52 0 = 12315904).

If any byte in '`rA`' or '`rB`' does not belong to the range 30-39, it is interpreted by '`NUM`' as the digit obtained by taking its value modulo 10. E.g. values 0, 10, 20, 30, 40, 50, 60 all represent the digit 0; 2, 12, 22, etc. represent the digit 2, and so on. For instance, the number 0012315904 mentioned above could also be represented as

```
[rA] = + 10 40 31 52 23
[rX] = + 11 35 49 20 54
```

'`CHAR`' performs the inverse operation, using only the values 30 to 39 for representing digits 0-9.

2.1.2.10 Shift operators

The following instructions perform byte-wise shifts of the contents of '`rA`' and '`rX`'.

[3] In Knuth's original definition, there are other control operations available, but they do not make sense when implementing the devices as disk files (as we do in MDK simulator). For the same reason, MDK devices are always ready, since all input-output operations are performed using synchronous system calls.

`SLA`
`SRA`
`SLAX`
`SRAX`
`SLC`
`SRC` Shift rA or rAX left, right, or rAX circularly (see example below) left or right. M specifies the number of bytes to be shifted. OPCODE = 6, MOD = 0, 1, 2, 3, 4, 5.

The following instructions perform binary shifts of the contents of '`rA`' and '`rX`'.

`SLB`
`SRB` Shift rAX left or right binary. M specifies the number of binary places to shift. OPCODE = 6, MOD = 6, 7

If we begin with, say, '`[rA]`' = - 01 02 03 04 05, we would have the following modifications to '`rA`' contents when performing the instructions on the left column:

SLA 2	[rA] = - 03 04 05 00 00
SLA 6	[rA] = - 00 00 00 00 00
SRA 1	[rA] = - 00 01 02 03 04

Note that the sign is unaffected by shift operations. On the other hand, '`SLC`', '`SRC`', '`SLAX`', '`SRAX`', '`SLB`' and '`SRB`' treat '`rA`' and '`rX`' as a single 10-bytes register (ignoring again the signs). For instance, if we begin with '`[rA]`' = + 01 02 03 04 05 and '`[rX]`' = - 06 07 08 09 10, we would have:

SLC 3	[rA] = + 04 05 06 07 08	[rX] = - 09 10 01 02 03
SLAX 3	[rA] = + 04 05 06 07 08	[rX] = - 09 10 00 00 00
SRC 4	[rA] = + 07 08 09 10 01	[rX] = - 02 03 04 05 06
SRAX 4	[rA] = + 00 00 00 00 01	[rX] = - 02 03 04 05 06
SLB 1	[rA] = + 02 04 06 08 10	[rX] = - 12 14 16 18 20

2.1.2.11 Miscellaneous operators

Finally, we list in the following table three miscellaneous MIX instructions which do not fit in any of the previous subsections:

`MOVE` Move MOD words from M to the location stored in rI1. OPCODE = 7, MOD = no. of words.

`NOP` No operation. OPCODE = 0, MOD = 0.

`HLT` Halt. Stops instruction fetching. OPCODE = 5, MOD = 2.

The only effect of executing '`NOP`' is increasing the location counter, while '`HLT`' usually marks program termination.

2.1.2.12 Execution times

When writing MIXAL programs (or any kind of programs, for that matter), we shall often be interested in their execution time. Loosely speaking, we will be interested in the answer to the question: how long does it take a program to execute? Of course, this execution time will be a function of the input size, and the answer to our question is commonly given as the asymptotic behaviour as a function of the input size. At any rate, to compute this asymptotic behaviour, we need a measure of how long execution of a single instruction takes in our (virtual) CPU. Therefore, each MIX instruction will have an associated execution time, given in arbitrary units (in a real computer, the value of this unit will depend on the hardware configuration). When our MIX virtual machine executes programs, it will (optionally) give you the value of their execution time based upon the execution time of each single instruction.

In the following table, the execution times (in the above mentioned arbitrary units) of the MIX instructions are given.

NOP	1	ADD	2	SUB	2	MUL	10
DIV	12	NUM	10	CHAR	10	HLT	10
SLx	2	SRx	2	LDx	2	STx	2
JBUS	1	IOC	1	IN	1	OUT	1
JRED	1	Jx	1	INCx	1	DECx	1
ENTx	1	ENNx	1	CMPx	1	MOVE	1+2F

In the above table, 'F' stands for the number of blocks to be moved (given by the `FSPEC` subfield of the instruction); `SLx` and `SRx` are a short cut for the byte-shifting operations; `LDx` denote all the loading operations; `STx` are the storing operations; `Jx` stands for all the jump operations, and so on with the rest of abbreviations.

2.2 MIXAL

In the previous sections we have listed all the available MIX binary instructions. As we have shown, each instruction is represented by a word which is fetched from memory and executed by the MIX virtual CPU. As is the case with real computers, the MIX knows how to decode instructions in binary format (the so–called machine language), but a human programmer would have a tough time if she were to write her programs in machine language. Fortunately, the MIX computer can be programmed using an assembly language, MIXAL, which provides a symbolic way of writing the binary instructions understood by the imaginary MIX computer. If you have used assembler languages before, you will find MIXAL a very familiar language. MIXAL source files are translated to machine language by a MIX assembler, which produces a binary file (the actual MIX program) which can be directly loaded into the MIX memory and subsequently executed.

In this section, we describe MIXAL, the MIX assembly language. The implementation of the MIX assembler program and MIX computer simulator provided by MDK are described later on (see Chapter 3 [Getting started], page 27).

2.2.1 Basic program structure

The MIX assembler reads MIXAL files line by line, producing, when required, a binary instruction, which is associated to a predefined memory address. To keep track of the current address, the assembler maintains an internal location counter which is incremented each time an instruction is compiled. In addition to MIX instructions, you can include in MIXAL file assembly directives (or pseudoinstructions) addressed at the assembler itself (for instance, telling it where the program starts and ends, or to reposition the location counter; see below).

MIX instructions and assembler directives[4] are written in MIXAL (one per source file line) according to the following pattern:

```
[LABEL]   MNEMONIC  [OPERAND]   [COMMENT]
```

where '`OPERAND`' is of the form

```
[ADDRESS][,INDEX][(MOD)]
```

Items between square brackets are optional, and

`LABEL`
: is an alphanumeric identifier (a *symbol*) which gets the current value of the location counter, and can be used in subsequent expressions,

`MNEMONIC`
: is a literal denoting the operation code of the instruction (e.g. `LDA`, `STA`; see see Section 2.1.2 [MIX instruction set], page 11) or an assembly pseudoinstruction (e.g. `ORIG`, `EQU`),

`ADDRESS`
: is an expression evaluating to the address subfield of the instruction,

`INDEX`
: is an expression evaluating to the index subfield of the instruction, which defaults to 0 (i.e., no use of indexing) and can only be used when `ADDRESS` is present,

`MOD`
: is an expression evaluating to the mod subfield of the instruction. Its default value, when omitted, depends on `OPCODE`,

`COMMENT`
: any number of spaces after the operand mark the beginning of a comment, i.e. any text separated by white space from the operand is ignored by the assembler (note that spaces are not allowed within the '`OPERAND`' field).

Note that spaces are *not* allowed between the `ADDRESS`, `INDEX` and `MOD` fields if they are present. White space is used to separate the label, operation code and operand parts of the instruction[5].

We have already listed the mnemonics associated with each MIX instruction; sample MIXAL instructions representing MIX instructions are:

```
HERE     LDA  2000          HERE represents the current location counter
         LDX  HERE,2(1:3)   this is a comment
         JMP  1234
```

2.2.2 MIXAL directives

MIXAL instructions can be either one of the MIX machine instructions (see Section 2.1.2 [MIX instruction set], page 11) or one of the following assembly pseudoinstructions:

`ORIG`
: Sets the value of the memory address to which following instructions will be allocated after compilation.

`EQU`
: Used to define a symbol's value, e.g. `SYM EQU 2*200/3`.

`CON`
: The value of the given expression is copied directly into the current memory address.

---

[4] We shall call them, collectively, MIXAL instructions.

[5] In fact, Knuth's definition of MIXAL restricts the column number at which each of these instruction parts must start. The MIXAL assembler included in MDK, `mixasm`, does not impose such restriction.

`ALF` Takes as operand five characters, constituting the five bytes of a word which is copied directly into the current memory address.

`END` Marks the end of the program. Its operand gives the start address for program execution.

The operand of `ORIG`, `EQU`, `CON` and `END` can be any expression evaluating to a constant MIX word, i.e., either a simple MIXAL expression (composed of numbers, symbols and binary operators, see Section 2.2.3 [Expressions], page 22) or a w-expression (see Section 2.2.4 [W-expressions], page 23).

All MIXAL programs must contain an `END` directive, with a twofold end: first, it marks the end of the assembler job, and, in the second place, its (mandatory) operand indicates the start address for the compiled program (that is, the address at which the virtual MIX machine must begin fetching instructions after loading the program). It is also very common (although not mandatory) to include at least an `ORIG` directive to mark the initial value of the assembler's location counter (remember that it stores the address associated with each compiled MIX instruction). Thus, a minimal MIXAL program would be

```
          ORIG  2000    set the initial compilation address
          NOP           this instruction will be loaded at address 2000
          HLT           and this one at address 2001
          END   2000    end of program; start at address 2000
this line is not parsed by the assembler
```

The assembler will generate two binary instructions (`NOP` (+ 00 00 00 00 00) and `HLT` (+ 00 00 02 05)), which will be loaded at addresses 2000 and 2001. Execution of the program will begin at address 2000. Every MIXAL program should also include a `HLT` instruction, which will mark the end of program execution (but not of program compilation).

The `EQU` directive allows the definition of symbolic names for specific values. For instance, we could rewrite the above program as follows:

```
START     EQU   2000
          ORIG  START
          NOP
          HLT
          END   START
```

which would give rise to the same compiled code. Symbolic constants (or symbols, for short) can also be implicitly defined placing them in the `LABEL` field of a MIXAL instruction: in this case, the assembler assigns to the symbol the value of the location counter before compiling the line. Hence, a third way of writing our trivial program is

```
          ORIG  2000
START     NOP
          HLT
          END   START
```

The `CON` directive allows you to directly specify the contents of the memory address pointed by the location counter. For instance, when the assembler encounters the following code snippet

```
          ORIG  1150
          CON   -1823473
```

it will assign to the memory cell number 1150 the contents - 00 06 61 11 49 (which corresponds to the decimal value -1823473).

Finally, the `ALF` directive lets you specify the memory contents as a set of five (optionally quoted) characters, which are translated by the assembler to their byte values, conforming in that way the binary word that is to be stored in the corresponding memory cell. This directive comes in handy when you need to store printable messages in a memory address, as in the following example[6]:

```
          OUT  MSG       MSG is not yet defined here (future reference)
MSG       ALF  "THIS "   MSG gets defined here
          ALF  "IS A "
          ALF  "MESSA"
          ALF  "GE.  "
```

The above snippet also shows the use of a *future reference*, that is, the usage of a symbol (`MSG` in the example) prior of its actual definition. The MIXAL assembler is able to handle future references subject to some limitations which are described in the following section (see Section 2.2.3 [Expressions], page 22).

Any line starting with an asterisk is treated as a comment and ignored by the assembler.

```
* This is a comment: this line is ignored.
    * This line is an error: * must be in column 1.
```

As noted in the previous section, comments can also be located after the `OPERAND` field of an instruction, separated from it by white space, as in

```
LABEL     LDA   100  This is also a comment
```

2.2.3 Expressions

The `ADDRESS`, `INDEX` and `MOD` fields of a MIXAL instruction can be expressions, formed by numbers, identifiers and binary operators (`+ - * / // :`). `+` and `-` can also be used as unary operators. Operator precedence is from left to right: there is no other operator precedence rule, and parentheses cannot be used for grouping. A stand-alone asterisk denotes the current memory location; thus, for instance,

```
     4+2**
```

evaluates to 6 (4 plus 2) times the current memory location. White space is not allowed within expressions.

The special binary operator `:` has the same meaning as in fspecs, i.e.,

```
A:B = 8*A + B
```

while `A//B` stands for the quotient of the ten-byte number `A` 00 00 00 00 00 (that is, A right-padded with 5 null bytes or, what amounts to the same, multiplied by 64 to the fifth power) divided by `B`. Sample expressions are:

```
18-8*3 = 30
14/3 = 4
1+3:11 = 4:11 = 43
```

---

[6] In the original MIXAL definition, the `ALF` argument is not quoted. You can write the operand (as the `ADDRESS` field) without quotes, but, in this case, you must follow the alignment rules of the original MIXAL definition (namely, the `ADDRESS` must start at column 17).

```
1//64 = (01 00 00 00 00 00)/(00 00 00 01 00) = (01 00 00 00 00)
```

Note that all MIXAL expressions evaluate to a MIX word (by definition).

All symbols appearing within an expression must be previously defined. Future references are only allowed when appearing standalone (or modified by an unary operator) in the `ADDRESS` part of a MIXAL instruction, e.g.

```
* OK: stand alone future reference
        STA  -S1(1:5)
* ERROR: future reference in expression
        LDX  2-S1
S1      LD1  2000
```

2.2.4 W-expressions

Besides expressions, as described above (see Section 2.2.3 [Expressions], page 22), the MIXAL assembler is able to handle the so called *w-expressions* as the operands of the directives `ORIG`, `EQU`, `CON` and `END` (see Section 2.2.2 [MIXAL directives], page 20). The general form of a w-expression is the following:

```
WEXP = EXP[(EXP)][,WEXP]
```

where `EXP` stands for an expression and square brackets denote optional items. Thus, a w-expression is made by an expression, followed by an optional expression between parenthesis, followed by any number of similar constructs separated by commas. Sample w-expressions are:

```
2000
235(3)
S1+3(S2),3000
S1,S2(3:5),23
```

W-expressions are evaluated from left to right as follows:

- Start with an accumulated result '`w`' equal to 0.
- Take the first expression of the comma-separated list and evaluate it. For instance, if the w-expression is '`S1+2(2:4),2000(S2)`', we evaluate first '`S1+2`'; let's suppose that '`S1`' equals 265230: then '`S1+2 = 265232 = + 00 01 00 48 16`'.
- Evaluate the expression within parenthesis, reducing it to an f-spec of the form '`L:R`'. In our previous example, the expression between parenthesis already has the desired form: 2:4.
- Substitute the bytes of the accumulated result '`w`' designated by the f-spec using those of the previous expression value. In our sample, '`w = + 00 00 00 00 00`', and we must substitute bytes 2, 3 and 4 of '`w`' using values from 265232. We need 3 bytes, and we take the least significant ones: 00, 48, and 16, and insert them in positions 2, 3 and 4 of '`w`', obtaining '`w = + 00 00 48 16 00`'.
- Repeat this operation with the remaining terms, acting on the new value of '`w`'. In our example, if, say, '`S2 = 1:1`', we must substitute the first byte of '`w`' using one byte (the least significant) from 2000, that is, 16 (since 2000 = `+` 00 00 00 31 16) and, therefore, we obtain '`w = + 16 00 48 16 00`'; summing up, we have obtained '`265232(1:4),2000(1:1) = + 16 00 48 16 00 = 268633088`'.

As a second example, in the w-expression

```
1(1:2),66(4:5)
```

we first take two bytes from 1 (00 and 01) and store them as bytes 1 and 2 of the result (obtaining '+ 00 01 00 00 00') and, afterwards, take two bytes from 66 (01 and 02) and store them as bytes 4 and 5 of the result, obtaining '+ 00 01 00 01 02' (262210). The process is repeated for each new comma-separated example. For instance:

```
1(1:1),2(2:2),3(3:3),4(4:4) = 01 02 03 04 00
```

As stated before, w-expressions can only appear as the operands of MIXAL directives taking a constant value (ORIG, EQU, CON and END). Future references are *not* allowed within w-expressions (i.e., all symbols appearing in a w-expression must be defined before it is used).

2.2.5 Local symbols

Besides user defined symbols, MIXAL programmers can use the so called *local symbols*, which are symbols of the form [1-9][HBF]. A local symbol nB refers to the address of the last previous occurrence of nH as a label, while nF refers to the next nH occurrence. Unlike user defined symbols, nH can appear multiple times in the LABEL part of different MIXAL instructions. The following code shows an instance of local symbols' usage:

```
* line 1
1H    LDA  100
* line 2: 1B refers to address of line 1, 3F refers to address of line 4
      STA  3F,2(1B//2)
* line 3: redefinition of 1H
1H    STZ
* line 4: 1B refers to address of line 3
3H    JMP  1B
```

Note that a B local symbol never refers to a definition in its own line, that is, in the following program:

```
ORIG 1999
ST NOP
3H EQU 69
3H ENTA 3B  local symbol 3B refers to 3H in previous line
HLT
END ST
```

the contents of 'rA' is set to 69 and *not* to 2001. An specially tricky case occurs when using local symbols in conjunction with ORIG pseudoinstructions. To wit[7],

```
ORIG 1999
ST NOP
3H CON 10
ENT1 *
LDA 3B
** rI1 is 2001, rA is 10.  So far so good!
```

[7] The author wants to thank Philip E. King for pointing these two special cases of local symbol usage to him.

```
3H ORIG 3B+1000
** at this point 3H equals 2003
** and the location counter equals 3000.
ENT2 *
LDX 3B
** rI2 contains 3000, rX contains 2003.
HLT
END ST
```

2.2.6 Literal constants

MIXAL allows the introduction of *literal constants*, which are automatically stored in memory addresses after the end of the program by the assembler. Literal constants are denoted as `=wexp=`, where `wexp` is a w-expression (see Section 2.2.4 [W-expressions], page 23). For instance, the code

```
L          EQU   5
           LDA   =20-L=
```

causes the assembler to add after the program's end an instruction with contents 15 ('20-L'), and to assemble the above code as the instruction `LDA a`, where `a` stands for the address in which the value 15 is stored. In other words, the compiled code is equivalent to the following:

```
L          EQU  5
           LDA  a
...
a          CON  20-L
           END  start
```

3 Getting started

In this chapter, you will find a sample code-compile-run-debug session using the MDK utilities. Familiarity with the MIX mythical computer and its assembly language MIXAL (as described in Knuth's TAOCP) is assumed; for a compact reminder, see Chapter 2 [MIX and MIXAL tutorial], page 9.

3.1 Writing a source file

MIXAL programs can be written as ASCII files with your editor of choice. Here you have the mandatory *hello world* as written in the MIXAL assembly language:

```
*                                                          (1)
* hello.mixal: say 'hello world' in MIXAL                  (2)
*                                                          (3)
* label ins    operand     comment                         (4)
TERM    EQU    19          the MIX console device number   (5)
        ORIG   3000        start address                   (6)
START   OUT    MSG(TERM)   output data at address MSG      (7)
        HLT                halt execution                  (8)
MSG     ALF    "MIXAL"                                     (9)
        ALF    " HELL"                                     (10)
        ALF    "O WOR"                                     (11)
        ALF    "LD   "                                     (12)
        END    START       end of the program              (13)
```

MIXAL source files should have the extension `.mixal` when used with the MDK utilities. As you can see in the above sample, each line in a MIXAL file can be divided into four fields separated by an arbitrary amount of whitespace characters (blanks and or tabs). While in Knuth's definition of MIXAL each field must start at a fixed pre-defined column number, the MDK assembler loosens this requirement and lets you format the file as you see fit. The only restrictions retained are for comment lines (like 1-4) which must begin with an asterisk (*) placed at column 1, and for the label field (see below) which, if present, must also start at column 1. The four fields in each non-comment line are:

- an optional label, which either refers to the current memory address (as `START` and `MSG` in lines 7 and 9) or a defined symbol (`TERM`) (if present, the label must always start at the first column in its line, for the first whitespace in the line marks the beginning of the second field),
- an operation mnemonic, which can represent either a MIX instruction (`OUT` and `HLT` in lines 7 and 8 above), or an assembly pseudoinstruction (e.g., the `ORIG` pseudoinstruction in line 6[1].
- an optional operand for the (pseudo)instruction, and
- an optional free text comment.

---

[1] If an `ORIG` directive is not used, the program will be loaded by the virtual machine at address 0. `ORIG` allows allocating the executable code where you see fit.

Lines 9-12 of the `hello.mixal` file above also show the second (and last) difference between Knuth's MIXAL definition and ours: the operand of the `ALF` pseudoinstruction (a word of five characters) must be quoted using `""`[2].

The workings of this sample program should be straightforward if you are familiar with MIXAL. See TAOCP vol. 1 for a thorough definition or Chapter 2 [MIX and MIXAL tutorial], page 9, for a tutorial.

3.2 Compiling

Three simulators of the MIX computer, called `mixvm`, `gmixvm` and `mixguile`, are included in the MDK tools. They are able to run binary files containing MIX instructions written in their binary representation. You can translate MIXAL source files into this binary form using `mixasm`, the MIXAL assembler. So, in order to compile the `hello.mixal` file, you can type the following command at your shell prompt:

```
mixasm hello RET
```

If the source file contains no errors, this will produce a binary file called `hello.mix` which can be loaded and run by the MIX virtual machine. Unless the `mixasm` option `-O` is provided, the assembler will include debug information in the executable file (for a complete description of all the compilation options, see Chapter 5 [mixasm], page 45). Now, your are ready to run your first MIX program, as described in the following section.

3.3 Running the program

MIX is a mythical computer, so it is no use ordering it from your favorite hardware provider. MDK provides three software simulators of the computer, though. They are

- `mixvm`, a command line oriented simulator,
- `gmixvm`, a GTK based graphical interface to `mixvm`, and
- `mixguile`, a Guile shell with a built-in MIX simulator.

All three simulators accept the same set of user commands, but offer a different user interface, as noted above. In this section we shall describe some of these commands, and show you how to use them from `mixvm`'s command line. You can use them as well at `gmixvm`'s command prompt (see Chapter 7 [gmixvm], page 59), or using the built-in Scheme primitives of `mixguile` (see Section 3.4 [Using mixguile], page 33).

Using the MIX simulators, you can run your MIXAL programs, after compiling them with `mixasm` into binary `.mix` files. `mixvm` can be used either in *interactive* or *non-interactive* mode. In the second case, `mixvm` will load your program into memory, execute it (producing any output due to MIXAL `OUT` instructions present in the program), and exit when it encounters a `HLT` instruction. In interactive mode, you will enter a shell prompt which allows you issuing commands to the running virtual machine. These commands will permit you to load, run and debug programs, as well as to inspect the MIX computer state (register contents, memory cells contents and so on).

[2] In Knuth's definition, the operand always starts at a fixed column number, and the use of quotation is therefore unnecessary. As `mixasm` releases this requirement, marking the beginning and end of the `ALF` operand disambiguates the parser's recognition of this operand when it includes blanks. Note that double-quotes (`"`) are not part of the MIX character set, and, therefore, no escape characters are needed within `ALF`'s operands.

3.3.1 Non-interactive mode

To make `mixvm` work in non-interactive mode, use the `-r` flag. Thus, to run our `hello.mix` program, simply type

```
mixvm -r hello RET
```

at your command prompt, and you will get the following output:

```
MIXAL HELLO WORLD
```

Since our hello world program uses MIX's device number 19 as its output device (see Section 3.1 [Writing a source file], page 27), the output is redirected to the shell's standard output. Had you used any other MIX output devices (disks, drums, line printer, etc.), `mixvm` would have created a file named after the device used (e.g. `disk4.dev`) and written its output there[3].

The virtual machine can also report the execution time of the program, according to the (virtual) time spent in each of the binary instructions (see Section 2.1.2.12 [Execution times], page 18). Printing of execution time statistics is activated with the `-t` flag; running

```
mixvm -t -r hello RET
```

produces the following output:

```
MIXAL HELLO WORLD
** Execution time: 11
```

Sometimes, you will prefer to store the results of your program in MIX registers rather than writing them to a device. In such cases, `mixvm`'s `-d` flag is your friend: it makes `mixvm` dump the contents of its registers and flags after executing the loaded program. For instance, typing the following command at your shell's prompt

```
mixvm -d -r hello
```

you will obtain the following output:

```
MIXAL HELLO WORLD
rA: + 00 00 00 00 00 (0000000000)
rX: + 00 00 00 00 00 (0000000000)
rJ: + 00 00 (0000)
rI1: + 00 00 (0000)     rI2: + 00 00 (0000)
rI3: + 00 00 (0000)     rI4: + 00 00 (0000)
rI5: + 00 00 (0000)     rI6: + 00 00 (0000)
Overflow: F
Cmp: E
```

which, in addition to the program's outputs and execution time, gives you the contents of the MIX registers and the values of the overflow toggle and comparison flag (admittedly, rather uninteresting in our sample).

As you can see, running programs non-interactively has many limitations. You cannot peek the virtual machine's memory contents, not to mention stepping through your program's instructions or setting breakpoints[4]. Enter interactive mode.

---

[3] The device files are stored, by default, in a directory called `.mdk`, which is created in your home directory the first time `mixvm` is run. You can change this default directory using the command `devdir` when running `mixvm` in interactive mode (see Section 6.2.4 [Configuration commands], page 56)

[4] The `mixguile` program allows you to execute arbitrary combinations of `mixvm` commands (using Scheme) non-interactively. See Section 3.4.5 [Scheme scripts], page 39.

3.3.2 Interactive mode

To enter the MIX virtual machine interactive mode, simply type

```
mixvm RET
```

at your shell command prompt. This command enters the `mixvm` command shell. You will be presented the following command prompt:

```
MIX >
```

The virtual machine is initialised and ready to accept your commands. The `mixvm` command shell uses GNU's readline, so that you have at your disposal command completion (using `TAB`) and history functionality, as well as other line editing shortcuts common to all utilities using this library (for a complete description of readline's line editing usage, see Section "Command Line Editing" in `Readline`.)

Usually, the first thing you will want to do is loading a compiled MIX program into memory. This is accomplished by the `load` command, which takes as an argument the name of the `.mix` file to be loaded. Thus, typing

```
MIX > load hello RET
Program loaded. Start address: 3000
MIX >
```

will load `hello.mix` into the virtual machine's memory and set the program counter to the address of the first instruction. You can obtain the contents of the program counter using the command `pc`:

```
MIX > pc
Current address: 3000
MIX >
```

After loading it, you are ready to run the program, using, as you surely have guessed, the `run` command:

```
MIX > run
Running ...
MIXAL HELLO WORLD
... done
Elapsed time: 11 /Total program time: 11 (Total uptime: 11)
MIX >
```

Note that now the timing statistics are richer. You obtain the elapsed execution time (i.e., the time spent executing instructions since the last breakpoint), the total execution time for the program up to now (which in our case coincides with the elapsed time, since there were no breakpoints), and the total uptime for the virtual machine (you can load and run more than one program in the same session)[5]. After running the program, the program counter will point to the address after the one containing the `HLT` instruction. In our case, asking the value of the program counter after executing the program will give us

```
MIX > pc
Current address: 3002
MIX >
```

[5] Printing of timing statistics can be disabled using the command `timing` (see Section 6.2.4 [Configuration commands], page 56).

You can check the contents of a memory cell giving its address as an argument of the command `pmem`, like this

```
MIX > pmem 3001
3001: + 00 00 00 02 05 (0000000133)
MIX >
```

and convince yourself that address 3001 contains the binary representation of the instruction `HLT`. An address range of the form FROM-TO can also be used as the argument of `pmem`:

```
MIX > pmem 3000-3006
3000: + 46 58 00 19 37 (0786957541)
3001: + 00 00 00 02 05 (0000000133)
3002: + 14 09 27 01 13 (0237350989)
3003: + 00 08 05 13 13 (0002118477)
3004: + 16 00 26 16 19 (0268542995)
3005: + 13 04 00 00 00 (0219152384)
3006: + 00 00 00 00 00 (0000000000)
MIX >
```

In a similar manner, you can look at the contents of the MIX registers and flags. For instance, to ask for the contents of the A register you can type

```
MIX > preg A
rA: + 00 00 00 00 00 (0000000000)
MIX >
```

Use the command `help` to obtain a list of all available commands, and `help COMMAND` for help on a specific command, e.g.

```
MIX > help run
run             Run loaded or given MIX code file. Usage: run [FILENAME]
MIX >
```

For a complete list of commands available at the MIX propmt, See Chapter 6 [mixvm], page 47. In the following subsection, you will find a quick tour over commands useful for debugging your programs.

3.3.3 Debugging commands

The interactive mode of `mixvm` lets you step by step execution of programs as well as breakpoint setting. Use `next` to step through the program, running its instructions one by one. To run our two-instruction `hello.mix` sample you can do the following:

```
MIX > load hello
Program loaded. Start address: 3000
MIX > pc
Current address: 3000
MIX > next
MIXAL HELLO WORLD
Elapsed time: 1 /Total program time: 1 (Total uptime: 1)
MIX > pc
Current address: 3001
MIX > next
End of program reached at address 3002
```

```
Elapsed time: 10 /Total program time: 11 (Total uptime: 11)
MIX > pc
Current address: 3002
MIX > next
MIXAL HELLO WORLD
Elapsed time: 1 /Total program time: 1 (Total uptime: 12)
MIX >
MIX > run
Running ...
... done
Elapsed time: 10 /Total program time: 11 (Total uptime: 22)
MIX >
```

(As an aside, the above sample also shows how the virtual machine handles cumulative time statistics and automatic program restart).

You can set a breakpoint at a given address using the command `sbpa` (set breakpoint at address). When a breakpoint is set, `run` will stop before executing the instruction at the given address. Typing `run` again will resume program execution. Coming back to our hello world example, we would have:

```
MIX > sbpa 3001
Breakpoint set at address 3001
MIX > run
Running ...
MIXAL HELLO WORLD
... stopped: breakpoint at line 8 (address 3001)
Elapsed time: 1 /Total program time: 1 (Total uptime: 23)
MIX > run
Running ...
... done
Elapsed time: 10 /Total program time: 11 (Total uptime: 33)
MIX >
```

Note that, since we compiled `hello.mixal` with debug info enabled, the virtual machine is able to tell us the line in the source file corresponding to the breakpoint we are setting. As a matter of fact, you can directly set breakpoints at source code lines using the command `sbp LINE_NO`, e.g.

```
MIX > sbp 4
Breakpoint set at line 7
MIX >
```

`sbp` sets the breakpoint at the first meaningful source code line; thus, in the above example we have requested a breakpoint at a line which does not correspond to a MIX instruction and the breakpoint is set at the first line containing a real instruction after the given one. To unset breakpoints, use `cbpa ADDRESS` and `cbp LINE_NO`, or `cabp` to remove all currently set breakpoints. You can also set conditional breakpoints, i.e., tell `mixvm` to interrupt program execution whenever a register, a memory cell, the comparison flag or the overflow toggle change using the commands `sbp[rmco]` (see Section 6.2.2 [Debug commands], page 50).

MIXAL lets you define symbolic constants, either using the EQU pseudoinstruction or starting an instruction line with a label (which assigns to the label the value of the current memory address). Each MIXAL program has, therefore, an associated symbol table which you can inspect using the psym command. For our hello world sample, you will obtain the following output:

```
MIX > psym
START:  3000
TERM:  19
MSG:  3002
MIX >
```

Other useful commands for debugging are strace (which turns on tracing of executed instructions), pbt (which prints a backtrace of executed instructions) and weval (which evaluates w-expressions on the fly). For a complete description of all available MIX commands, See Chapter 6 [mixvm], page 47.

3.4 Using mixguile

With mixguile you can run a MIX simulator embedded in a Guile shell, that is, using Scheme functions and programs. As with mixvm, mixguile can be run both in interactive and non-interactive modes. The following subsections provide a quick tour on using this MIX emulator.

3.4.1 The mixguile shell

If you simply type

```
mixguile RET
```

at the command prompt, you'll be presented a Guile shell prompt like this

```
guile>
```

At this point, you have entered a Scheme read-eval-print loop (REPL) which offers you all the Guile functionality plus a new set of built-in procedures to execute and debug MIX programs. Each of the mixvm commands described in the previous sections (and in see Chapter 6 [mixvm], page 47) have a Scheme function counterpart named after it by prepending the prefix mix- to its name. Thus, to load our hello world program, you can simply enter

```
guile> (mix-load "hello")
Program loaded. Start address: 3000
guile>
```

and run it using mix-run:

```
guile> (mix-run)
Running ...
MIXAL HELLO WORLD
... done
Elapsed time: 11 /Total program time: 11 (Total uptime: 11)
guile>
```

In the same way, you can execute it step by step using the Scheme function mix-next or set a breakpoint:

```
guile> (mix-sbp 4)
Breakpoint set at line 5
guile>
```

or, if you one to peek at a register contents:

```
guile> (mix-preg 'A)
rA: + 00 00 00 00 00 (0000000000)
guile>
```

You get the idea: you have at your disposal all the `mixvm` and `gmixvm` commands by means of `mix-` functions. But, in case you are wondering, this is only the beginning. You also have at your disposal a whole Scheme interpreter, and you can, for instance, define new functions combining the `mix-` and all other Scheme primitives. In the next sections, you'll find examples of how to take advantage of the Guile interpreter.

3.4.2 Additional MIX Scheme functions

The `mix-` function counterparts of the `mixvm` commands don't return any value, and are evaluated only for their side-effects (possibly including informational messages to the standard output and/or error stream). When writing your own Scheme functions to manipulate the MIX virtual machine within `mixguile` (see Section 3.4.3 [Defining new functions], page 35), you'll probably need Scheme functions returning the value of the registers, memory cells and so on. Don't worry: `mixguile` also offers you such functions. For instance, to access the (numerical) value of a register you can use `mix-reg`:

```
guile> (mix-reg 'I2)
0
guile>
```

Note that, unlike `(mix-preg 'I2)`, the expression `(mix-reg 'I2)` in the above example evaluates to a Scheme number and does not produce any side-effect:

```
guile> (number? (mix-reg 'I2))
#t
guile> (number? (mix-preg 'I2))
rI2: + 00 00 (0000)
#f
guile>
```

In a similar fashion, you can access the memory contents using `(mix-cell)`, or the program counter using `(mix-loc)`:

```
guile> (mix-cell 3000)
786957541
guile> (mix-loc)
3002
guile>
```

Other functions returning the contents of the virtual machine components are `mix-cmp` and `mix-over`, which eval to the value of the comparison flag and the overflow toggle respectively. For a complete list of these additional functions, See Chapter 8 [mixguile], page 65.

In the next section, we'll see a sample of using these functions to extend `mixguile`'s functionality.

3.4.3 Defining new functions

Scheme is a powerful language, and you can use it inside `mixguile` to easily extend the MIX interpreter's capabilities. For example, you can easily define a function that loads a file, prints its name, executes it and, finally, shows the registers contents, all in one shot:

```
guile> (define my-load-and-run  RET
         (lambda (file)   RET
           (mix-load file)   RET
           (display "File loaded: ")   RET
           (mix-pprog)   RET
           (mix-run)   RET
           (mix-preg)))   RET
guile>
```

and use it to run your programs:

```
guile> (my-load-and-run "hello")
Program loaded. Start address: 3000
File loaded: hello.mix
Running ...
MIXAL HELLO WORLD
... done
Elapsed time: 11 /Total program time: 11 (Total uptime: 33)
rA: + 00 00 00 00 00 (0000000000)
rX: + 00 00 00 00 00 (0000000000)
rJ: + 00 00 (0000)
rI1: + 00 00 (0000) rI2: + 00 00 (0000)
rI3: + 00 00 (0000) rI4: + 00 00 (0000)
rI5: + 00 00 (0000) rI6: + 00 00 (0000)
guile>
```

Or, maybe, you want a function which sets a breakpoint at a specified line number before executing it:

```
guile> (define my-load-and-run-with-bp
         (lambda (file line)
           (mix-load file)
           (mix-sbp line)
           (mix-run)))
guile> (my-load-and-run-with-bp "samples/primes" 10)
Program loaded. Start address: 3000
Breakpoint set at line 10
Running ...
... stopped: breakpoint at line 10 (address 3001)
Elapsed time: 1 /Total program time: 1 (Total uptime: 45)
guile>
```

As a third example, the following function loads a program, runs it and prints the contents of the memory between the program's start and end addresses:

```
guile> (define my-run
         (lambda (file)
```

```
              (mix-load file)
              (let ((start (mix-loc)))
                (mix-run)
                (mix-pmem start (mix-loc)))))
guile> (my-run "hello")
Program loaded. Start address: 3000
Running ...
MIXAL HELLO WORLD
... done
Elapsed time: 11 /Total program time: 11 (Total uptime: 11)
3000: + 46 58 00 19 37 (0786957541)
3001: + 00 00 00 02 05 (0000000133)
3002: + 14 09 27 01 13 (0237350989)
guile>
```

As you can see, the possibilities are virtually unlimited. Of course, you don't need to type a function definition each time you start `mixguile`. You can write it in a file, and load it using Scheme's `load` function. For instance, you can create a file named, say, `functions.scm` with your definitions (or any Scheme expression) and load it at the `mixguile` prompt:

```
guile> (load "functions.scm")
```

Alternatively, you can make `mixguile` to load it for you. When `mixguile` starts, it looks for a file named `mixguile.scm` in your MDK configuration directory (`~/.mdk`) and, if it exists, loads it before entering the REPL. Therefore, you can copy your definitions in that file, or load the `functions.scm` file in `mixguile.scm`.

3.4.4 Hook functions

Hooks are functions called before or after a given event occurs. In `mixguile`, you can define command and break hooks, which are associated, respectively, with command execution and program interruption events. The following sections give you a tutorial on using hook functions within `mixguile`.

3.4.4.1 Command hooks

In the previous section, we have seen how to extend `mixguile`'s functionality through the use of user defined functions. Frequently, you'll write new functions that improve in some way the workings of a built-in `mixvm` command, following this pattern:

a. Prepare the command execution
b. Execute the desired command
c. Perform post execution operations

We call the functions executed in step (a) *pre-hooks*, and those of step *post-hooks* of the given command. `mixguile` lets you specify pre- and post-hooks for any `mixvm` command using the `mix-add-pre-hook` and `mix-add-post-hook` functions, which take as arguments a symbol naming the command and a function to be executed before (resp. after) the command. In other words, `mixguile` will execute for you steps (a) and (c) above whenever you eval (b). The hook functions must take a single argument, which is a string list of the command's arguments. As an example, let us define the following hooks for the `next` command:

```
(define next-pre-hook
  (lambda (arglist)
    (mix-slog #f)))

(define next-post-hook
  (lambda (arglist)
    (display "Stopped at line ")
    (display (mix-src-line-no))
    (display ": ")
    (display (mix-src-line))
    (newline)
    (mix-slog #t)))
```

In these functions, we are using the function `mix-slog` to turn off the informational messages produced by the virtual machine, since we are providing our own ones in the post hook function. To install these hooks, we would write:

```
(mix-add-pre-hook 'next next-pre-hook)
(mix-add-post-hook 'next next-post-hook)
```

Assuming we have put the above expressions in `mixguile`'s initialisation file, we would obtain the following results when evaluating `mix-next`:

```
guile> (mix-next)
MIXAL HELLO WORLD
Stopped at line 6:             HLT
guile>
```

As a second, more elaborate, example, let's define hooks which print the address and contents of a cell being modified using `smem`. The hook functions could be something like this:

```
(define smem-pre-hook
  (lambda (arglist)
    (if (eq? (length arglist) 2)
        (begin
          (display "Changing address ")
          (display (car arglist))
          (newline)
          (display "Old contents: ")
          (display (mix-cell (string->number (car arglist))))
          (newline))
        (error "Wrong arguments" arglist))))

(define smem-post-hook
  (lambda (arglist)
    (if (eq? (length arglist) 2)
        (begin
          (display "New contents: ")
```

```
              (display (mix-cell (string->number (car arglist))))
              (newline)))))
```

and we can install them using

```
(mix-add-pre-hook 'smem smem-pre-hook)
(mix-add-post-hook 'smem smem-post-hook)
```

Afterwards, a sample execution of `mix-smem` would look like this:

```
guile> (mix-smem 2000 100)
Changing address 2000
Old contents: 0
New contents: 100
guile>
```

You can add any number of hooks to a given command. They will be executed in the same order as they are registered. You can also define global post (pre) hooks, which will be called before (after) any `mixvm` command is executed. Global hook functions must admit two arguments, namely, a string naming the invoked command and a string list of its arguments, and they are installed using the Scheme functions `mix-add-global-pre-hook` and `mix-add-global-post-hook`. A simple example of global hook would be:

```
guile> (define pre-hook
         (lambda (cmd args)
           (display cmd)
           (display " invoked with arguments ")
           (display args)
           (newline)))
guile> (mix-add-global-pre-hook pre-hook)
ok
guile> (mix-pmem 120 125)
pmem invoked with arguments (120-125)
0120: + 00 00 00 00 00 (0000000000)
0121: + 00 00 00 00 00 (0000000000)
0122: + 00 00 00 00 00 (0000000000)
0123: + 00 00 00 00 00 (0000000000)
0124: + 00 00 00 00 00 (0000000000)
0125: + 00 00 00 00 00 (0000000000)
guile>
```

Note that if you invoke `mixvm` commands within a global hook, its associated command hooks will be run. Thus, if you have installed both the `next` hooks described earlier and the global hook above, executing `mix-next` will yield the following result:

```
guile> (mix-next 5)
next invoked with arguments (5)
slog invoked with arguments (off)
MIXAL HELLO WORLD
Stopped at line 7: MSG         ALF   "MIXAL"
slog invoked with arguments (on)
guile>
```

Adventurous readers may see the above global hook as the beginning of a command log utility or a macro recorder that saves your commands for replay.

3.4.4.2 Break hooks

We have seen in the previous section how to associate hooks to command execution, but they are not the whole story. You can also associate hook functions to program interruption, that is, specify functions that should be called every time the execution of a MIX program is stopped due to the presence of a breakpoint, either explicit or conditional. Break hooks take as arguments the line number and memory address at which the break occurred. A simple hook that logs the line and address of the breakpoint could be defined as:

```
(define break-hook
  (lambda (line address)
    (display "Breakpoint encountered at line ")
    (display line)
    (display " and address ")
    (display address)
    (newline)))
```

and installed for explicit and conditional breakpoints using

```
(mix-add-break-hook break-hook)
(mix-add-cond-break-hook break-hook)
```

after that, every time the virtual machine encounters a breakpoint, `break-code` shall be evaluated for you[6].

3.4.5 Scheme scripts

Another useful way of using `mixguile` is writing executable scripts that perform a set of commands for you. This is done using the `mixguile` switch `-s` (being a Guile shell, `mixguile` accepts all the command options of `guile`; type `mixguile -h` for a list of all available command options). For instance, if you have a very useful MIX program `foo.mix` which you want to run often, you don't have to fire up a MIX virtual machine, load and run it every time; you can write a Scheme script instead:

```
#! /usr/bin/mixguile -s
!#
;;; runprimes: execute the primes.mix program

;; load the file you want to run
(mix-load "../samples/primes")
;; execute it
(mix-run)
;; print the contents of registers
(mix-pall)
;; ...
```

[6] You may have noticed that break hooks can be implemented in terms of command hooks associated to `mix-run` and `mix-next`. As a matter of fact, they *are* implemented this way: take a look at the file *install_dir*/`share/mdk/mix-vm-stat.scm` if you are curious.

Just save the above script to a file named, say, `runtest`, make it executable (`chmod +x runtest`), and, well, execute it from the Unix shell:

```
$ ./runtest
Program loaded. Start address: 3000
Running ...
... done
Elapsed time: 190908 /Total program time: 190908 (Total uptime: 190908)
rA: + 30 30 30 30 30 (0511305630)
rX: + 30 30 32 32 39 (0511313959)
rJ: + 47 18 (3026)
rI1: + 00 00 (0000)     rI2: + 55 51 (3571)
rI3: + 00 19 (0019)     rI4: + 31 51 (2035)
rI5: + 00 00 (0000)     rI6: + 00 00 (0000)
Overflow: F
Cmp: L
$
```

Note that this is far more flexible that running programs non-interactively using `mixvm` (see Section 3.3.1 [Non-interactive mode], page 29), for you can execute any combination of commands you want from a Scheme script (not just running and dumping the registers). For additional `mixguile` command line options, see Section 8.1 [Invoking mixguile], page 65.

3.5 Using Scheme in `mixvm` and `gmixvm`

In the previous section (see Section 3.4 [Using mixguile], page 33) we have seen how the Guile shell `mixguile` offers you the possibility of using Scheme to manipulate a MIX virtual machine and extend the set of commands offered by `mixvm` and `gmixvm`. This possibility is not limited to the `mixguile` shell. Actually, both `mixvm` and `gmixvm` incorporate an embedded Guile interpreter, and can evaluate Scheme expressions. To evaluate a single-line expression at the `mixvm` or `gmixvm` command prompt, simply write it and press return (the command parser will recognise it as a Scheme expression because it is parenthesized, and will pass it to the Guile interpreter). A sample `mixvm` session using Scheme expressions could be:

```
MIX > load hello
Program loaded. Start address: 3000
MIX > (define a (mix-loc))
MIX > run
Running ...
MIXAL HELLO WORLD
... done
Elapsed time: 11 /Total program time: 11 (Total uptime: 11)
MIX > (mix-pmem a)
3000: + 46 58 00 19 37 (0786957541)
MIX > (mix-pmem (mix-loc))
3002: + 14 09 27 01 13 (0237350989)
MIX >
```

You can also load and evaluate a file, using the `scmf` command like this:

```
MIX> scmf /path/to/file/file.scm
```

Therefore, you have at your disposal all the `mixguile` goodies described above (new functions, new command definitions, hooks...) inside `mixvm` and `gmixvm`. In other words, these programs are extensible using Scheme. See Section 3.4 [Using mixguile], page 33, for examples of how to do it.

4 Emacs tools

Everyone writing code knows how important a good editor is. Most systems already come with Emacs, and excellent programmer's editor. MDK adds support to Emacs for both writing and debugging MIX programs. A major mode for MIXAL source files eases edition of your code, while integration with Emacs' debugging interface (GUD) lets you use `mixvm` without leaving your favourite text editor.

This chapter shows how to use the Elisp modules included in MDK, assuming that you have followed the installation instructions in See Section 1.4 [Emacs support], page 6.

4.1 MIXAL mode

The module `mixal-mode.el` provides a new mode, mixal-mode, for editing MIXAL source files[1]. When everything is installed correctly, Emacs will select it as the major mode for editing files with extension `.mixal`. You can also activate mixal-mode in any buffer issuing the Emacs command `M-x mixal-mode`.

4.1.1 Basics

The mode for editing mixal source files is inherited from fundamental-mode, meaning that all your favorite editing operations will still work. If you want a short introduction to Emacs, type *`C-h t`* inside Emacs to start the tutorial.

Mixal mode adds font locking. If you do not have font locking globally enabled, you can turn it on for mixal-mode by placing the following line in your `.emacs` file:

```
(add-hook 'mixal-mode-hook 'turn-on-font-lock)
```

You can also customize the colors used to colour your mixal code by changing the requisite faces. This is the list of faces used by mixal-mode:

- *font-lock-comment-face* Face to use for comments.
- *mixal-font-lock-label-face* Face to use for label names.
- *mixal-font-lock-operation-code-face* Face to use for operation code names.
- *mixal-font-lock-assembly-pseudoinstruction-face* Face to use for assembly pseudo-instruction names.

4.1.2 Help system

When coding your program, you will be thinking, looking up documentation and editing files. Emacs already helps you with editing files, but Emacs can do much more. In particular, looking up documentation is one of its strong points. Besides the info system (which you are probably already using), mixal-mode defines commands for getting particular information about a MIX operation code.

With *`M-x mixal-describe-operation-code`* (or its keyboard shortcut *`C-h o`*) you will get the documentation about a particular MIX operation code. Keep in mind that these are not assembly (MIXAL) pseudoinstructions. When the `point` is around a MIXAL pseudoinstruction in your source file, Emacs will recognize it and will suggest the right MIX operation code.

---

[1] mixal-mode has been developed and documented by Pieter E. J. Pareit

4.1.3 Compiling and running

After you have written your MIXAL program, you'll probably want to test it. This can be done with the MIX virtual machine. First you will need to compile your code into MIX byte code. This can be done within Emacs with the command *`M-x compile`* (*`C-c c`*). In case of compilation errors, you can jump to the offending source code line with *`M-x next-error`*.

Once the program compiles without errors, you can debug or run it. To invoke the debugger, use *`M-x mixal-debug`* (*`C-c d`*). Emacs will open a `GUD` buffer where you can use the debugging commands described in See Chapter 6 [mixvm], page 47.

If you just want to execute the program, you can do so with *`M-x mixal-run`* (*`C-c r`*). This will invoke mixvm, execute the program and show its output in a separate buffer.

4.2 GUD integration

If you are an Emacs user and write your MIXAL programs using this editor, you will find the elisp program `mixvm.el` quite useful[2]. `mixvm.el` allows running the MIX virtual machine `mixvm` (see Chapter 6 [mixvm], page 47) inside an Emacs GUD buffer, while visiting the MIXAL source file in another buffer.

After installing `mixvm.el` (see Section 1.4 [Emacs support], page 6), you can initiate an MDK/GUD session inside Emacs with the command

```
M-x mixvm
```

and you will have a `mixvm` prompt inside a newly created GUD buffer. GUD will reflect the current line in the corresponding source file buffer.

[2] `mixvm.el` has been kindly contributed by Philip E. King. `mixvm.el` is based on a study of gdb, perldb, and pdb as found in `gud.el`, and `rubydb3x.el` distributed with the source code to the Ruby language.

5 mixasm, the MIXAL assembler

MIX programs, as executed by **mixvm**, are composed of binary instructions loaded into the virtual machine memory as MIX words. Although you could write your MIX programs directly as a series of words in binary format, you have at your disposal a more friendly assembly language, MIXAL (see Section 2.2 [MIXAL], page 19) which is compiled into binary form by **mixasm**, the MIXAL assembler included in MDK. In this chapter, you will find a complete description of **mixasm** options.

5.1 Invoking mixasm

In its simplest form, **mixasm** is invoked with a single argument, which is the name of the MIXAL file to be compiled, e.g.

```
mixasm hello
```

will compile either **hello** or **hello.mixal**, producing a binary file named **hello.mix** if no errors are found.

In addition, **mixasm** can be invoked with the following command line options (note, that, following GNU's conventions, we provide a long option name for each available single letter switch):

```
mixasm [-vhulO] [-o OUTPUT_FILE] [--version] [--help] [--usage]
       [--ndebug] [--output=OUTPUT_FILE] [--list[=LIST_FILE]] file
```

The meaning of these options is as follows:

`-v` [User Option]
`--version` [User Option]
Prints version and copyleft information and exits.

`-h` [User Option]
`--help` [User Option]
`-u` [User Option]
`--usage` [User Option]
Prints a summary of available options and exits.

`-O` [User Option]
`--ndebug` [User Option]
Do not include debugging information in the compiled file, saving space but disallowing breakpoint setting at source level and symbol table inspection under **mixvm**.

`-o` *output_file* [User Option]
`--output=output_file` [User Option]
By default, the given source file *file.mixal* is compiled into *file.mix*. You can provide a different name for the output file using this option.

`-l` [User Option]
`--list[=list_file]` [User Option]
This option causes **mixasm** to produce, in addition to the **.mix** file, an ASCII file containing a summary of the compilation results. The file is named after the MIXAL source file, changing its extension to **.mls** if no argument is provided; otherwise, the listing file is named according to the argument.

6 mixvm, the MIX computer simulator

This chapter describes `mixvm`, the MIX computer simulator. `mixvm` is a command line interface programme which simulates the MIX computer (see Section 2.1 [The MIX computer], page 9). It is able to run MIXAL programs (see Section 2.2 [MIXAL], page 19) previously compiled with the MIX assembler (see Chapter 5 [mixasm], page 45). The simulator allows inspection of the MIX computer components (registers, memory cells, comparison flag and overflow toggle), step by step execution of MIX programmes, and breakpoint setting to aid you in debugging your code. For a tutorial description of `mixvm` usage, See Section 3.3 [Running the program], page 28.

6.1 Invoking mixvm

`mixvm` can be invoked with the following command line options (note that, following GNU's conventions, we provide a long option name for each available single letter switch):

```
mixvm [-vhurdtq] [--version] [--help] [--usage] [--run] [--dump]
      [--time] [--noinit]  [FILE[.mix]]
```

The meaning of these options is as follows:

`-v` [User Option]
`--version` [User Option]

Prints version and copyleft information and exits.

`-h` [User Option]
`--help` [User Option]
`-u` [User Option]
`--usage` [User Option]

Prints a summary of available options and exits.

`-r` [User Option]
`--run` [User Option]

Loads the specified *FILE* and executes it. After the program execution, `mixvm` exits. *FILE* must be the name of a binary `.mix` program compiled with `mixasm`. If your program does not produce any output, use the `-d` flag (see below) to peek at the virtual machine's state after execution.

`-d` [User Option]
`--dump` [User Option]

This option must be used in conjunction with `-r`, and tells `mixvm` to print the value of the virtual machine's registers, comparison flag and overflow toggle after executing the program named *FILE*. See See Section 3.3.1 [Non-interactive mode], page 29, for sample usage.

`-t` [User Option]
`--time` [User Option]

This option must be used in conjunction with `-r`, and tells `mixvm` to print virtual time statistics for the program's execution.

When run without the `-r` flag, `mixvm` enters its interactive mode, showing you a prompt like this one:

```
MIX >
```

and waiting for your commands (see Section 6.2 [Commands], page 48). If the optional *FILE* argument is given, the file `FILE.mix` will be loaded into the virtual machine memory before entering the interactive mode.

The first time `mixvm` is invoked, a directory named `.mdk` is created in your home directory. It contains the `mixvm` configuration file, the command history file and (by default) the block devices files (see Section 6.3 [Devices], page 57). Before showing you the command prompt, `mixvm` looks in the `~/.mdk` directory for a file named `mixguile.scm`; if it exists, it is read and evaluated by the embedded Guile interpreter (see Section 3.4.3 [Defining new functions], page 35). You can use the `-q` command line option to skip this file loading:

`-q` [User Option]
`--noinit` [User Option]
Do not load the Guile initialisation file `~/.mdk/mixguile.scm` at startup.

6.2 Interactive commands

You can enter the interactive mode of the MIX virtual machine by simply invoking `mixvm` without arguments. You will then be greeted by a shell prompt[1]

```
MIX >
```

which indicates that a new virtual machine has been initialised and is ready to execute your commands. As we have already mentioned, this command prompt offers you command line editing facilities which are described in the Readline user's manual (chances are that you are already familiar with these command line editing capabilities, as they are present in many GNU utilities, e.g. the `bash` shell)[2]. In a nutshell, readline provides command completion using the *`TAB`* key and command history using the cursor keys. A history file containing the last commands typed in previous sessions is stored in the MDK configuration directory (`~/.mdk`).

As a beginner, your best friend will be the `help` command, which shows you a summary of all available MIX commands and their usage; its syntax is as follows:

`help` [*command*] [`mixvm` command]
Prints a short description of the given *command* and its usage. If *command* is omitted, `help` prints the short description for all available commands.

6.2.1 File commands

You have at your disposal a series of commands that let you load and execute MIX executable files, as well as manipulate MIXAL source files:

---

[1] The default command prompt, '`MIX > `', can be changed using the `prompt` command (see Section 6.2.4 [Configuration commands], page 56)

[2] The readline functionality will be available if you have compiled MDK with readline support, i.e., if GNU readline is installed in your system. This is often the case in GNU/Linux and BSD systems

`load` *file*[*.mix*] [file command]

This command loads a binary file, *file.mix* into the virtual machine memory, and positions the program counter at the beginning of the loaded program. This address is indicated in the MIXAL source file as the operand of the `END` pseudoinstruction. Thus, if your `sample.mixal` source file contains the line:

```
END 3000
```

and you compile it with `mixasm` to produce the binary file `sample.mix`, you will load it into the virtual machine as follows:

```
MIX > load sample
Program loaded. Start address: 3000
MIX >
```

`run` [*file*[*.mix*]] [file command]

When executed without argument, this command initiates or resumes execution of instructions from the current program counter address. Therefore, issuing this command after a successful `load`, will run the loaded program until either a `HLT` instruction or a breakpoint is found. If you provide a MIX filename as argument, the given file will be loaded (as with `load` *file*) and executed. If `run` is invoked again after program execution completion (i.e., after the `HLT` instruction has been found in a previous run), the program counter is repositioned and execution starts again from the beginning (as a matter of fact, a `load` command preserving the currently set breakpoints is issued before resuming execution).

`edit` [*file*[*.mixal*]] [file command]

The source file *file.mixal* is edited using the editor defined in the environment variable *MDK_EDITOR*. If this variable is not set, the following ones are tried out in order: *X_EDITOR*, *EDITOR* and *VISUAL*. If invoked without argument, the source file for the currently loaded MIX file is edited. The command used to edit source files can also be configured using the `sedit` command (see Section 6.2.4 [Configuration commands], page 56).

`compile` *file*[*.mixal*] [file command]

The source file *file.mixal* is compiled (with debug information enabled) using `mixasm`. If invoked without argument, the source file for the currently loaded MIX file is recompiled. The compilation command can be set using the `sasm` command (see Section 6.2.4 [Configuration commands], page 56).

`pprog` [file command]
`psrc` [file command]

Print the path of the currently loaded MIX program and its source file:

```
MIX > load ../samples/primes
Program loaded. Start address: 3000
MIX > pprog
../samples/primes.mix
MIX > psrc
/home/jao/projects/mdk/gnu/samples/primes.mixal
MIx>
```

Finally, you can use the `quit` command to exit `mixvm`:

`quit` [file command]

Exit `mixvm`, saving the current configuration parameters in `~/.mdk/mixvm.config`.

6.2.2 Debug commands

Sequential execution of loaded programs can be interrupted using the following debug commands:

`next` [*ins_number*] [debug command]

This command causes the virtual machine to fetch and execute up to *ins_number* instructions, beginning from the current program counter position. Execution is interrupted either when the specified number of instructions have been fetched or a breakpoint is found, whatever happens first. If run without arguments, one instruction is executed. If `next` is invoked again after program execution completion (i.e., after the `HLT` instruction has been found in a previous run), the program counter is repositioned and execution starts again from the beginning (as a matter of fact, a `load` command preserving the currently set breakpoints is issued before resuming execution).

`sbp` *line_number* [debug command]
`cbp` *line_no* [debug command]

Sets a breakpoint at the specified source file line number. If the line specified corresponds to a command or to a MIXAL pseudoinstruction which does not produce a MIX instruction in the binary file (such as `ORIG` or `EQU`) the breakpoint is set at the first source code line giving rise to a MIX instruction after the specified one. Thus, for our sample `hello.mixal` file:

```
*                                                      (1)
* hello.mixal: say 'hello world' in MIXAL              (2)
*                                                      (3)
* label ins    operand     comment                     (4)
TERM    EQU    19          the MIX console device number (5)
        ORIG   1000        start address               (6)
START   OUT    MSG(TERM)   output data at address MSG  (7)
...
```

trying to set a breakpoint at line 5, will produce the following result:

```
MIX > sbp 5
Breakpoint set at line 7
MIX >
```

since line 7 is the first one compiled into a MIX instruction (at address 3000).

The command `cbp` clears a (previously set) breakpoint at the given source file line.

`spba` *address* [debug command]
`cbpa` *address* [debug command]

Sets a breakpoint at the given memory *address*. The argument must be a valid MIX memory address, i.e., it must belong into the range [0-3999]. Note that no check is performed to verify that the specified address is reachable during program execution.

No debug information is needed to set a breakpoint by address with `sbpa`. The command `cbpa` clears a (previously set) breakpoint at the given memory address.

`sbpr` *A* | *X* | *J* | *Ii* [debug command]
`cbpr` *A* | *X* | *J* | *Ii* [debug command]

Sets a conditional breakpoint on the specified register change. For instance,

```
sbpr I1
```

will cause an interruption during program execution whenever the contents of register `I1` changes. A previously set breakpoint is cleared using the `cbpr` command.

`sbpm` *address* [debug command]
`cbpm` *address* [debug command]

Sets a conditional breakpoint on the specified memory cell change. The argument must be a valid MIX memory address, i.e., it must belong into the range [0-3999]. For instance,

```
sbpm 1000
```

will cause an interruption during program execution whenever the contents of the memory cell number 1000 changes. A previously set breakpoint is cleared using the `cbpm` command.

`sbpo` [debug command]
`cbpo` [debug command]

Sets/clears a conditional breakpoint on overflow toggle change.

`sbpc` [debug command]
`cbpc` [debug command]

Sets/clears a conditional breakpoint on comparison flag change.

`cabp` [debug command]

Clears all currently set breakpoints.

`psym` [*symbol_name*] [debug command]

MIXAL programs can define symbolic constants, using either the `EQU` pseudoinstruction or a label at the beginning of a line. Thus, in the program fragment

```
VAR     EQU  2168
        ORIG 4000
START   LDA  VAR
```

the symbol `VAR` stands for the value 2168, while `START` is assigned the value 4000. The symbol table can be consulted from the `mixvm` command line using `psym` followed by the name of the symbol whose contents you are interested in. When run without arguments, `psym` will print all defined symbols and their values.

The virtual machine can also show you the instructions it is executing, using the following commands:

`strace` [*on*|*off*] [debug command]

`strace on` enables instruction tracing. When tracing is enabled, each time the virtual machine executes an instruction (due to your issuing a `run` or `next` command), it is printed in its canonical form (that is, with all expressions evaluated to their numerical values) and, if the program was compiled with debug information, as it was originally typed in the MIXAL source file. Instruction tracing is disabled with `strace off` command. A typical tracing session could be like this:

```
MIX > strace on
MIX > next
3000: [OUT 3002,0(2:3)] START OUT MSG(TERM)
MIXAL HELLO WORLD
Elapsed time: 1 /Total program time: 1 (Total uptime: 1)
MIX > next
3001: [HLT 0,0] HLT
End of program reached at address 3002
Elapsed time: 10 /Total program time: 11 (Total uptime: 11)
MIX > strace off
MIX >
```

The executed instruction, as it was translated, is shown between square brackets after the memory address, and, following it, you can see the actual MIXAL code that was compiled into the executed instruction. The tracing behaviour is stored as a configuration parameter in `~/.mdk`.

`pline` [*LINE_NUMBER*] [debug command]

Prints the requested source line (or the current one if *line_number* is omitted:

```
MIX > load ../samples/hello
Program loaded. Start address: 3000
MIX > pline
Line 5: START       OUT   MSG(TERM)
MIX > pline 6
Line 6:             HLT
MIX >
```

`sbt` [*NUMBER*] [debug command]

This command changes the limit for the backtrace of executed instructions. If the number is omitted, the command prints the current limit. If you use a 0, backtraces are turned off. This can improve performance. If you wish for all the instructions to be logged, a -1 will enable that. The amount of memory required for unlimited backtraces can be substantial for long-running programs.

`pbt` [*INS_NUMBER*] [debug command]

This command prints a backtrace of executed instructions. Its optional argument *ins_number* is the number of instructions to print. If it is omitted or equals zero, all executed instructions are printed. For instance, if you compile and load the following program (`bt.mixal`):

```
    ORIG 0
BEG JMP *+1
    JMP *+1
FOO JMP BAR
BAR HLT
```

```
        END BEG
```

you could get the following traces:

```
MIX > load bt
Program loaded. Start address: 0
MIX > next
MIX > pbt
#0      BEG     in bt.mixal:2
MIX > next
MIX > pbt
#0      1       in bt.mixal:3
#1      BEG     in bt.mixal:2
MIX > run
Running ...
... done
MIX > pbt 3
#0      BAR     in bt.mixal:5
#1      FOO     in bt.mixal:4
#2      1       in bt.mixal:3
MIX > pbt
#0      BAR     in bt.mixal:5
#1      FOO     in bt.mixal:4
#2      1       in bt.mixal:3
#3      BEG     in bt.mixal:2
MIX >
```

Note that the executed instruction trace gives you the label of the executed line or, if it has no label, its address.

As you have probably observed, `mixvm` prints timing statistics when running programs. This behaviour can be controlled using the `stime` command (see Section 6.2.4 [Configuration commands], page 56).

`mixvm` is also able of evaluating w-expressions (see Section 2.2.4 [W-expressions], page 23) using the following command:

`weval` *WEXP* [debug command]

Evaluates the given w-expression, *WEXP*. The w-expression can contain any currently defined symbol. For instance:

```
MIX > psym START
+ 00 00 00 46 56 (0000003000)
MIX > weval START(0:1),START(3:4)
+ 56 00 46 56 00 (0939716096)
MIX >
```

New symbols can be defined using the `ssym` command:

`ssym` *SYM WEXP* [debug command]

Defines the symbol named *SYM* with the value resulting from evaluating *WEXP*, a w-expression. The newly defined symbol can be used in subsequent `weval` commands, as part of the expression to be evaluated. E.g.,

```
MIX > ssym S 2+23*START
+ 00 00 18 19 56 (0000075000)
MIX > psym S
+ 00 00 18 19 56 (0000075000)
MIX > weval S(3:4)
+ 00 00 19 56 00 (0000081408)
MIX >
```

Finally, if you want to discover which is the decimal value of a MIX word expressed as five bytes plus sign, you can use

`w2d` *WORD* [debug command]

Computes the decimal value of the given word. *WORD* must be expressed as a sign (+/-) followed by five space-delimited, two-digit decimal values representing the five bytes composing the word. The reverse operation (showing the word representation of a decimal value) can be accomplished with `weval`. For instance:

```
MIX > w2d - 01 00 00 02 02
-16777346
MIX > weval -16777346
- 01 00 00 02 02 (0016777346)
MIX >
```

6.2.3 State commands

Inspection and modification of the virtual machine state (memory, registers, overflow toggle and comparison flag contents) is accomplished using the following commands:

`pstat` [state command]

This commands prints the current virtual machine state, which can be one of the following:

- No program loaded
- Program successfully loaded
- Execution stopped (`next` executed)
- Execution stopped: breakpoint encountered
- Execution stopped: conditional breakpoint encountered
- Program successfully terminated

`pc` [state command]

Prints the current value of the program counter, which stores the address of the next instruction to be executed in a non-halted program.

`sreg` *A* | *X* | *J* | *I*[*1-6*] *value* [state command]
`preg` [*A* | *X* | *J* | *I*[*1-6*]] [state command]
`pall` [state command]

`preg` prints the contents of a given MIX register. For instance, `preg` *A* will print the contents of the A-register. When invoked without arguments, all registers shall be printed:

```
MIX > preg
```

```
rA: - 00 00 00 00 35 (0000000035)
rX: + 00 00 00 15 40 (0000001000)
rJ: + 00 00 (0000)
rI1: + 00 00 (0000) rI2: + 00 00 (0000)
rI3: + 00 00 (0000) rI4: + 00 00 (0000)
rI5: + 00 00 (0000) rI6: + 00 00 (0000)
MIX >
```

As you can see in the above sample, the contents are printed as the sign plus the values of the MIX bytes stored in the register and, between parenthesis, the decimal representation of its module.

`pall` prints the contents of all registers plus the comparison flag and overflow toggle.

Finally, `sreg` Sets the contents of the given register to *value*, expressed as a decimal constant. If *value* exceeds the maximum value storable in the given register, `VALUE mod MAXIMUM_VALUE` is stored, e.g.

```
MIX > sreg I1 1000
MIX > preg I1
rI1: + 15 40 (1000)
MIX > sreg I1 1000000
MIX > preg I1
rI1: + 09 00 (0576)
MIX >
```

pflags [state command]
scmp *E* | *G* | *L* [state command]
sover *F* | *T* [state command]

`pflags` prints the value of the comparison flag and overflow toggle of the virtual machine, e.g.

```
MIX > pflags
Overflow: F
Cmp: E
MIX >
```

The values of the overflow toggle are either *F* (false) or *T* (true), and, for the comparison flag, *E*, *G*, *L* (equal, greater, lesser). `scmp` and `sover` are setters of the comparison flag and overflow toggle values.

pmem *from*[-*to*] [state command]
smem *address value* [state command]

`pmem` prints the contents of memory cells in the address range [*FROM-TO*]. If the upper limit *to* is omitted, only the contents of the memory cell with address *FROM* is printed, as in

```
MIX > pmem 3000
3000: + 46 58 00 19 37 (0786957541)
MIX >
```

The memory contents are displayed both as the set of five MIX bytes plus sign composing the stored MIX word and, between parenthesis, the decimal representation of the module of the stored value.

`smem` sets the content of the memory cell with address *address* to *value*, expressed as a decimal constant.

6.2.4 Configuration commands

This section describes commands that allow you to configure the virtual machine behaviour. This configuration is stored in the MDK directory `~/.mdk`.

As you can see in their description, some commands print, as a side effect, informational messages to the standard output (e.g. `load` prints a message telling you the loaded program's start address): these messages can be enabled/disabled using `slog`:

`slog` *on|off* [config command]

Turns on/off the logging of informational messages. Note that error messages are always displayed, as well as state messages required using commands prefixed with `p` (`preg`, `pmem` and the like).

`stime` *on|off* [config command]
`ptime` [config command]

The `stime` command (un)sets the printing of timing statistics, and `ptime` prints their current value:

```
MIX > ptime
Elapsed time: 10 /Total program time: 11 (Total uptime: 11)
MIX >
```

`sedit` *TEMPLATE* [config command]
`pedit` [config command]

`sedit` sets the command to be used to edit MIXAL source files with the `edit` command. *TEMPLATE* must contain the control characters `%s` to mark the place where the source's file name will be inserted. For instance, if you type

```
MIX > sedit emacsclient %s
MIX >
```

issuing the `mixvm` command `edit foo.mixal` will invoke the operating system command `emacsclient foo.mixal`.

`pedit` prints the current value of the edit command template.

`sasm` *TEMPLATE* [config command]
`pasm` [config command]

`sasm` sets the command to be used to compile MIXAL source files with the `compile` command. *template* must contain the control characters `%s` to mark the place where the source's file name will be inserted. For instance, if you type

```
MIX > sasm mixasm -l %s
MIX >
```

issuing the `mixvm` command `compile foo.mixal` will invoke the operating system command `mixasm -l foo.mixal`.

`pasm` prints the current value of the compile command template.

sddir *DIRNAME* [config command]
pddir [config command]

MIX devices (see Section 6.3 [Devices], page 57) are implemented as regular files stored, by default, inside `~/.mdk`. The `sddir` command lets you specify an alternative location for storing these device files, while `pddir` prints the current device directory.

Finally, you can change the default command prompt, '`MIX > `', using the `prompt` command:

prompt *PROMPT* [config command]

Changes the command prompt to *prompt*. If you want to include white space(s) at the end of the new prompt, bracket *prompt* using double quotes (e.g., `prompt ">> "`).

6.2.5 Scheme commands

If you have compiled MDK with `libguile` support (see Section 1.5 [Special configure flags], page 7), `mixvm` will start and initialise an embedded Guile Scheme interpreter when it is invoked. That means that you have at your disposal, at `mixvm`'s command prompt, all the Scheme primitives described in Section 3.4 [Using mixguile], page 33, and Chapter 8 [mixguile], page 65, as well as any other function or hook that you have defined in the initialisation file `~/.mdk/mixguile.scm`. To evaluate a Scheme function, simply type it at the `mixvm` command prompt (see Section 3.5 [Using Scheme in mixvm and gmixvm], page 40, for a sample). Compared to the `mixguile` program, this has only one limitation: the expressions used in `mixvm` cannot span more than one line. You can get over this inconvenience writing your multiline Scheme expressions in a file and loading it using the `scmf` command:

scmf *FILE_NAME* [scheme command]

Loads the given Scheme file and evaluates it using the embedded Guile interpreter.

6.3 MIX block devices

The MIX computer comes equipped with a set of block devices for input-output operations (see Section 2.1.2.8 [Input-output operators], page 16). `mixvm` implements these block devices as disk files, with the exception of block device no. 19 (typewriter terminal) which is redirected to standard input/output. When you request an output operation on any other (output) device, a file named according to the following table will be created, and the specified MIX words will be written to the file in binary form (for binary devices) or in ASCII (for char devices). Files corresponding to input block devices should be created and filled beforehand to be used by the MIX virtual machine (for input-output devices this creation can be accomplished by a MIXAL program writing to the device the required data, or, if you prefer, with your favourite editor). The device files are stored, by default, in the directory `~/.mdk`; this location can be changed using the `mixvm` command `devdir` (see Section 6.2.4 [Configuration commands], page 56).

Device	*No.*	*filename*	*type and block size*
Tape	0-7	`tape[0-7].dev`	bin i/o - 100 words

Disks	8-15	`disk[0-7].dev`	bin i/o - 100 words
Card reader	16	`cardrd.dev`	char in - 16 words
Card writer	17	`cardwr.dev`	char out - 16 words
Line printer	18	`printer.dev`	char out - 24 words
Terminal	19	`stdin/stdout`	char i/o - 14 words
Paper tape	20	`paper.dev`	char in - 14 words

Devices of type *char* are stored as ASCII files, using one line per block. For instance, since the card reader has blocks of size 16, that is, 80 characters, it will be emulated by an ASCII file consisting of lines with length 80. If the reader finds a line with less than the required number of characters, it pads the memory with zeroes (MIX character 'space') to complete the block size.

Note that the virtual machine automatically converts between the MIX and ASCII character encodings, so that you can manipulate char device files with any ASCII editor. In addition, the reader is not case-sensitive, i.e., it automatically converts lowercase letters to their uppercase counterparts (since the MIX character set does not include the former).

The typewriter (device no. 19) lets you use the standard input and output in your MIXAL programs. For instance, here is a simple 'echo' program:

```
* simple echo program
TERM    EQU     19          the typewriter device
BUF     EQU     500         input buffer
        ORIG    1000
START   IN      BUF(TERM)   read a block (70 chars)
        OUT     BUF(TERM)   write the read chars
        HLT
        END     START
```

Input lines longer than 70 characters (14 words) are trimmed. On the other hand, if you type less than a block of characters, whitespace (MIX character zero) is used as padding.

7 gmixvm, the GTK virtual machine

This chapter describes the graphical MIX virtual machine emulator shipped with MDK. In addition to having all the command-oriented functionalities of the other virtual machines (`mixvm` and `mixguile`), `gmixvm` offers you a graphical interface displaying the status of the virtual machine, the source code of the the downloaded programs and the contents of the MIX devices.

7.1 Invoking gmixvm

If you have built MDK with GTK+ support (see Chapter 1 [Installing MDK], page 5), a graphical front-end for the MIX virtual machine will be available in your system. You can invoke it by typing

```
gmixvm [-vhuq] [--version] [--help] [--usage] [--noinit]
```

at your command prompt, where the options have the following meanings:

`-v` [User Option]
`--version` [User Option]
: Prints version and copyleft information and exits.

`-h` [User Option]
`--help` [User Option]
`-u` [User Option]
`--usage` [User Option]
: Prints a summary of available options and exits.

`-q` [User Option]
`--noinit` [User Option]
: Do not load the Guile initialisation file `~/.mdk/mixguile.scm` at startup. This file contains any local Scheme code to be executed by the embedded Guile interpreter at startup (see Section 3.5 [Using Scheme in mixvm and gmixvm], page 40).

Typing `gmixvm` or `gmixvm -q` at your command prompt, the main window will appear, offering you a graphical interface to run and debug your MIX programs.

Apart from the menu and status bars, we can distinguish two zones (or halves) in this main window. In the upper half of `gmixvm`'s main window there is a notebook with three pages, namely,

- a MIX virtual machine view, which shows you the registers, flags, memory contents and time statistics of the virtual machine;
- a MIXAL source view, which shows the MIXAL file and lets you manage breakpoints;
- a Devices view, which shows you the output to character based MIX block devices.

These three windows can be detached from the notebook, using either the penultimate toolbar button (which detachs the currently visible notebook page) or the menu entries under `View->Detached windows`.

On the other hand, the main window's lower half presents you a `mixvm` command prompt and a logging area where results of the issued commands are presented. These widgets implement a `mixvm` console which offers almost the same functionality as its CLI counterpart.

When gmixvm is run, it creates a directory named .mdk in your home directory (if it does not already exist). The .mdk directory contains the program settings, the device files used by your MIX programs (see Section 6.3 [Devices], page 57), and a command history file.

The following sections describe the above mentioned components of gmixvm.

7.2 MIXVM console

In the lower half of the gmixvm main window, you will find a command text entry and, above it, an echo area. These widgets offer you the same functionality as its CLI counterpart, mixvm (see Chapter 6 [mixvm], page 47). You can issue almost all mixmv commands at the gmixvm's command prompt in order to manipulate the MIX virtual machine. Please refer to See Chapter 6 [mixvm], page 47, for a description of these commands, and to See Chapter 3 [Getting started], page 27, for a tutorial on using the MIX virtual machine. The command prompt offers command line completion for partially typed commands using the TAB key; e.g., if you type

```
lo TAB
```

the command is automatically completed to load. If multiple completions are available, they will be shown in the echo area. Thus, typing

```
p TAB
```

will produce the following output on the echo area:

```
Completions:
pc      psym      preg      pflags      pall
pmem
```

which lists all the available commands starting with p. In addition, the command prompt maintains a history of typed commands, which can be recovered using the arrow up and down keys. As mentioned above, a file containing previous sessions' commands is stored in the configuration directory ~/.mdk, and reloaded every time you start gmixvm.

You can change the font used to display the issued commands and the messages in the echo area using the Settings->Change font->Command prompt and Settings->Change font->Command log menu commands.

7.3 MIX virtual machine

The first notebook's page displays the current status of the virtual machine. There you can find the registers' contents, the value of the comparison and overflow flags, the location pointer, a list with all MIX memory cells and their contents, and the time statistics (including total uptime, elapsed time since the last run command and total execution time for the currently loaded MIX program).

If you click any register entry, you will be prompted for a new register's contents.

In the same manner, click on any address of the memory cells list to be prompted for the new contents of the clicked cell. If you click the address column's title, a dialog asking you for a memory address will appear; if you introduce a valid address, this will be the first cell displayed in the scrollable list after you click the OK button.

The register contents are shown as a list of MIX bytes plus sign. If you place the mouse pointer over any of them, the decimal value of this MIX word will appear inside a tooltip.

You can change the font used to display the MIX virtual machine contents using the `Settings->Change font->MIX` menu command.

7.4 MIXAL source view

The second notebook's page, dubbed Source, shows you the MIXAL source of the currently loaded MIX file.

The information is presented in four columns. The first column displays little icons showing the current program pointer and any set breakpoints. The second and third columns show the address and memory contents of the compiled MIX instruction, while the last one displays its corresponding MIXAL representation, together with the source file line number. You can set/unset breakpoints by clicking on any line that has an associated memory address.

You can change the font used to display the MIXAL source code using the `Settings->Change font->MIXAL` menu command.

7.5 MIX devices view

The last notebook page, dubbed Devices, shows you the output/input to/from MIX block devices (the console, line printer, paper tape, disks, card and tapes see Section 6.3 [Devices], page 57) produced by the running program.

Input device contents is read from files located in the `~/.mdk` directory, and the output is also written to files at the same location. Note that device tabs will appear as they are used by the MIX program being run, and that loading a new MIX program will close all previously open devices.

The input/output for binary block devices (tapes and disks) is a list of MIX words, which can be displayed either in decimal or word format (e.g. - 67 or - 00 00 00 01 03). The format used by `gmixvm` can be configured using the `Settings->Device output` menu command for each binary device.

You can change the font used to display the devices content using the `Settings->Change font->Devices` menu command.

7.6 Menu and status bars

The menu bar gives you access to the following commands:

`Load...` [File]

Opens a file dialog that lets you specify a binary MIX file to be loaded in the virtual machine's memory. It is equivalent to the `mixvm`'s `load` command (see Section 6.2.1 [File commands], page 48).

`Edit...` [File]

Opens a file dialog that lets your specify a MIXAL source file to be edited. It is equivalent to the `mixvm`'s `edit` command (see Section 6.2.1 [File commands], page 48). The program used for editing can be specified using the menu entry `Settings->External programs`, or using the `mixvm` command `sedit`.

`Compile...` [File]

Opens a file dialog that lets your specify a MIXAL source file to be compiled. It is equivalent to the `mixvm`'s `compile` command (see Section 6.2.1 [File commands], page 48). The command used for compiling can be specified using the menu entry `Settings->External programs`, or using the `mixvm` command `sasm`.

`Exit` [File]

Exits the application.

`Run` [Debug]

Runs the currently loaded MIX program, up to the next breakpoint. It is equivalent to the `mixvm`'s `run` command (see Section 6.2.2 [Debug commands], page 50).

`Next` [Debug]

Executes the next MIX instruction. It is equivalent to the `mixvm`'s `next` command (see Section 6.2.2 [Debug commands], page 50).

`Clear breakpoints` [Debug]

Clears all currently set breakpoints. It is equivalent to the `mixvm`'s `cabp` command.

`Symbols...` [Debug]

Opens a dialog showing the list of symbols defined in the currently loaded MIX program. The font used to display this list can be customised using the meny entry `Settings->Change font->Symbol list`.

`Toolbar(s)` [View]

Toggles the toolbar(s) in the `gmixvm` window(s) (when notebook pages are detached, each one has its own toolbar).

`Detached windows` *Virtual machine* [View]
`Detached windows` *Source* [View]
`Detached windows` *Devices* [View]

These toggles let you detach (or re-attach) the corresponding notebook page.

`Change font` [Settings]

Lets you change the font used in the various `gmixv` widgets (i.e. commad prompt, command log, Virtual machine, Source, Devices and Symbol list). There is also an entry (`All`) to change all fonts at once.

`Device output...` [Settings]

Opens a dialog that lets you specify which format shall be used to show the contents of MIX binary block devices.

The available formats are decimal (e.g. -1234) and MIX word (e.g. - 00 00 00 19 18).

`Devices dir...` [Settings]

Opens a dialog that lets you choose where the MIX device files will be stored (`~/.mdk` is the default location).

You can also specify the devices directory using the `mixvm` command `sddir` (see Section 6.2.4 [Configuration commands], page 56).

`External programs...` [Settings]

This menu command opens a dialog that lets you specify the commands used for editing and compiling MIXAL source files.

The commands are specified as template strings, where the control substring `%s` will be substituted by the actual file name. Thus, if you want to edit programs using `vi` running in an `xterm`, you must enter the command template `xterm -e vi %s` in the corresponding dialog entry. These settings can also be changed using the `mixvm` commands `sedit` and `sasm` (see Section 6.2.4 [Configuration commands], page 56).

`Save` [Settings]

Saves the current settings.

`Save on exit` [Settings]

Mark this checkbox if you want `gmixvm` to save its settings every time you quit the program.

`About...` [Help]

Shows information about `gmixvm`'s version and copyright.

On the other hand, the status bar displays the name of the last loaded MIX file. In addition, when the mouse pointer is over a MIXAL source file line that contains symbols, a list of these symbols with their values will appear in the status bar.

8 mixguile, the Scheme virtual machine

This chapter provides a reference to using mixguile and the Scheme function library giving access to the MIX virtual machine in the MDK emulators (mixguile, mixvm and gmixvm). See Section 3.4 [Using mixguile], page 33, for a tutorial, step by step introduction to mixguile and using Scheme as an extension language for the MDK MIX virtual machines.

8.1 Invoking mixguile

Invoking mixguile without arguments will enter the Guile REPL (read-eval-print loop) after loading, if it exists, the user's initialisation file (~/.mdk/mixguile.scm).

mixguile accepts the same command line options than Guile:

```
mixguile [-s SCRIPT] [-c EXPR] [-l FILE] [-e FUNCTION] [-qhv]
         [--help] [--version]
```

The meaning of these options is as follows:

-h [User Option]
--help [User Option]
: Prints usage summary and exits.

-v [User Option]
--version [User Option]
: Prints version and copyleft information and exits.

-s *SCRIPT* [User Option]
: Loads Scheme code from *script*, evaluates it and exits. This option can be used to write executable Scheme scripts, as described in Section 3.4.5 [Scheme scripts], page 39.

-c *EXPR* [User Option]
: Evaluates the given Scheme expression and exits.

-l *FILE* [User Option]
: Loads the given Scheme file and enters the REPL (read-eval-print loop).

-e *FUNCTION* [User Option]
: After reading the script, executes the given function using the provided command line arguments. For instance, you can write the following Scheme script:

```
#! /usr/bin/mixguile \
-e main -s
!#

;;; execute a given program and print the registers.

(define main
  (lambda (args)
    ;; load the file provided as a command line argument
    (mix-load (cadr args))
```

```
;; execute it
(mix-run)
;; print the contents of registers
(mix-pall)))
```

save it in a file called, say, `foo`, make it executable, and run it as

```
$ ./foo hello
```

This invocation will cause the evaluation of the `main` function with a list of command line parameters as its argument (`("./foo" "hello")` in the above example. Note that command line options to mixguile must be written in their own line after the `\` symbol.

`-q` [User Option]

Do not load user's initialisation file. When `mixguile` starts up, it looks for a file named `mixguile.scm` in the user's MDK configuration directory (`~/.mdk`), and loads it if it exists. This option tells `mixguile` to skip this initialisation file loading.

8.2 Scheme functions reference

As we have previously pointed out, `mixguile` embeds a MIX virtual machine that can be accessed through a set of Scheme functions, that is, of a Scheme library. Conversely, `mixvm` and `gmixvm` contain a Guile interpreter, and are able to use this same Scheme library, as well as all the other Guile/Scheme primitives and any user defined function. Therefore, you have at your disposal a powerful programming language, Scheme, to extend the MDK virtual machine emulators (see Section 3.5 [Using Scheme in mixvm and gmixvm], page 40, for samples of how to do it).

The following subsections describe available functions the MIX/Scheme library.

8.2.1 `mixvm` command wrappers

For each of the `mixvm` commands listed in Section 6.2 [Commands], page 48, there is a corresponding Scheme function named by prefixing the command name with `mix-` (e.g., `mix-load`, `mix-run` and so on). These command wrappers are implemented using a generic command dispatching function:

`mixvm-cmd` *command argument* [Function]

Dispatches the given *command* to the MIX virtual machine appending the provided *argument*. Both *command* and `argument` must be strings. The net result is as writing `"`*command argument*`"` at the `mixvm` or `gmixvm` command prompt.

For instance, you can invoke the `run` command at the `mixvm` prompt in three equivalent ways:

```
MIX > run hello
MIX > (mix-run "hello")
MIX > (mixvm-cmd "run" "hello")
```

(only the two last forms can be used at the `mixguile` prompt or inside a Scheme script).

The `mix-` functions evaluate to a unspecified value. If you want to check the result of the last `mixvm` command invocation, use the `mix-last-result` function:

`mix-last-result` [Function]

Returns *#t* if the last `mixvm` command invocation was successful, *#f* otherwise.

Using this function, we could improve the script for running a program presented in the previous section by adding error checking:

```
#! /usr/bin/mixguile \
-e main -s
!#

;;; Execute a given program and print the registers.

(define main
  (lambda (args)
    ;; load the file provided as a command line argument
    (mix-load (cadr args))
    ;; execute it if mix-load succeeded
    (if (mix-last-result) (mix-run))
    ;; print the contents of registers if the above commands succeeded
    (if (mix-last-result) (mix-pall))))
```

Please, refer to Section 6.2 [Commands], page 48, for a list of available commands. Given the description of a `mixvm`, it is straightforward to use its Scheme counterpart and, therefore, we shall not give a complete description of these functions here. Instead, we will only mention those wrappers that exhibit a treatment of their differing from that of their command counterpart.

`mix-preg` [*register*] [Function]
`mix-sreg` *register value* [Function]

The argument *register* of these functions can be either a string or a symbol representing the desired register. For instance, the following invocations are equivalent:

```
(mix-preg 'I1)
(mix-preg "I1")
```

`mix-pmem` *from* [*to*] [Function]

The command `pmem` takes a single argument which can be either a cell number or a range of the form `FROM-TO`. This function takes one argument to ask for a single memory cell contents, or two parameters to ask for a range. For instance, the following commands are equivalent:

```
MIX > pmem 10-12
0010: + 00 00 00 00 00 (0000000000)
0011: + 00 00 00 00 00 (0000000000)
0012: + 00 00 00 00 00 (0000000000)
MIX > (mix-pmem 10 12)
0010: + 00 00 00 00 00 (0000000000)
0011: + 00 00 00 00 00 (0000000000)
0012: + 00 00 00 00 00 (0000000000)
MIX >
```

`mix-sover` *#t*|*#f* [Function]

The command `sover` takes as argument either the string `T` or the string `F`, to set, respectively, the overflow toggle to true or false. Its Scheme counterpart, `mix-sover`, takes as argument a Scheme boolean value: `#t` (true) or `#f`.

For the remaining functions, you simply must take into account that when the command arguments are numerical, the corresponding Scheme function takes as arguments Scheme number literals. On the other hand, when the command argument is a string, the argument of its associated Scheme function will be a Scheme string. By way of example, the following invocations are pairwise equivalent:

```
MIX > load ../samples/hello
MIX > (mix-load "../samples/hello")

MIX > next 5
MIX > (mix-next 5)
```

8.2.2 Hook functions

Hooks are functions evaluated before or after executing a `mixvm` command (or its corresponding Scheme function wrapper), or after an explicit or conditional breakpoint is found during the execution of a MIX program. The following functions let you install hooks:

`mix-add-pre-hook` *command hook* [Function]

Adds a function to the list of pre-hooks associated with the given *command*. *command* is a string naming the corresponding `mixvm` command, and *hook* is a function which takes a single argument: a string list of the commands arguments. The following scheme code defines a simple hook and associates it with the `run` command:

```
(define run-hook
  (lambda (args)
    (display "argument list: ")
    (display args)
    (newline)))
(mix-add-pre-hook "run" run-hook)
```

Pre-hooks are executed, in the order they are added, before invoking the corresponding command (or its associated Scheme wrapper function).

`mix-add-post-hook` *command hook* [Function]

Adds a function to the list of pre-hooks associated with the given *command*. The arguments have the same meaning as in `mix-add-pre-hook`.

`mix-add-global-pre-hook` *hook* [Function]
`mix-add-global-post-hook` *hook* [Function]

Global pre/post hooks are executed before/after any `mixvm` command or function wrapper invocation. In this case, *hook* takes two arguments: a string with the name of the command being invoked, and a string list with its arguments.

`mix-add-break-hook` *hook* [Function]
`mix-add-cond-break` *hook* [Function]

Add a hook funtion to be executed when an explicit (resp. conditional) breakpoint is encountered during program execution. *hook* is a function taking two arguments: the source line number where the hook has occurred, and the current program counter value. The following code shows a simple definition and installation of a break hook:

```
(define break-hook
  (lambda (line address)
    (display "Breakpoint at line ") (display line)
    (display " and address ") (display address)
    (newline)))
(mix-add-break-hook break-hook)
```

Break hook functions are entirely implemented in Scheme using regular post-hooks for the `next` and `run` commands. If you are curious, you can check the Scheme source code at *prefix*`/share/mdk/mixguile-vm-stat.scm` (where *prefix* stands for your root install directory, usually `/usr` or `/usr/local`.

See Section 3.4.4 [Hook functions], page 36, for further examples on using hook functions.

8.2.3 Additional VM functions

When writing non-trivial Scheme extensions using the MIX/Scheme library, you will probably need to evaluate the contents of the virtual machine components (registers, memory cells and so on). For instance, you may need to store the contents of the `A` register in a variable. The Scheme functions described so far are of no help: you can print the contents of `A` using `(mix-preg 'A)`, but you cannot define a variable containing the contents of `A`. To address this kind of problems, the MIX/Scheme library provides the following additional functions:

`mixvm-status` [Function]
`mix-vm-status` [Function]

Return the current status of the virtual machine, as a number (`mixvm-status`) or as a symbol (`mix-vm-status`). Possible return values are:

`(mixvm-status)`	`(mix-vm-status)`	
0	MIX_ERROR	Loading or execution error
1	MIX_BREAK	Breakpoint encountered
2	MIX_COND_BREAK	Conditional breakpoint
3	MIX_HALTED	Execution terminated
4	MIX_RUNNING	Execution stopped after `next`
5	MIX_LOADED	Program successfully loaded
6	MIX_EMPTY	No program loaded

`mix-vm-error?` [Function]
`mix-vm-break?` [Function]
`mix-vm-cond-break?` [Function]
`mix-vm-halted?` [Function]
`mix-vm-running?` [Function]
`mix-vm-loaded?` [Function]
`mix-vm-empty?` [Function]

Predicates asking whether the current virtual machine status is `MIX_ERROR`, `MIX_BREAK`, etc.

`mix-reg` *register* [Function]
`mix-set-reg!` *register value* [Function]

`mix-reg` evaluates to a number which is the contents of the specified *register*. `mix-set-reg` sets the contents of the given *register* to *value*. The register can be specified either as a string (`"A"`, `"X"`, etc.) or as a symbol (`'A`, `'X`, etc.). For instance,

```
guile> (mix-reg 'A)
2341
guile> (mix-set-reg! "A" 2000)
ok
guile> (define reg-a (mix-reg 'A))
guile> (display reg-a)
2000
guile>
```

`mix-cell` *cell_no* [Function]
`mix-set-cell!` *cell_no value* [Function]

Evaluate and set the contents of the memory cell number *cell_no*. Both *cell_no* and *value* are Scheme numbers.

`mix-loc` [Function]

Evaluates to the value of the location counter (i.e., the address of the next instruction to be executed).

`mix-over` [Function]
`mix-set-over!` *#t|#f* [Function]

`mix-over` evaluates to `#t` if the overflow toggle is set, and to `#f` otherwise. The value of the overflow toggle can be modified using `mix-set-over!`.

`mix-cmp` [Function]
`mix-set-cmp!` *'L|'E|'G* [Function]

Evaluate and set the comparison flag. Possible values are the scheme symbols `L` (lesser), `E` (equal) and `G` (greater).

`mix-up-time` [Function]

Evaluates to the current virtual machine uptime.

`mix-lap-time` [Function]

Evaluates to the current virtual machine lapsed time, i.e., the time elapsed since the last `run` or `next` command.

`mix-prog-time` [Function]

Evaluates to the total time spent executing the currently loaded program.

`mix-prog-name` [Function]

Evaluates to a string containing the basename (without any leading path) of the currently loaded MIX program.

`mix-prog-path` [Function]

Evaluates to a string containing the full path to the currently loaded MIX program.

`mix-src-path` [Function]

Evaluates to a string containing the full path to the source file of the currently loaded MIX program.

`mix-src-line` [*lineno*] [Function]

`mix-src-line-no` [Function]

`mix-src-line-no` evaluates to the current source file number during the execution of a program. `mix-src-line` evaluates to a string containing the source file line number *lineno*; when invoked without argument, it evaluates to `(mix-src-line (mix-src-line-no))`.

`mix-ddir` [Function]

Evaluates to a string containing the full path of the current device directory.

9 Reporting Bugs

If you have any questions, comments or suggestions, please send electronic mail to the author.

If you find a bug in MDK, please send electronic mail to the MDK bug list.

In your report, please include the version number, which you can find by running '`mixasm --version`'. Also include in your message the output that the program produced and the output you expected.

Appendix A Copying

GNU MDK is distributed under the GNU General Public License (GPL) and this manual under the GNU Free Documentation License (GFDL).

A.1 GNU General Public License

Version 3, 29 June 2007

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Concept Index

Instructions and commands

M

N

O

P

Q

R

S

T

W