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Preface

OpenBoot 3.x Command Reference describes how to use Sun™ systems that implement firmware that responds as those described by IEEE Standard 1275-1994., Standard For Boot Firmware.

This manual contains information on using the OpenBoot firmware to perform tasks such as:

- Booting the operating system
- Running diagnostics
- Modifying system start-up configuration parameters
- Loading and executing programs
- Troubleshooting

This manual also describes the commands of the OpenBoot Forth Interpreter which you can use to write Forth programs or if you want or use the more advanced features of this firmware (such as its debugging capabilities).

Who Should Use This Book

This manual is written for all users, including systems designers, systems administrators, and end users, who want to use the OpenBoot to configure and debug their SBus and PCI-based systems.
Assumptions

The information in this manual is for a system that uses Version 3.x OpenBoot. Other OpenBoot implementations may use different prompts or formatting, and may not support all of the tools and capabilities described in this manual.

How This Book Is Organized

Chapter 1 describes the user interface and other main features of OpenBoot.

Chapter 2 explains the most common tasks for which OpenBoot is used.

Chapter 3 details how to perform system administration tasks with NVRAM parameters.

Chapter 4 describes both basic and advanced functions of the OpenBoot Forth language.

Chapter 5 describes how to load and execute programs from various sources (such as Ethernet, disk, or serial port).

Chapter 6 describes the debugging capabilities of the OpenBoot, including decompiler, Forth source-level debugger, and breakpoints.

Appendix A describes how to create a bootable floppy diskette from which you can load programs or files.

Appendix B describes how to create a bootable floppy diskette from which you can load programs or files.

Appendix C discusses solutions for typical situations when you cannot boot the operating system.

Appendix D contains some PCI-related information for Sun Ultra 5/10 systems.

Appendix E contains some PCI-related information for Sun Ultra 30 systems.

Appendix F contains some PCI-related information for Sun Ultra 60 systems.

Appendix G contains some PCI-related information for Sun Ultra 250 systems.

Appendix H contains some PCI-related information for Sun Ultra 450 systems.

Appendix I contains all currently-supported OpenBoot Forth commands.
Related Documentation

A companion document to this manual is:
- OpenBoot 3.x Quick Reference Guide

For information on OpenBoot FCode, refer to:
- Writing FCode 2.x Programs
- Writing FCode 3.x Programs

For information about Open Firmware, refer to the following manual:


For more information about Forth and Forth programming, refer to:
- Forth Interest Group (1-510-89-FORTH)

http://forth.org/fig.html
What Typographic Changes and Symbols Mean

The following table describes the typeface changes and symbols used in this book.

**TABLE P-1  Typographic Conventions**

<table>
<thead>
<tr>
<th>Typeface or Symbol</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>AaBbCc123</td>
<td>The names of commands, files, and directories; on-screen computer output</td>
<td>Edit your .login file. Use <code>ls -a</code> to list all files. `machine_name% You have mail.</td>
</tr>
<tr>
<td>AaBbCc123</td>
<td>What you type, contrasted with on-screen computer output</td>
<td><code>machine_name% su Password:</code></td>
</tr>
<tr>
<td>AaBbCc123</td>
<td>Command-line placeholder: replace with a real name or value</td>
<td>To delete a file, type <code>rm filename</code>.</td>
</tr>
<tr>
<td>AaBbCc123</td>
<td>Book titles, new words or terms, or words to be emphasized</td>
<td>Read Chapter 6 in <em>User’s Guide</em>. These are called <em>class</em> options. You <em>must</em> be root to do this.</td>
</tr>
</tbody>
</table>

Code samples are included in boxes and may display the following:

- **ok** OpenBoot command prompt `ok`
- **%** UNIX C shell prompt `system%`
- **$** UNIX Bourne and Korn shell prompt `system$
- **#** Superuser prompt, all shells `system#`

This manual follows a number of typographic conventions:

- Keys are indicated by their name. For example:

  Press the Return key.

- When you see two key names separated by a dash, press and hold the first key down, then press the second key. For example:

  To enter Control-C, press and hold Control, then press C, then release both keys.

- When you see two key names separated by a space, press and release the first key and then press and release the second key. For example:
To enter Escape B, press and release Escape, then press and release B.
- In a command line, square brackets indicate an optional entry and italics indicate an argument that you must replace with the appropriate text. For example:

```
help [word]
```

---

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- Email: smcc-docs@sun.com
- Fax: SMCC Document Feedback
  1-415-786-6443
Overview

This chapter introduces OpenBoot as defined by *IEEE Standard 1275-1994.*, Standard for Boot Firmware. OpenBoot firmware is executed immediately after you turn on your system. The primary tasks of OpenBoot firmware are to:

- Test and initialize the system hardware
- Determine the hardware configuration
- Boot the operating system from either a mass storage device or from a network
- Provide interactive debugging facilities for testing hardware and software

Features of OpenBoot

The OpenBoot architecture provides a significant increase in functionality and portability when compared to proprietary systems of the past. Although this architecture was first implemented by Sun Microsystems as OpenBoot on SPARC systems, its design is processor-independent. The following paragraphs describe some notable features of OpenBoot firmware.

Plug-in Device Drivers

A plug-in device driver is usually loaded from a plug-in device such as an SBus card. The plug-in device driver can be used to boot the operating system from that device or to display text on the device before the operating system has activated its own drivers. This feature enables the input and output devices supported by a particular system to evolve without changing the system PROM.
FCode Interpreter

Plug-in drivers are written in a *machine-independent* interpreted language called *FCode*. Each OpenBoot system PROM contains an FCode interpreter. Thus, the same device and driver can be used on machines with different CPU instruction sets.

Device Tree

The device tree is a data structure describing the devices (permanently installed and plug-in) attached to a system. Both the user and the operating system can determine the hardware configuration of the system by inspecting the device tree.

Programmable User Interface

The OpenBoot User Interface is based on the interactive programming language Forth. Sequences of user commands can be combined to form complete programs, and this provides a powerful capability for debugging hardware and software.

The User Interface

The user interface is based on an interactive command interpreter that gives you access to an extensive set of functions for hardware and software development, fault isolation, and debugging. Any level of users can use these functions.

The user interface prompt is implementation dependent.

You can enter the OpenBoot environment in the following ways:

- By halting the operating system
- By pressing the Stop-A key
- By power-cycling the system

If your system is not configured to boot automatically, the system will stop at the user interface.

If automatic booting is configured, you can make the system stop at the user interface by pressing the Stop-A keys from the keyboard after the display console banner is displayed but before the system starts booting the operating system.

- When the system hardware detects an error from which it cannot recover (This is known as a Watchdog Reset.)
See “A Caution About Using Some OpenBoot Commands” on page 11 for information on using commands after entering OpenBoot from the operating system.

The Device Tree

Devices are attached to a host computer through a hierarchy of interconnected buses. OpenBoot represents the interconnected buses and their attached devices as a tree of nodes. Such a tree is called the device tree. A node representing the host computer’s main physical address bus forms the tree’s root node.

Each device node can have:

- Properties, which are data structures describing the node and its associated device
- Methods, which are the software procedures used to access the device
- Data, which are the initial values of the private data used by the methods
- Children, which are other device nodes “attached” to a given node and that lie directly below it in the device tree
- A parent, which is the node that lies directly above a given node in the device tree.

Nodes with children usually represent buses and their associated controllers, if any. Each such node defines a physical address space that distinguishes the devices connected to the node from one another. Each child of that node is assigned a physical address in the parent’s address space.

The physical address generally represents a physical characteristic unique to the device (such as the bus address or the slot number where the device is installed). The use of physical addresses to identify devices prevents device addresses from changing when other devices are installed or removed.

Nodes without children are called leaf nodes and generally represent devices. However, some such nodes represent system-supplied firmware services.
Device Path Names, Addresses, and Arguments

OpenBoot deals directly with hardware devices in the system. Each device has a unique name representing the type of device and where that device is located in the system addressing structure. The following example shows a full device path name:

```
/sbus@1f,0/SUNW,fas@e,8800000/sd@3,0:a
```

A full device path name is a series of node names separated by slashes (/). The root of the tree is the machine node, which is not named explicitly but is indicated by a leading slash (/). Each node name has the form:

```
driver-name@unit-address:device-arguments
```

TABLE 1-1 describes each of these parameters.

<table>
<thead>
<tr>
<th>Path Name Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>driver-name</code></td>
<td>A human-readable string consisting of one to 31 letters, digits and punctuation characters from the set &quot;-, _ + -&quot; that, ideally, has some mnemonic value. Uppercase and lowercase characters are distinct. In some cases, this name includes the name of the device’s manufacturer and the device’s model name, separated by a comma. Typically, the manufacturer’s upper-case, publicly-listed stock symbol is used as the manufacturer’s name (e.g. SUNW, sd). For built-in devices, the manufacturer’s name is usually omitted (e.g. sbus).</td>
</tr>
<tr>
<td><code>@</code></td>
<td>Must precede the address parameter.</td>
</tr>
<tr>
<td><code>unit-address</code></td>
<td>A text string representing the physical address of the device in its parent’s address space. The format of the text is bus dependent.</td>
</tr>
<tr>
<td><code>:</code></td>
<td>Must precede the arguments parameter.</td>
</tr>
<tr>
<td><code>device-arguments</code></td>
<td>A text string, whose format depends on the particular device. It can be used to pass additional information to the device’s software.</td>
</tr>
</tbody>
</table>

The full device path name mimics the hardware addressing used by the system to distinguish between different devices. Thus, you can specify a particular device without ambiguity.

In general, the `unit-address` part of a node name represents an address in the physical address space of its parent. The exact meaning of a particular address depends on the bus to which the device is attached. Consider this example:

```
/sbus@1f,0/esp@0,400000/sd@3,0:a
```
1f,0 represents an address on the main system bus, because the SBus is directly attached to the main system bus in this example.

0,40000 is an SBus slot number (in other words, 0) and an offset (in other words, 40000), because the esp device is at offset 40000 on the card in SBus slot 0.

3,0 is a SCSI target and logical unit number, because the disk device is attached to a SCSI bus at target 3, logical unit 0.

When specifying a path name, either the unit-address or driver-name part of a node name is optional, in which case the firmware tries to pick the device that best matches the given name. If there are several matching nodes, the firmware chooses one (but it may not be the one you want).

For example, using /sbus/esp@0,40000/sd@3,0 assumes that the system in question has exactly one SBus on the main system bus, making sbus as unambiguous an address as sbus@1f,0. On the same system, however, /sbus/esp/sd@3,0 might or might not be ambiguous. Since SBus accepts plug-in cards, there could be more than one esp device on the same SBus bus. If there were more than one on the system, using esp alone would not specify which one, and the firmware might not choose the one you intended.

As another example, /sbus/@2,1/sd@3,0 would normally be unambiguous, while /sbus/scsi@2,1/@3,0 usually would not, since both a SCSI disk device driver and a SCSI tape device driver can use the SCSI target, logical unit address 3,0.

The device-arguments part of the node name is also optional. Once again, in the example:

```
/sbus@1f,0/scsi@2,1/sd@3,0:a
```

the argument for the disk device is a. The software driver for this device interprets its argument as a disk partition, so the device path name refers to partition a on that disk.

Some implementations also enable you to omit path name components. So long as the omission does not create any ambiguity, those implementations will select the device that you intended. For example, if our example system had only one sd device,/sd:a would identify the same device as the much longer preceding expression.

**Device Aliases**

A device alias, or simply, alias, is a shorthand representation of a device path.
For example, the alias disk may represent the complete device path name:

```
/sbus@1f,0/esp@0,40000/sd@3,0:a
```

Systems usually have predefined device aliases for the most commonly used devices, so you rarely need to type a full device path name.

TABLE 1-2 describes the `devalias` command, which is used to examine, create, and change aliases.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>devalias</code></td>
<td>Display all current device aliases.</td>
</tr>
<tr>
<td><code>devalias alias</code></td>
<td>Display the device path name corresponding to alias.</td>
</tr>
<tr>
<td><code>devalias aliasdevice-path</code></td>
<td>Define an alias representing device-path. If an alias with the same name already exists, the new value supersedes the old.</td>
</tr>
</tbody>
</table>

User-defined aliases are lost after a system reset or power cycle. If you want to create permanent aliases, you can either manually store the `devalias` command in a portion of non-volatile RAM (NVRAM) called `nvramrc`, or use the `nvalias` and `nvunalias` commands. (See Chapter 3, for more details.)

### Displaying the Device Tree

You can browse the device tree to examine and modify individual device tree nodes. The device tree browsing commands are similar to the Solaris™ commands for changing, displaying and listing the current directory in the Solaris directory tree. Selecting a device node makes it the current node.

The User Interface commands for browsing the device tree are shown in TABLE 1-3.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.properties</code></td>
<td>Display the names and values of the current node’s properties.</td>
</tr>
<tr>
<td><code>dev device-path</code></td>
<td>Choose the indicated device node, making it the current node.</td>
</tr>
<tr>
<td><code>dev node-name</code></td>
<td>Search for a node with the given name in the subtree below the current node, and choose the first such node found.</td>
</tr>
</tbody>
</table>
### TABLE 1-3  Commands for Browsing the Device Tree  (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>dev ..</td>
<td>Choose the device node that is the parent of the current node.</td>
</tr>
<tr>
<td>dev /</td>
<td>Choose the root machine node.</td>
</tr>
<tr>
<td>device-end</td>
<td>Leave the device tree.</td>
</tr>
<tr>
<td>&quot;device-path&quot; find-device</td>
<td>Choose device node, similar to dev.</td>
</tr>
<tr>
<td>ls</td>
<td>Display the names of the current node’s children.</td>
</tr>
<tr>
<td>pwd</td>
<td>Display the device path name that names the current node.</td>
</tr>
<tr>
<td>see wordname</td>
<td>Decompile the specified word.</td>
</tr>
<tr>
<td>show-devs [device-path]</td>
<td>Display all the devices directly beneath the specified device in the device tree. show-devs used by itself shows the entire device tree.</td>
</tr>
<tr>
<td>words</td>
<td>Display the names of the current node’s methods.</td>
</tr>
<tr>
<td>&quot;device-path&quot; select-dev</td>
<td>Select the specified device and make it the active node.</td>
</tr>
</tbody>
</table>

.properties displays the names and values of all the properties in the current node:

```plaintext
ok  dev   /zs@1,f0000000
ok  .properties
address                ffee9000
port-b-ignore-cd
port-a-ignore-cd
keyboard
device_type           serial
slave                 00000001
intr                  0000000c  00000000
interrupts            0000000c
reg                   00000001  f0000000  00000008
name                  zs
ok
```

develops the current node to the named node so its contents can be viewed. For example, to make the ACME company’s SBus device named “ACME,widget” the current node:

```plaintext
ok  dev       /sbus/ACME,widget
```
find-device is essentially identical to dev differing only in the way the input pathname is passed.

```plaintext
ok "/sbus/ACME,widget" find-device
```

**Note** – After choosing a device node with dev or find-device, you can’t execute that node’s methods because dev does not establish the current instance. For a detailed explanation of this issue, refer to Writing FCode 3.x Programs.
show-devs lists all the devices in the OpenBoot device tree, as shown in the following example:

```
ok show-devs
/SUNW,UltraSPARC@0,0
/sbus@1f,0
/counter-timer@1f,3c00
/virtual-memory
/memory@0,0
/aliases
/options
/openprom
/chosen
/packages
/sbus@1f,0/cgsix@1,0
/sbus@1f,0/lebuffer@0,40000
/sbus@1f,0/dma@0,81000
/sbus@1f,0/SUNW,bpp@e,c800000
/sbus@1f,0/SUNW,hme@e,8c00000
/sbus@1f,0/SUNW,fas@e,8800000
/sbus@1f,0/sc@f,1300000
/sbus@1f,0/zs@f,1000000
/sbus@1f,0/zs@f,1100000
/sbus@1f,0/eeprom@f,1200000
/sbus@1f,0/SUNW,fdtwo@f,1400000
/sbus@1f,0/flashprom@f,0
/sbus@1f,0/auxio@f,1900000
/sbus@1f,0/SUNW,CS4231@d,c000000
/sbus@1f,0/SUNW,fas@e,8800000/st
/sbus@1f,0/SUNW,fas@e,8800000/sd
/openprom/client-services
/packages/disk-label
/packages/obp-tftp
/packages/deblocker
/packages/terminal-emulator
ok
```

Here is an example of the use of words:

```
ok dev /zs
ok words
ring-bell   read        remove-abort?  install-abort
close       open         abort?        restore
clear       reset        initkbdmouse  keyboard-addr mouse
1200baud    setbaud     initport      port-addr
```
Getting Help

Whenever you see the ok prompt on the display, you can ask the system for help by typing one of the help commands shown in TABLE 1-4.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>help</td>
<td>List main help categories.</td>
</tr>
<tr>
<td>help category</td>
<td>Show help for all commands in the category. Use only the first word of the category description.</td>
</tr>
<tr>
<td>help command</td>
<td>Show help for individual command (where available).</td>
</tr>
</tbody>
</table>

help, without any specifier, displays instructions on how to use the help system and lists the available help categories. Because of the large number of commands, help is available only for commands that are used frequently.

If you want to see the help messages for all the commands in a selected category, or, possibly, a list of subcategories, type:

```
ok help category
```

If you want help for a specific command, type:

```
ok help command
```

For example, when you ask for information on the dump command, you might see the following message:

```
ok help dump
Category: Memory access
dump ( addr length -- ) display memory at addr for length bytes
ok
```

The above help message first shows that dump is a command from the Memory access category. The message also shows the format of the command.
Note – In some newer systems, descriptions of additional machine-specific commands are available with the `help` command. Help as described may not be available on all systems.

A Caution About Using Some OpenBoot Commands

OpenBoot may not operate correctly after the operating system has begun execution. (For example, after `Stop-a` or `halt`.) This occurs when the operating system can modify the system state in ways that are inconsistent with continued OpenBoot operation. In this case, you may have to power cycle the system to restore normal operation.

For example, suppose you boot the operating system, exit to OpenBoot, then execute the `probe-scsi` command (described in “Booting and Testing Your System”). You may find that `probe-scsi` fails, and you may not be able to resume the operating system, or you may have to power cycle the systems.

Re-execute an OpenBoot command that failed because the operating system has executed:

1. **Note the value of `auto-boot?` NVRAM configuration variable using `printenv`. If it is true, set the value to false using `SETENV`.
2. Reset the system.
3. Execute OpenBoot command after it stops at the user interface.
4. Restore the value of `auto-boot?` NVRAM configuration.
5. Reset the system.
Booting and Testing Your System

This chapter describes the most common tasks that you perform using OpenBoot. These tasks enable you to:

- Boot your system
- Run diagnostics
- Display system information
- Reset the system

Booting Your System

The most important function of OpenBoot firmware is to boot the system. Booting is the process of loading and executing a stand-alone program such as an operating system. Booting can either be initiated automatically or by typing a command at the User Interface.

The boot process is controlled by a number of configuration variables. (Configuration variables are discussed in detail in Chapter 3) The configuration variables that affect the boot process are:

- **auto-boot?**
  
  This variable controls whether or not the system automatically boots after a system reset or when the power is turned on. This variable is typically **true**.

- **boot-command**
  
  This variable specifies the command to be executed when **auto-boot?** is **true**. The default value of **boot-command** is **boot** with no command line arguments.

- **diag-switch?**
  
  If the value is **true**, run in the Diagnostic mode. This variable is **false** by default.

- **boot-device**
This variable contains the name of the default boot device that is used when OpenBoot is not in diagnostic mode.

- **boot-file**

This variable contains the default boot arguments that are used when OpenBoot is not in diagnostic mode.

- **diag-device**

This variable contains the name of the default diagnostic mode boot device.

- **diag-file**

This variable contains the default diagnostic mode boot arguments.

Based on the values of the above configuration variables, the boot process can proceed in a number of different ways. For instance:

- If `auto-boot?` is true, the machine will boot from either the default boot device or from the diagnostic boot device depending on whether OpenBoot is in diagnostic mode.

- If `auto-boot?` is false, the machine will stop at the OpenBoot User Interface without booting the system. To boot the system, you can do one of the following:
  - Type the `boot` command without any arguments. The machine will boot from the default boot device using the default boot arguments.
  - Type the `boot` command with an explicit boot device. The machine will boot from the specified boot device using the default boot arguments.
  - Type the `boot` command with explicit boot arguments. The machine will use the specified arguments to boot from the default boot device.
  - Type the `boot` command with an explicit boot device and with explicit arguments. The machine will boot from the specified device with the specified arguments.

**Booting for the Casual User**

Typically, `auto-boot?` will be true, `boot-command` will be `boot`, and OpenBoot will not be in diagnostic mode. Consequently, the system will automatically load and execute the program and arguments described by `boot-file` from the device described by `boot-device` when the system is first turned on or following a system reset.

If you want to boot the default program when `auto-boot?` is false, simply type boot at the `ok` prompt.
Booting for the Expert User

Booting is the process of loading and executing a client program. The client program is normally an operating system or an operating system’s loader program, but boot can also be used to load and execute other kinds of programs, such as diagnostics. (For more details about loading programs other than the operating system, see Chapter 5”).

Booting usually happens automatically based on the values contained in the configuration variables described above. However, the user can also initiate booting from the User Interface.

OpenBoot performs the following steps during the boot process:

- The firmware may reset the machine if a client program has been executed since the last reset. (The execution of a reset is implementation dependent.)
- A device is selected by parsing the boot command line to determine the boot device and the boot arguments to use. Depending on the form of the boot command, the boot device and/or argument values may be taken from configuration variables.
- The bootpath and bootargs properties in the /chosen node of the device tree are set with the selected values.
- The selected program is loaded into memory using a protocol that depends on the type of the selected device. For example, a disk boot might read a fixed number of blocks from the beginning of the disk, while a tape boot might read a particular tape file.
- The loaded program is executed. The behavior of the program may be further controlled by the argument string (if any) that was either contained in the selected configuration variable or was passed to the boot command on the command line.

Often, the program loaded and executed by the boot process is a secondary boot program whose purpose is to load yet another program. This secondary boot program may use a protocol different from that used by OpenBoot to load the secondary boot program. For example, OpenBoot might use the Trivial File Transfer Protocol (TFTP) to load the secondary boot program while the secondary boot program might then use the Network File System (NFS) protocol to load the operating system.

Typical secondary boot programs accept arguments of the form:

filename  -flags

where filename is the name of the file containing the operating system and where -flags is a list of options controlling the details of the start-up phase of either the secondary boot program, the operating system or both. Please note that, as shown in
the `boot` command template immediately below, OpenBoot treats all such text as a single, opaque `arguments` string that has no special meaning to OpenBoot itself; the arguments string is passed unaltered to the specified program.

The `boot` command has the following format:

```
ok boot [device-specifier] [arguments]
```

The optional parameters for the `boot` command are described in TABLE 2-1.

**TABLE 2-1 Optional `boot` Command Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
</table>
| `[device-specifier]` | The name (full path name or devalias) of the boot device. Typical values include: cdrom (CD-ROM drive) disk (hard disk) floppy (3-1/2” diskette drive) net (Ethernet) tape (SCSI tape)
If device-specifier is not specified and if diagnostic-mode? returns false, boot uses the device specified by the boot-device configuration variable. If device-specifier is not specified and if diagnostic-mode? returns true, boot uses the device specified by the diag-device configuration variable. |
| `[arguments]`    | The name of the program to be booted (e.g. stand/diag) and any program arguments. If `arguments` is not specified and if diagnostic-mode? returns false, boot uses the file specified by the boot-file configuration variable. If `arguments` is not specified and if diagnostic-mode? returns true, boot uses the file specified by the diag-file configuration variable. |

**Note** – Most commands (such as `boot` and `test`) that require a device name accept either a full device path name or a device alias. In this manual, the term `device-specifier` indicates that either an appropriate device path name or a device alias is acceptable for such commands.

Since a device alias cannot be syntactically distinguished from the `arguments`, OpenBoot resolves this ambiguity as follows:

- If the space-delimited word following `boot` on the command line begins with `/`, the word is a device-path and, thus, a `device-specifier`. Any text to the right of this `device-specifier` is included in `arguments`.
- Otherwise, if the space-delimited word matches an existing device alias, the word is a `device-specifier`. Any text to the right of this `device-specifier` is included in `arguments`. 
Otherwise, the appropriate default boot device is used, and any text to the right of `boot` is included in arguments.

Consequently, `boot` command lines have the following possible forms.

```
ok boot
```

With this form, `boot` loads and executes the program specified by the default boot arguments from the default boot device.

```
ok boot device-specifier
```

If `boot` has a single argument that either begins with the character `/` or is the name of a defined `devalias`, `boot` uses the argument as a device specifier. `boot` loads and executes the program specified by the default boot arguments from the specified device.

For example, to explicitly boot from the primary disk, type:

```
ok boot disk
```

To explicitly boot from the primary network device, type:

```
ok boot net
```

If `boot` has a single argument that neither begins with the character `/` nor is the name of a defined `devalias`, `boot` uses all of the remaining text as its arguments.

```
ok boot arguments
```

`boot` loads and executes the program specified by the arguments from the default boot device.

```
ok boot device-specifier arguments
```

If there are at least two space-delimited arguments, and if the first such argument begins with the character `/` or if it is the name of a defined `devalias`, `boot` uses the first argument as a device specifier and uses all of the remaining text as its arguments. `boot` loads and executes the program specified by the arguments from the specified device.
For all of the above cases, boot records the device that it uses in the bootpath property of the /chosen node. boot also records the arguments that it uses in the bootargs property of the /chosen node.

Device alias definitions vary from system to system. Use the devalias command, described in Chapter 1”, to obtain the definitions of your system’s aliases.

---

Running Diagnostics

Several diagnostic routines are available from the User Interface. These on-board tests let you check devices such as the network controller, the floppy disk system, memory, installed SBus cards and SCSI devices, and the system clock.

The value returned by diagnostic-mode? controls:

- The selection of the device and file that are used by the boot and load commands (if the device and file are not explicitly specified as arguments to those commands).
- The extent of the diagnostics performed during power-on self-test, and the (implementation dependent) number of diagnostic messages produced.

OpenBoot will be in diagnostic mode and the diagnostic-mode? command will return true if at least one of the following conditions is met:

- The configuration variable diag-switch? is set to true.
- The machine’s diagnostic switch (if any) is “on”.
- Another system-dependent indicator requests extensive diagnostics.

When OpenBoot is in the Diagnostic mode, the value of diag-device is used as the default boot device and the value of diag-file is used as the default boot arguments for the boot command.

When OpenBoot is not in the Diagnostic mode, the value of boot-device is used as the default boot device and the value of boot-file is used as the default boot arguments for the boot command.
TABLE 2-2 lists diagnostic test commands. Not all of these tests are available in all OpenBoot implementations.

**TABLE 2-2  Diagnostic Test Commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>probe-scsi</td>
<td>Identify devices attached to a SCSI bus.</td>
</tr>
<tr>
<td>test device-specifier</td>
<td>Execute the specified device’s selftest method. For example:</td>
</tr>
<tr>
<td>watch-clock</td>
<td>Test a clock function.</td>
</tr>
<tr>
<td>watch-net</td>
<td>Monitor a network connection.</td>
</tr>
</tbody>
</table>

### Testing the SCSI Bus

To check a SCSI bus for connected devices, type:

```
ok probe-scsi
Target 1
   Unit 0 Disk SEAGATE ST1480 SUN04246266 Copyright (C) 1991 Seagate All rights reserved
Target 3
   Unit 0 Disk SEAGATE ST1480 SUN04245826 Copyright (C) 1991 Seagate All rights reserved
ok
```

The actual response depends on the devices on the SCSI bus.

### Testing Installed Devices

To test a single installed device, type:

```
ok test device-specifier
```

In general, if no message is displayed, the test succeeded.
Note – Many devices require the system’s `diag-switch?` parameter to be true in order to run this test.

Testing the Diskette Drive

The diskette drive test determines whether or not the diskette drive is functioning properly. For some implementations, a formatted, high-density (HD) disk must be in the diskette drive for this test to succeed.

To test the diskette drive, type:

```
ok test floppy
Testing floppy disk system. A formatted disk should be in the drive.
Test succeeded.
ok
```

Note – Not all OpenBoot systems include this test word.

To eject the diskette from the diskette drive of a system capable of software-controlled ejection, type:

```
ok eject-floppy
ok
```

Testing Memory

To test memory, type:

```
ok test /memory
Testing 16 megs of memory at addr 4000000 11
ok
```

Note – Not all OpenBoot systems include this test word.
In the preceding example, the first number (4000000) is the base address of the testing, and the following number (11) is the number of megabytes to go.

Testing the Clock

To test the clock function, type:

```
ok watch-clock
Watching the ‘seconds’ register of the real time clock chip.
It should be ticking once a second.
Type any key to stop.
1
ok
```

The system responds by incrementing a number once a second. Press any key to stop the test.

**Note** – Not all OpenBoot systems include this test word.

Testing the Network Controller

To test the primary network controller, type:

```
ok test net
Internal Loopback test - (result)
External Loopback test - (result)
ok
```

The system responds with a message indicating the result of the test.

**Note** – Depending on the particular network controller and the type of network to which your system is attached, various levels of testing are possible. Some such tests may require that the network interface be connected to the network.
Monitoring the Network

To monitor a network connection, type:

```
ok watch-net
Internal Loopback test - succeeded
External Loopback test - succeeded
Looking for Ethernet packets.
'.' is a good packet. 'X' is a bad packet.
Type any key to stop
....................X.....X.............
ok
```

The system monitors network traffic, displaying “." each time it receives an error-free packet and “X” each time it receives a packet with an error that can be detected by the network hardware interface.

**Note** – Not all OpenBoot systems include this test word.

Displaying System Information

The User Interface provides one or more commands to display system information. `banner` is provided by all OpenBoot implementations; the remaining commands represent extensions provided by some implementations. These commands, listed in **TABLE 2-3**, let you display the system banner, the Ethernet address for the Ethernet controller, the contents of the ID PROM, and the version number of OpenBoot. (The ID PROM contains information specific to each individual machine, including the serial number, date of manufacture, and Ethernet address assigned to the machine.)

**TABLE 2-3** System Information Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>banner</td>
<td>Display power-on banner.</td>
</tr>
<tr>
<td>show-sbus</td>
<td>Display list of installed and probed SBus devices.</td>
</tr>
<tr>
<td>.enet-addr</td>
<td>Display current Ethernet address.</td>
</tr>
<tr>
<td>.idprom</td>
<td>Display ID PROM contents, formatted.</td>
</tr>
</tbody>
</table>
reset-all

If your system is set up to run the power-on self-test (POST) and initialization procedures on reset, these procedures begin executing once you initiate this command. (On some systems, POST is only executed after power-on.) Once POST completes, the system either boots automatically or enters the User Interface, just as it would have done after a power cycle.

Also see the device tree browsing commands in TABLE 1-3.
This chapter describes how to access and modify non-volatile RAM (NVRAM) configuration variables.

System configuration variables are stored in the system NVRAM. These variables determine the start-up machine configuration and related communication characteristics. You can modify the values of the configuration variables, and any changes you make remain in effect even after a power cycle. Configuration variables should be adjusted cautiously.

The procedures described in this chapter assume that the user interface is active. See Chapter 1 for information about entering the user interface.

TABLE 3-1 lists a typical set of NVRAM configuration variables defined by IEEE Standard 1275-1994.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Typical Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>auto-boot?</td>
<td>true</td>
<td>If true, boot automatically after power on or reset.</td>
</tr>
<tr>
<td>boot-command</td>
<td>boot</td>
<td>Command that is executed if auto-boot? is true.</td>
</tr>
<tr>
<td>boot-device</td>
<td>disk net</td>
<td>Device from which to boot.</td>
</tr>
<tr>
<td>boot-file</td>
<td>empty string</td>
<td>Arguments passed to booted program.</td>
</tr>
<tr>
<td>diag-device</td>
<td>net</td>
<td>Diagnostic boot source device.</td>
</tr>
<tr>
<td>diag-file</td>
<td>empty string</td>
<td>Arguments passed to booted program in diagnostic mode.</td>
</tr>
<tr>
<td>diag-switch?</td>
<td>false</td>
<td>If true, run in diagnostic mode.</td>
</tr>
<tr>
<td>fcode-debug?</td>
<td>false</td>
<td>If true, include name fields for plug-in device FCodes.</td>
</tr>
<tr>
<td>input-device</td>
<td>keyboard</td>
<td>Console input device (usually keyboard, ttya, or ttyb).</td>
</tr>
<tr>
<td>nvramrc</td>
<td>empty</td>
<td>Contents of NVRAMRC.</td>
</tr>
<tr>
<td>oem-banner</td>
<td>empty string</td>
<td>Custom OEM banner (enabled by oem-banner? true).</td>
</tr>
</tbody>
</table>
An additional configuration variable is defined by the SBus binding to IEEE Standard 1275-1994. The variable is shown in TABLE 3-2.

### TABLE 3-2  SBus Configuration Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>Typical Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>sbus-probe-list</td>
<td>0123</td>
<td>Which SBus slots to probe and in what order.</td>
</tr>
</tbody>
</table>

**Note** — Different OpenBoot implementations may use different defaults and/or different configuration variables.
Displaying and Changing Variable Settings

NVRAM configuration variables can be viewed and changed using the commands listed in TABLE 3-3.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>printenv</td>
<td>Display current variables and current default values.</td>
</tr>
<tr>
<td>printenv variable</td>
<td>Shows the current value of the named variable.</td>
</tr>
<tr>
<td>setenv variable value</td>
<td>Set variable to the given decimal or text value.</td>
</tr>
<tr>
<td>set-default variable</td>
<td>Reset the value of variable to the factory default.</td>
</tr>
<tr>
<td>set-defaults</td>
<td>Reset variable values to the factory defaults.</td>
</tr>
<tr>
<td>password</td>
<td>Set security-password</td>
</tr>
</tbody>
</table>

The following pages show how these commands can be used.

**Note** – Solaris provides the `eeprom` utility for modifying OpenBoot configuration variables.
To display a list of the current variable settings on your system, type:

```
ok printenv
```

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Value</th>
<th>Default Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>oem-logo</td>
<td>31 2c 2d 00 00 00 00 ...</td>
<td></td>
</tr>
<tr>
<td>oem-logo?</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>oem-banner</td>
<td></td>
<td></td>
</tr>
<tr>
<td>oem-banner?</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>output-devicettyascreen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>input-devicettyakeyboard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sbus-probe-list</td>
<td>030123</td>
<td></td>
</tr>
<tr>
<td>diag-file</td>
<td></td>
<td></td>
</tr>
<tr>
<td>diag-devicenetnet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>boot-file</td>
<td></td>
<td></td>
</tr>
<tr>
<td>boot-devicediskdisknet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>auto-boot?</td>
<td>false</td>
<td>true</td>
</tr>
<tr>
<td>fcode-debug?</td>
<td>true</td>
<td>false</td>
</tr>
<tr>
<td>use-nvramrc?</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>nvramrc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>screen-#columns</td>
<td>8080</td>
<td></td>
</tr>
<tr>
<td>screen-#rows</td>
<td>3434</td>
<td></td>
</tr>
<tr>
<td>security-modenone</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>security-password</td>
<td></td>
<td></td>
</tr>
<tr>
<td>security-#badlogins</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>diag-switch?</td>
<td>true</td>
<td>false</td>
</tr>
</tbody>
</table>
| ok
```

In the displayed, formatted list of the current settings, numeric variables are often shown in decimal.

To change a variable setting, type:

```
ok setenv variable-name value
```

`variable-name` is the name of the variable. `value` is a numeric value or text string appropriate to the named variable. A numeric value is interpreted as a decimal number, unless preceded by 0x, which is the qualifier for a hexadecimal number.

For example, to set the auto-boot? variable to false, type:

```
ok setenv auto-boot? false
ok
```
**Note** – *Many variable changes do not affect the operation of the firmware until the next power cycle or system reset at which time the firmware uses the variable’s new value.*

You can reset one or most of the variables to the original defaults using the set-default variable and set-defaults commands.

For example, to reset the auto-boot? variable to its default setting (true), type:

```plaintext
ok set-default auto-boot?
ok
```

To reset most variables to their default settings, type:

```plaintext
ok set-defaults
ok
```

On SPARC systems, it is possible to reset the NVRAM variables to their default settings by holding down Stop-N while the machine is powering up. When issuing this command, hold down Stop-N immediately after turning on the power to the SPARC system, and keep it pressed for a few seconds or until you see the banner (if the display is available). This is a good technique to force a SPARC compatible machine’s NVRAM variables to a known condition.

---

### Setting Security Variables

The NVRAM system security variables are:

- security-mode
- security-password
- security-#badlogins
security-mode can restrict the set of operations that users are allowed to perform from the User Interface. The three security modes, and their available commands, are listed in the following table in the order of most to least secure.

**TABLE 3-4** Commands Available for security-mode Settings

<table>
<thead>
<tr>
<th>Mode</th>
<th>Commands</th>
</tr>
</thead>
<tbody>
<tr>
<td>full</td>
<td>All commands except for go require the password.</td>
</tr>
<tr>
<td>command</td>
<td>All commands except for boot and go require the password.</td>
</tr>
<tr>
<td>none</td>
<td>No password required (default).</td>
</tr>
</tbody>
</table>

Command Security

With security-mode set to command:

- A password is not required if you type the boot command by itself. However, if you use the boot command with an argument, a password is required.
- The go command never asks for a password.
- A password is required to execute any other command.

Examples are shown in the following screen.

```
ok boot (no password required)
ok go (no password required)
ok boot filename (password required)
Password: (password is not echoed as it is typed)
ok reset-all(password required)
Password: (password is not echoed as it is typed)
```

**Caution** – It is important to remember your security password and to set the security password before setting the security mode. If you forget this password, you cannot use your system; you must call your vendor’s customer support service to make your machine bootable again.
To set the security password and command security mode, type the following at the ok prompt:

```
ok password
ok New password (only first 8 chars are used):
ok Retype new password:
ok setenv security-mode command
ok
```

The security password you assign must be between zero and eight characters. Any characters after the eighth are ignored. You do not have to reset the system; the security feature takes effect as soon as you type the command.

If you enter an incorrect security password, there will be a delay of about 10 seconds before the next boot prompt appears. The number of times that an incorrect security password is typed is stored in the `security-#badlogins` variable.

**Full Security**

The full security mode is the most restrictive. With `security-mode` set to `full`:

- A password is required any time you execute the `boot` command.
- The `go` command never asks for a password.
- A password is required to execute any other command.

Here are some examples.

```
ok go       (no password required)
ok boot     (password required)
Password:   (password is not echoed as it is typed)
ok boot filename (password required)
Password:   (password is not echoed as it is typed)
ok reset-all (password required)
Password:   (password is not echoed as it is typed)
```

**Caution** – It is important to remember your security password and to set the security password before setting the security mode. If you forget this password, you cannot use your system; you must call your vendor’s customer support service to make your machine bootable again.
To set the security password and full security, type the following at the ok prompt:

```
ok password
ok New password (only first 8 chars are used):
ok Retype new password:
ok setenv security-mode full
ok
```

## Changing the Power-on Banner

The banner configuration variables are:

- `oem-banner`
- `oem-banner?`
- `oem-logo`
- `oem-logo?`

To view the power-on banner, type:

```
ok banner
Sun Ultra 1 SBus (UltraSPARC 167 MHz), Keyboard PresentPROM Rev. 3.0, 64MB memory installed, Serial # 289Ethernet address 8:0:20:d:e2:7b, Host ID: 80000121
ok
```

The banner for your system may be different.

The banner consists of two parts: the text field and the logo (over serial ports, only the text field is displayed). You can replace the existing text field with a custom text message using the `oem-banner` and `oem-banner?` configuration variables.

To insert a custom text field in the power-on banner, type:

```
ok setenv oem-banner Hello Mom and Dad
ok setenv oem-banner? true
ok banner
Hello Mom and Dad
ok
```

The system displays the banner with your new message, as shown in the preceding screen.
The graphic logo is handled differently. `oem-logo` is a 512-byte array, containing a total of 4096 bits arranged in a 64 x 64 array. Each bit controls one pixel. The most significant bit (MSB) of the first byte controls the upper-left corner pixel. The next bit controls the pixel to the right of it, and so on.

To create a new logo, first create a Forth array containing the correct data; then copy this array into `oem-logo`. The array is then installed in `oem-logo` with `$setenv`. The example below fills the top half of `oem-logo` with an ascending pattern.

```
ok create logoarray d# 512 allot
ok logoarray d# 256 0 do i over i + c! loop drop
ok logoarray d# 256 " oem-logo" $setenv
ok setenv oem-logo? true
ok banner
```

To restore the system’s original power-on banner, set the `oem-logo?` and `oem-banner?` variables to `false`.

```
ok setenv oem-logo? false
ok setenv oem-banner? false
ok
```

Because the `oem-logo` array is so large, `printenv` displays approximately the first 8 bytes (in hexadecimal). To display the entire array, use the phrase `oem-logo dump`. The `oem-logo` array is not erased by `set-defaults`, since it might be difficult to restore the data. However, `oem-logo?` is set to `false` when `set-defaults` executes, so the custom logo is no longer displayed.

**Note** – Some systems do not support the `oem-logo` feature.

---

**Input and Output Control**

The console is used as the primary means of communication between OpenBoot and the user. The console consists of an input device, used for receiving information supplied by the user, and an output device, used for sending information to the user. Typically, the console is either the combination of a text/graphics display device and a keyboard or an ASCII terminal connected to a serial port.

The configuration variables related to the control of the console are:

- `input-device`
You can use these variables to assign the power-on defaults for the console. These values do not take effect until after the next power cycle or system reset.

Selecting Input and Output Device Options

The input-device and output-device variables control the firmware’s selection of input and output devices after a power-on reset. The default input-device value is keyboard and the default output-device value is screen. The values of input-device and output-device must be device specifiers. The aliases keyboard and screen are often used as the values of these variables.

When the system is reset, the named device becomes the initial firmware console input or output device. (If you want to temporarily change the input or output device, use the input or output commands described in Chapter 4)

To set ttya as the initial console input device, type:

```
ok setenv input-device ttya
ok
```

If you select keyboard for input-device, and the device is not plugged in, input is accepted from a fallback device (typically ttya) after the next power cycle or system reset. If you select screen for output-device, but no frame buffer is available, output is sent to the fall-back device after the next power cycle or system reset.

To specify an SBus frame buffer as the default output device (especially if there are multiple frame buffers in the system), type:

```
ok setenv output-device /sbus/SUNW,leo
ok
```

Serial Port Characteristics

The following values represent the typical range of communications characteristics for serial ports:

- **baud** = 110, 300, 1200, 2400, 4800, 9600, 19200, or 38400 bits/second
- \#bits = 5, 6, 7, or 8 (data bits)
- parity = n (none), e (even), or o (odd), parity bit
- \#stop = 1 (1), . (1.5), or 2 (2) stop bits

**Note** — rts/cts and xon/xoff handshaking are not implemented on some systems. When a selected protocol is not implemented, the handshake variable is accepted but ignored; no messages are displayed.

---

## Selecting Boot Options

You can use the following configuration variable to determine whether or not the system will boot automatically after a power cycle or system reset.

- auto-boot?

If auto-boot? is true and if OpenBoot is not in diagnostic mode, the system boots automatically after a power-cycle or system reset using the boot-device and boot-file values.

These variables can also be used during manual booting to select the boot device and the program to be booted. For example, to specify default booting from the network server, type:

```
ok setenv boot-device net
ok
```

Changes to boot-file and boot-device take effect the next time that boot is executed.

---

## Controlling Power-on Self-Test (POST)

The Power-on Testing variables are:

- diag-switch?
- diag-device
- diag-file
- diag-level
Setting `diag-switch?` to `true` causes the function `diagnostic-mode?` to return `true`. When `diagnostic-mode?` returns `true`, the system:

- Performs more thorough self tests during any subsequent power-on or system reset process.
- May display additional status messages (the details are implementation dependent).
- Uses different configuration variables for booting. (For more details on the effects on the boot process, see Chapter 2)

Most systems have a factory default of `false` for the `diag-switch?` variable. To set `diag-switch?` to `true`, type:

```
ok setenv diag-switch? true
ok
```

**Note** – Some systems have a hardware diagnostic switch that also cause `diagnostic-mode?` to return `true`. Such systems run the full tests at power-on and system reset if either the hardware switch is set or `diag-switch?` is `true`.

```
Note – Some implementations enable you to force `diag-switch?` to `true` by using an implementation-dependent key sequence during power-on. Check your system’s documentation for details, or see Appendix C.”
```

To set `diag-switch?` to `false`, type:

```
ok setenv diag-switch? false
ok
```

When not in diagnostic mode, the system does not announce the diagnostic tests as they are performed (unless a test fails) and may perform fewer tests.

---

**Using nvramrc**

The `nvramrc` configuration variable whose contents are called the `script`, can be used to store user-defined commands executed during start-up.
Typically, `nvramrc` is used by a device driver to save start-up configuration variables, to patch device driver code, or to define installation-specific device configuration and device aliases. It can also be used for bug patches or for user-installed extensions. Commands are stored in ASCII, just as the user would type them at the console.

If the `use-nvramrc?` configuration variable is `true`, the script is evaluated during the OpenBoot start-up sequence as shown:

- Perform power-on self-test (POST)
- Perform system initialization
- Evaluate the script (if `use-nvramrc?` is true)
- Execute `probe-all` (evaluate FCode)
- Execute `install-console`
- Execute `banner`
- Execute secondary diagnostics
- Perform default boot (if `auto-boot?` is true)

It is sometimes desirable to modify the sequence `probe-all install-console banner`. For example, commands that modify the characteristics of plug-in display devices may need to be executed after the plug-in devices have been probed, but before the console device has been selected. Such commands would need to be executed between `probe-all` and `install-console`. Commands that display output on the console would need to be placed after `install-console` or `banner`.

This is accomplished by creating a custom script which contains either `banner` or `suppress-banner` since the sequence `probe-all install-console banner` is not executed if either `banner` or `suppress-banner` is executed from the script. This allows the use of `probe-all`, `install-console` and `banner` inside the script, possibly interspersed with other commands, without having those commands re-executed after the script finishes.

Most User Interface commands can be used in the script. The following cannot:

- `boot`
- `go`
- `nedit`
- `password`
- `reset-all`
- `setenv security-mode`
Editing the Contents of the Script

The script editor, nvedit, lets you create and modify the script using the commands listed in TABLE 3-5.

**TABLE 3-5  Commands Affecting NVRAMAC**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>nvalias alias device-path</td>
<td>Stores the command “devalias alias device-path” in the script. The alias persists until either nvunalias or set-defaults is executed.</td>
</tr>
<tr>
<td>$nvalias</td>
<td>Performs the same function as nvalias except that it takes its arguments, name-string and device-string, from the stack.</td>
</tr>
<tr>
<td>nvedit</td>
<td>Enters the script editor. If data remains in the temporary buffer from a previous nvedit session, resumes editing those previous contents. If not, reads the contents of nvramrc into the temporary buffer and begins editing it.</td>
</tr>
<tr>
<td>nvquit</td>
<td>Discards the contents of the temporary buffer, without writing it to nvramrc. Prompts for confirmation.</td>
</tr>
<tr>
<td>nvrecover</td>
<td>Recovers the contents of nvramrc if they have been lost as a result of the execution of set-defaults; then enters the editor as with nvedit. nvrecover fails if nvedit is executed between the time that the nvramrc contents were lost and the time that nvrecover is executed.</td>
</tr>
<tr>
<td>nvrun</td>
<td>Executes the contents of the temporary buffer.</td>
</tr>
<tr>
<td>nvstore</td>
<td>Copies the contents of the temporary buffer to nvramrc; discards the contents of the temporary buffer.</td>
</tr>
<tr>
<td>nvunalias alias</td>
<td>Deletes the specified alias from nvramrc.</td>
</tr>
<tr>
<td>$nvunalias</td>
<td>Performs the same function as nvunalias except that it takes its argument, name-string, from the stack.</td>
</tr>
</tbody>
</table>

The editing commands shown in TABLE 3-6 are used in the script editor.

**TABLE 3-6  Script Editor Keystroke Commands**

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-B</td>
<td>Moves backward one character.</td>
</tr>
<tr>
<td>Escape B</td>
<td>Moves backward one word.</td>
</tr>
<tr>
<td>Control-F</td>
<td>Moves forward one character.</td>
</tr>
<tr>
<td>Escape F</td>
<td>Moves forward one word.</td>
</tr>
<tr>
<td>Control-A</td>
<td>Moves backward to beginning of the line.</td>
</tr>
</tbody>
</table>
Activating the Script

Use the following steps to create and activate the script:

- **At the ok prompt, type** `nvedit`.
  
  Edit the script using editor commands.

- **Type Control-C to get out of the editor and back to the ok prompt.**

---

### Table 3-6

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-E</td>
<td>Moves forward to end of the line.</td>
</tr>
<tr>
<td>Control-N</td>
<td>Moves to the next line of the script editing buffer.</td>
</tr>
<tr>
<td>Control-P</td>
<td>Moves to the previous line of the script editing buffer.</td>
</tr>
<tr>
<td>Return (Enter)</td>
<td>Inserts a new line at the cursor position and advances to the next line.</td>
</tr>
<tr>
<td>Control-O</td>
<td>Inserts a newline at the cursor position and stays on the current line.</td>
</tr>
<tr>
<td>Control-K</td>
<td>Erases from the cursor position to the end of the line, storing the erased characters in a save buffer. If at the end of a line, joins the next line to the current line (i.e. deletes the newline).</td>
</tr>
<tr>
<td>Delete</td>
<td>Erases the previous character.</td>
</tr>
<tr>
<td>Backspace</td>
<td>Erases the previous character.</td>
</tr>
<tr>
<td>Control-H</td>
<td>Erases the previous character.</td>
</tr>
<tr>
<td>Escape H</td>
<td>Erases from beginning of word to just before the cursor, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-W</td>
<td>Erases from beginning of word to just before the cursor, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-D</td>
<td>Erases the next character.</td>
</tr>
<tr>
<td>Escape D</td>
<td>Erases from the cursor to the end of the word, storing the erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-U</td>
<td>Erases the entire line, storing the erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-Y</td>
<td>Inserts the contents of the save buffer before the cursor.</td>
</tr>
<tr>
<td>Control-Q</td>
<td>Quotes the next character (i.e. allows you to insert control characters).</td>
</tr>
<tr>
<td>Control-R</td>
<td>Retypes the line.</td>
</tr>
<tr>
<td>Control-L</td>
<td>Displays the entire contents of the editing buffer.</td>
</tr>
<tr>
<td>Control-C</td>
<td>Exits the script editor, returning to the OpenBoot command interpreter. The temporary buffer is preserved, but is not written back to the script. (Use <code>nvstore</code> afterwards to write it back.)</td>
</tr>
</tbody>
</table>
If you have not yet typed `nvstore` to save your changes, you may type `nvrun` to execute the contents of the temporary edit buffer.

1. **Type `nvstore` to save your changes.**

2. **Enable the interpretation of the script by typing:**

   ```
   setenv use-nvramrc? true
   ```

3. **Type `reset-all` to reset the system and execute the script, or type:**

   ```
   nvramrc evaluate
   ```

to execute the contents directly.

The following example shows you how to create a simple colon definition in the script.

```
ok nvedit
0: : hello ( -- )
1: ." Hello, world. " cr
2: ;
3: ^C
ok nvstore
ok setenv use-nvramrc? true
ok reset-all
...
ok hello
Hello, world.
ok
```

Notice the `nvedit` line number prompts (0:, 1:, 2:, 3:) in the above example. These prompts are system-dependent.
Using Forth Tools

This chapter introduces the Forth programming language as it is implemented in OpenBoot. Even if you are familiar with Forth, work through the examples shown in this chapter; they provide specific, OpenBoot-related information.

The version of Forth contained in OpenBoot is based on ANS Forth. Appendix I, listings the complete set of available commands.

Note – This chapter assumes that you know how to enter and leave the User Interface. At the ok prompt, if you type commands that hang the system and you cannot recover using a key sequence, you may need to perform a power cycle to return the system to normal operation.

Forth Commands

Forth has a very simple command structure. Forth commands, also called Forth words, consist of any combination of characters that can be printed. For example, letters, digits, or punctuation marks. Examples of legitimate words are shown below:

```
@
dump.
0< +
probe-scsi
```
Forth words must be separated from one another by one or more spaces (blanks). Characters that are normally treated as “punctuation” in some other programming languages do not separate Forth words. In fact, many of those “punctuation” characters are Forth words!

Pressing Return at the end of any command line executes the typed commands. (In all the examples shown, a Return at the end of the line is assumed.)

A command line can have more than one word. Multiple words on a line are executed one at a time, from left to right, in the order in which they were typed. For example:

```
ok testa testb testc
ok
```

is equivalent to:

```
ok testa
ok testb
ok testc
ok
```

In OpenBoot, uppercase and lowercase letters are equivalent in Forth word names. Therefore, testa, TESTA, and TesTa all invoke the same command. However, words are conventionally written in lowercase.

Some commands generate large amounts of output (for example, dump or words). You can interrupt such a command by pressing any key except q. (If you press q, the output is aborted, not suspended.) Once a command is interrupted, output is suspended and the following message appears:

```
More [<space>,<cr>,q] ?
```

Press the space bar (<space>) to continue, press Return (<cr>) to output one more line and pause again, or type q to abort the command. When a command generates more than one page of output, the system automatically displays this prompt at the end of each page.
Data Types

The terms shown in TABLE 4-1 describe the data types used by Forth.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte</td>
<td>An 8-bit value.</td>
</tr>
<tr>
<td>cell</td>
<td>The implementation-defined fixed size of a cell is specified in address units and the corresponding number of bits. Data-stack elements, return-stack elements, addresses, execution tokens, flags and integers are one cell wide. On OpenBoot systems, a cell consists of at least 32-bits, and is sufficiently large to contain a virtual address. The cell size may vary between implementations. A 32-bit implementation has a cell size of 4. A 64-bit implementation has a cell size of 8. OpenBoot 3.x is a 64-bit implementation.</td>
</tr>
<tr>
<td>doublet</td>
<td>A 16-bit value.</td>
</tr>
<tr>
<td>octlet</td>
<td>A 64-bit value; only defined on 64-bit implementations,</td>
</tr>
<tr>
<td>quadlet</td>
<td>A 32-bit value.</td>
</tr>
</tbody>
</table>

Using Numbers

Enter a number by typing its value, for example, 55 or -123. Forth accepts only integers (whole numbers); it does not understand fractional values (e.g., 2/3). A period at the end of a number signifies a double number. Periods or commas embedded in a number are ignored, so 5.77 is understood as 577. By convention, such punctuation usually appears every four digits. Use one or more spaces to separate a number from a word or from another number.

Unless otherwise specified, OpenBoot performs integer arithmetic on data items that are one cell in size, and creates results that are one cell in size.

Although OpenBoot implementations are encouraged to use base 16 (hexadecimal) by default, they are not required to do so. Consequently, you must establish a specific number base if your code depends on a given base for proper operation. You can change the number base with the commands decimal and hex to cause all subsequent numeric input and output to be performed in base 10 or 16, respectively.
For example, to operate in decimal, type:

```
ok decimal
ok
```

To change to hexadecimal, type:

```
ok hex
ok
```

To identify the current number base, you can use:

```
ok 10 .d
16
ok
```

The 16 on the display shows that you are operating in hexadecimal. If 10 showed on the display, it would mean that you are in decimal base. The .d command displays a number in base 10, regardless of the current number base.

---

**The Stack**

The Forth stack is a last-in, first-out buffer used for temporarily holding numeric information. Think of it as a stack of books: the last one you put on the top of the stack is the first one you take off. Understanding the stack is essential to using Forth.

To put a number on the stack, simply type its value.

```
ok 44  (The value 44 is now on top of the stack)
ok 7   (The value 7 is now on top, with 44 just underneath)
ok
```
Displaying Stack Contents

The contents of the stack are normally invisible. However, properly visualizing the current stack contents is important for achieving the desired result. To show the stack contents with every ok prompt, type:

```
ok showstack
44 7 ok 8
44 7 8ok noshowstack
ok
```

The topmost stack item is always shown as the last item in the list, immediately before the ok prompt. In the above example, the topmost stack item is 8.

If showstack has been previously executed, noshowstack will remove the stack display prior to each prompt.

**Note** – In some of the examples in this chapter, showstack is enabled. In those examples, each ok prompt is immediately preceded by a display of the current contents of the stack. The examples work the same if showstack is not enabled, except that the stack contents are not displayed.

Nearly all words that require numeric parameters fetch those parameters from the top of the stack. Any values returned are generally left on top of the stack, where they can be viewed or consumed by another command. For example, the Forth word + removes two numbers from the stack, adds them together, and leaves the result on the stack. In the example below, all arithmetic is in hexadecimal.

```
44 7 8 ok +
44 f ok +
53 ok
```
Once the two values are added together, the result is put onto the top of the stack. The Forth word \texttt{.} removes the top stack item and displays that value on the screen. For example:

\begin{verbatim}
53  ok  12
53 12  ok  .
12
53  ok  .
53
ok   \texttt{(The stack is now empty)}
ok 3 5 + .
8
ok   \texttt{(The stack is now empty)}
ok  .
Stack Underflow
ok
\end{verbatim}

The Stack Diagram

To aid understanding, conventional coding style requires that a \textit{stack diagram} of the form \texttt{(-- --)} appear on the first line of every definition of a Forth word. The stack diagram specifies what the execution of the word does to the stack.

Entries to the left of \texttt{--} represent those stack items that the word removes from the stack and uses during its operation. The right-most of these items is on top of the stack, with any preceding items beneath it. In other words, arguments are pushed onto the stack in left to right order, leaving the most recent one (the right-most one in the diagram) on the top.

Entries to the right of \texttt{--} represent those stack items that the word leaves on the stack after it finishes execution. Again, the right-most item is on top of the stack, with any preceding items beneath it.

For example, a stack diagram for the word \texttt{+} is:

\begin{verbatim}
( nu1 nu2  --  sum )
\end{verbatim}

Therefore, \texttt{+} removes two numbers (\texttt{nu1} and \texttt{nu2}) from the stack and leaves their sum (\texttt{sum}) on the stack. As a second example, a stack diagram for the word \texttt{.} is:

\begin{verbatim}
( nu  -- )
\end{verbatim}

The word \texttt{.} removes the number on the top of the stack (\texttt{nu}) and displays it.

Words that have no effect on the contents of the stack (such as \texttt{showstack} or \texttt{decimal}), have a \texttt{(-- --)} stack diagram.
Occasionally, a word will require another word or other text immediately following it on the command line. The word `see`, used in the form:

```
see thisword
```

is such an example.

Stack items are generally written using descriptive names to help clarify correct usage. See TABLE 4-2 for stack item abbreviations used in this manual.

### TABLE 4-2 Stack Item Notation

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>`</td>
<td>`</td>
</tr>
<tr>
<td><code>??</code></td>
<td>Unknown stack item(s).</td>
</tr>
<tr>
<td><code>...</code></td>
<td>Unknown stack item(s). If used on both sides of a stack comment, means the same stack items are present on both sides.</td>
</tr>
<tr>
<td><code>&lt; &gt; &lt;space&gt;</code></td>
<td>Space delimiter. Leading spaces are ignored.</td>
</tr>
<tr>
<td><code>a-addr</code></td>
<td>Variable-aligned address.</td>
</tr>
<tr>
<td><code>addr</code></td>
<td>Memory address (generally a virtual address).</td>
</tr>
<tr>
<td><code>addr len</code></td>
<td>Address and length for memory region</td>
</tr>
<tr>
<td><code>byte bxxx</code></td>
<td>8-bit value (low order byte in a cell).</td>
</tr>
<tr>
<td><code>char</code></td>
<td>7-bit value (low order byte in a cell, high bit of low order byte unspecified).</td>
</tr>
<tr>
<td><code>cnt</code></td>
<td>Count.</td>
</tr>
<tr>
<td><code>len</code></td>
<td>Length.</td>
</tr>
<tr>
<td><code>size</code></td>
<td>Count or length.</td>
</tr>
<tr>
<td><code>dxxx</code></td>
<td>Double (extended-precision) numbers. 2 cells, most significant cell on top of stack.</td>
</tr>
<tr>
<td><code>&lt;eol&gt;</code></td>
<td>End-of-line delimiter.</td>
</tr>
<tr>
<td><code>false</code></td>
<td>0 (false flag).</td>
</tr>
<tr>
<td><code>n n1 n2 n3</code></td>
<td>Normal signed, one-cell values.</td>
</tr>
<tr>
<td><code>nu nu1</code></td>
<td>Signed or unsigned one-cell values.</td>
</tr>
<tr>
<td><code>&lt;nothing&gt;</code></td>
<td>Zero stack items.</td>
</tr>
<tr>
<td><code>o o1 o2 oct1 oct2</code></td>
<td>Octlet (64 bit signed value).</td>
</tr>
<tr>
<td><code>oaddr</code></td>
<td>Octlet (64-bit ) aligned address.</td>
</tr>
<tr>
<td><code>octlet</code></td>
<td>An eight-byte quantity.</td>
</tr>
<tr>
<td><code>phys</code></td>
<td>Physical address (actual hardware address).</td>
</tr>
</tbody>
</table>
Manipulating the Stack

Stack manipulation commands (described in TABLE 4-3) allow you to add, delete, and reorder items on the stack.

TABLE 4-3 Stack Manipulation Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear</td>
<td>(??: --)</td>
<td>Empty the stack.</td>
</tr>
<tr>
<td>depth</td>
<td>( ... -- u )</td>
<td>Return the number of items on the stack.</td>
</tr>
<tr>
<td>drop</td>
<td>( x -- )</td>
<td>Remove top item from the stack.</td>
</tr>
<tr>
<td>2drop</td>
<td>( x1 x2 -- )</td>
<td>Remove 2 items from the stack.</td>
</tr>
</tbody>
</table>
A typical use of stack manipulation might be to display the top stack item while preserving all stack items, as shown in this example:

```
5 77 ok dup  (Duplicates the top item on the stack)
5 77 77 ok .  (Removes and displays the top stack item)
77
5 77 ok
```
Creating Custom Definitions

Forth provides an easy way to create new command words from sequences of existing words. TABLE 4-4 shows the Forth words used to create such new words.

TABLE 4-4 Colon Definition Words

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>: new-name</td>
<td>( -- )</td>
<td>Start a new colon definition of the word new-name.</td>
</tr>
<tr>
<td>;</td>
<td>( -- )</td>
<td>End a colon definition.</td>
</tr>
</tbody>
</table>

This kind of word is called a colon definition, named after the word that is used to create them. For example, suppose you want to create a new word, add4, that will add any four numbers together and display the result. You could create the definition as follows:

```
ok : add4 + + . ;
ok
```

The ; (semicolon) marks the end of the definition that defines add4 to have the behavior (+ + + .). The three addition operators (+) reduce the four stack items to a single sum on the stack; then . removes and displays that result. An example follows:

```
ok 1 2 3 3 + + + .
9
ok 1 2 3 3 add4
9
ok
```

Definitions are forgotten if a machine reset takes place. To keep useful definitions, put them into the script or save them in a text file on a host system. This text file can then be loaded as needed. (See Chapter 5 for more information on loading files.)
When you type a definition from the User Interface, the ok prompt becomes a ] (right square bracket) prompt after you type the : (colon) and before you type the ; (semicolon). For example, you could type the definition for add4 like this:

```
ok : add4
] + + +
] .
] ;
ok
```

The above use of ] while inside a multi-line definition is a characteristic of Sun’s implementation.

- The stack diagram shows proper use of a word, so include a stack diagram with every definition you create, even if the stack effect is nil (--). Use generous stack comments in complex definitions to trace the flow of execution. For example, when creating add4, you could define it as:

```
: add4 ( n1 n2 n3 n4 -- ) + + + . ;
```

Or you could define it as follows:

```
: add4 ( n1 n2 n3 n4 -- )
  + + +( sum )
  . (     )
 ;
```

**Note** – The "(" is a Forth word meaning ignore the text up to the ")". Like any other Forth word, the "(“ must have one or more spaces after it.
Using Arithmetic Functions

Single-Precision Integer Arithmetic

The commands listed in TABLE 4-5 perform single-precision arithmetic.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>( nu1 nu2 -- sum )</td>
<td>Adds ( nu1 + nu2 ).</td>
</tr>
<tr>
<td>-</td>
<td>( nu1 nu2 -- diff )</td>
<td>Subtracts ( nu1 - nu2 ).</td>
</tr>
<tr>
<td>*</td>
<td>( nu1 nu2 -- prod )</td>
<td>Multiplies ( nu1 \times nu2 ).</td>
</tr>
<tr>
<td>*/</td>
<td>( n1 n2 n3 -- quot )</td>
<td>Calculates ( nu1 \times nu2 / n3 ). Inputs, outputs and intermediate products are all one cell.</td>
</tr>
<tr>
<td>/</td>
<td>( n1 n2 -- quot )</td>
<td>Divides ( n1 ) by ( n2 ); remainder is discarded.</td>
</tr>
<tr>
<td>1+</td>
<td>( nu1 -- nu2 )</td>
<td>Adds one.</td>
</tr>
<tr>
<td>1-</td>
<td>( nu1 -- nu2 )</td>
<td>Subtracts one.</td>
</tr>
<tr>
<td>2+</td>
<td>( nu1 -- nu2 )</td>
<td>Adds two.</td>
</tr>
<tr>
<td>2-</td>
<td>( nu1 -- nu2 )</td>
<td>Subtracts two.</td>
</tr>
<tr>
<td>abs</td>
<td>( n -- u )</td>
<td>Absolute value.</td>
</tr>
<tr>
<td>bounds</td>
<td>( start len -- len+start start )</td>
<td>Converts start,len to end,start for do or ?do loop.</td>
</tr>
<tr>
<td>even</td>
<td>( n -- n \mid n+1 )</td>
<td>Round to nearest even integer ( \geq n ).</td>
</tr>
<tr>
<td>max</td>
<td>( n1 n2 -- n3 )</td>
<td>( n3 ) is maximum of ( n1 ) and ( n2 ).</td>
</tr>
<tr>
<td>min</td>
<td>( n1 n2 -- n3 )</td>
<td>( n3 ) is minimum of ( n1 ) and ( n2 ).</td>
</tr>
<tr>
<td>mod</td>
<td>( n1 n2 -- rem )</td>
<td>Remaider of ( n1 / n2 ).</td>
</tr>
<tr>
<td>*/mod</td>
<td>( n1 n2 n3 -- rem quot )</td>
<td>Remainder, quotient of ( n1 \times n2 / n3 ).</td>
</tr>
<tr>
<td>/mod</td>
<td>( n1 n2 -- rem quot )</td>
<td>Remainder, quotient of ( n1 / n2 ).</td>
</tr>
<tr>
<td>negate</td>
<td>( n1 -- n2 )</td>
<td>Change the sign of ( n1 ).</td>
</tr>
<tr>
<td>u*</td>
<td>(u1 u2 -- uprod )</td>
<td>Multiply 2 unsigned numbers yielding an unsigned product.</td>
</tr>
<tr>
<td>u/mod</td>
<td>( u1 u2 -- urem uquot )</td>
<td>Divide unsigned one-cell number by an unsigned one-cell number; yield one-cell remainder and quotient.</td>
</tr>
</tbody>
</table>
Double Number Arithmetic

The commands listed in TABLE 4-6 perform double number arithmetic.

**TABLE 4-6**  Double Number Arithmetic Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>d+</code></td>
<td><code>( d1 d2 -- d.sum )</code></td>
<td>Add d1 to d2 yielding double number d.sum.</td>
</tr>
<tr>
<td><code>d-</code></td>
<td><code>( d1 d2 -- d.diff )</code></td>
<td>Subtract d2 from d1 yielding double number d.diff.</td>
</tr>
<tr>
<td><code>fm/mod</code></td>
<td><code>( d n -- rem quot )</code></td>
<td>Divide d by n.</td>
</tr>
<tr>
<td><code>m*</code></td>
<td><code>( n1 n2 -- d )</code></td>
<td>Signed multiply with double-number product.</td>
</tr>
<tr>
<td><code>s&gt;d</code></td>
<td><code>( n1 -- d1 )</code></td>
<td>Convert a number to a double number.</td>
</tr>
<tr>
<td><code>sm/rem</code></td>
<td><code>( d n -- rem quot )</code></td>
<td>Divide d by n, symmetric division.</td>
</tr>
<tr>
<td><code>um*</code></td>
<td><code>( u1 u2 -- ud )</code></td>
<td>Unsigned multiply yielding unsigned double number product.</td>
</tr>
<tr>
<td><code>um/mod</code></td>
<td><code>( ud u -- urem uprod )</code></td>
<td>Divide <code>ud</code> by <code>u</code>.</td>
</tr>
</tbody>
</table>
Data Type Conversion

The commands listed in TABLE 4-7 perform data type conversion.

**TABLE 4-7** 32-Bit Data Type Conversion Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bljoin</td>
<td>( b.low b2 b3 b hi -- quad )</td>
<td>Join four bytes to form a quadlet</td>
</tr>
<tr>
<td>bwjoin</td>
<td>( b.low b hi -- word )</td>
<td>Join two bytes to form a doublet.</td>
</tr>
<tr>
<td>lbflip</td>
<td>( quad1 -- quad2 )</td>
<td>Reverse the bytes in a quadlet</td>
</tr>
<tr>
<td>lbsplit</td>
<td>( quad -- b.low b2 b3 b hi )</td>
<td>Split a quadlet into four bytes.</td>
</tr>
<tr>
<td>lwflip</td>
<td>( quad1 -- quad2 )</td>
<td>Swap the doublets in a quadlet.</td>
</tr>
<tr>
<td>lwsplit</td>
<td>( quad -- w.low w hi )</td>
<td>Split a quadlet into two doublets.</td>
</tr>
<tr>
<td>wbflip</td>
<td>( word1 -- word2 )</td>
<td>Swap the bytes in a doublet.</td>
</tr>
<tr>
<td>wbsplit</td>
<td>( word -- b.low b hi )</td>
<td>Split a doublet into two bytes.</td>
</tr>
<tr>
<td>wljoin</td>
<td>( w.low w hi -- quad )</td>
<td>Join two doublets to form a quadlet.</td>
</tr>
</tbody>
</table>

The data type conversion commands listed in TABLE 4-8 are available only on 64-bit OpenBoot implementations.

**TABLE 4-8** 64-Bit Data Type Conversion Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bxjoin</td>
<td>( b.lo b.2 b.3 b.4 b.5 b.6 b.7 b hi -- o )</td>
<td>Join eight bytes to form an octlet.</td>
</tr>
<tr>
<td>lxjoin</td>
<td>( quad.lo quad.hi -- o )</td>
<td>Join two quadlets to form an octlet.</td>
</tr>
<tr>
<td>wxjoin</td>
<td>( w.lo w.2 w.3 w hi -- o )</td>
<td>Join four doublets to form an octlet.</td>
</tr>
<tr>
<td>xbflip</td>
<td>( oct1 -- oct2 )</td>
<td>Reverse the bytes in an octlet.</td>
</tr>
<tr>
<td>xbsplit</td>
<td>( o -- b.lo b.2 b.3 b.4 b.5 b.6 b.7 b hi )</td>
<td>Split an octlet into eight bytes.</td>
</tr>
<tr>
<td>xlflip</td>
<td>( oct1 -- oct2 )</td>
<td>Reverse the quadlets in an octlet. The bytes in each quadlet are not reversed.</td>
</tr>
<tr>
<td>xlsplit</td>
<td>( o -- quad.lo quad.hi )</td>
<td>Split on octlet into two quadlets.</td>
</tr>
<tr>
<td>xwflip</td>
<td>( oct1 -- oct2 )</td>
<td>Reverse the doublets in an octlet. The bytes in each doublet are not reversed.</td>
</tr>
<tr>
<td>xwsplit</td>
<td>( o -- w.lo w.2 w.3 w hi )</td>
<td>Split an octlet into four doublets.</td>
</tr>
</tbody>
</table>
Address Arithmetic

The commands listed in TABLE 4-9 perform address arithmetic.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>aligned</td>
<td>( n1 -- n1</td>
<td>a-addr)</td>
</tr>
<tr>
<td>/c</td>
<td>( -- n )</td>
<td>The number of address units to a byte: 1.</td>
</tr>
<tr>
<td>/c*</td>
<td>( nu1 -- nu2 )</td>
<td>Synonym for chars.</td>
</tr>
<tr>
<td>ca+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /c.</td>
</tr>
<tr>
<td>ca1+</td>
<td>( addr1 -- addr2 )</td>
<td>Synonym for char+.</td>
</tr>
<tr>
<td>cell+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /n.</td>
</tr>
<tr>
<td>cells</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /n.</td>
</tr>
<tr>
<td>char+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /c.</td>
</tr>
<tr>
<td>chars</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /c.</td>
</tr>
<tr>
<td>/l</td>
<td>( -- n )</td>
<td>Number of address units to a quadlet; typically 4.</td>
</tr>
<tr>
<td>/l*</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /l.</td>
</tr>
<tr>
<td>la+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /l.</td>
</tr>
<tr>
<td>la1+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /l.</td>
</tr>
<tr>
<td>/n</td>
<td>( -- n )</td>
<td>Number of address units in a cell.</td>
</tr>
<tr>
<td>/n*</td>
<td>( nu1 -- nu2 )</td>
<td>Synonym for cells.</td>
</tr>
<tr>
<td>na+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /n.</td>
</tr>
<tr>
<td>nal+</td>
<td>( addr1 -- addr2 )</td>
<td>Synonym for cell+.</td>
</tr>
<tr>
<td>/w</td>
<td>( -- n )</td>
<td>Number of address units to a doublet; typically 2.</td>
</tr>
<tr>
<td>/w*</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /w.</td>
</tr>
<tr>
<td>wa+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /w.</td>
</tr>
<tr>
<td>wal+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /w.</td>
</tr>
</tbody>
</table>
The address arithmetic commands listed in TABLE 4-10 are available only on 64-bit OpenBoot implementations.

**TABLE 4-10  64-Bit Address Arithmetic Functions**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>/x</code></td>
<td>( -- n )</td>
<td>Number of address units in an octlet, typically eight.</td>
</tr>
<tr>
<td><code>/x*</code></td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of <code>/x</code>.</td>
</tr>
<tr>
<td><code>xa+</code></td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of <code>/x</code>.</td>
</tr>
<tr>
<td><code>xa1+</code></td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of <code>/x</code>.</td>
</tr>
</tbody>
</table>

---

**Accessing Memory**

**Virtual Memory**

The User Interface provides interactive commands for examining and setting memory. With it, you can:

- Read and write to any virtual address.
- Map virtual addresses to physical addresses.

Memory operators let you read from and write to any memory location. All memory addresses shown in the examples that follow are virtual addresses.

A variety of 8-bit, 16-bit, and 32-bit (and in some systems, 64-bit) operations are provided. In general, a `c` (character) prefix indicates an 8-bit (one byte) operation; a `w` (word) prefix indicates a 16-bit (doublet) operation; an `l` (longword) prefix indicates a 32-bit (quadlet) operation; and an `x` prefix indicates a 64-bit (octlet) operation.
waddr, qaddr, and oaddr indicate addresses with alignment restrictions. For example, qaddr indicates 32-bit (4 byte) alignment; on many systems such an address must be a multiple of 4, as shown in the following example:

```
ok 4028 l@
ok 4029 l@
Memory address not aligned
ok
```

Forth, as implemented in OpenBoot, adheres closely to the ANS Forth Standard. If you explicitly want a 16-bit fetch, a 32-bit fetch or (on some systems) a 64-bit fetch, use w@, l@ or x@ instead of @. Other memory and device register access commands also follow this convention.

TABLE 4-11 lists commands used to access memory.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>!</td>
<td>( x a-addr -- )</td>
<td>Store a number at a-addr.</td>
</tr>
<tr>
<td>+!</td>
<td>( nu a-addr -- )</td>
<td>Add nu to the number stored at a-addr.</td>
</tr>
<tr>
<td>@</td>
<td>( a-addr -- x )</td>
<td>Fetch a number from a-addr.</td>
</tr>
<tr>
<td>2!</td>
<td>( x1 x2 a-addr -- )</td>
<td>Store 2 numbers at a-addr, x2 at lower address.</td>
</tr>
<tr>
<td>2@</td>
<td>( a-addr -- x1 x2 )</td>
<td>Fetch 2 numbers from a-addr, x2 from lower address.</td>
</tr>
<tr>
<td>blank</td>
<td>( addr len -- )</td>
<td>Set len bytes of memory beginning at addr to the space character (decimal 32).</td>
</tr>
<tr>
<td>c!</td>
<td>( byte addr -- )</td>
<td>Store byte at addr.</td>
</tr>
<tr>
<td>c@</td>
<td>( addr -- byte )</td>
<td>Fetch a byte from addr.</td>
</tr>
<tr>
<td>cpeek</td>
<td>( addr -- false</td>
<td>byte true )</td>
</tr>
<tr>
<td>cpoke</td>
<td>( byte addr -- okay? )</td>
<td>Attempt to store the byte to addr. Return true if the access was successful. Return false if a write access error occurred.</td>
</tr>
<tr>
<td>comp</td>
<td>( addr1 addr2 len -- diff? )</td>
<td>Compare two byte arrays. diff? is 0 if the arrays are identical, diff? is -1 if the first byte that is different is lesser in the string at addr1, diff? is 1 otherwise.</td>
</tr>
<tr>
<td>dump</td>
<td>( addr len -- )</td>
<td>Display len bytes of memory starting at addr.</td>
</tr>
<tr>
<td>erase</td>
<td>( addr len -- )</td>
<td>Set len bytes of memory beginning at addr to 0.</td>
</tr>
<tr>
<td>fill</td>
<td>( addr len byte -- )</td>
<td>Set len bytes of memory beginning at addr to the value byte.</td>
</tr>
<tr>
<td>Command</td>
<td>Stack Diagram</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>l!</td>
<td>( q qaddr -- )</td>
<td>Store a quadlet q at qaddr.</td>
</tr>
<tr>
<td>l0</td>
<td>( qaddr -- q )</td>
<td>Fetch a quadlet q from qaddr.</td>
</tr>
<tr>
<td>lbflips</td>
<td>( qaddr len -- )</td>
<td>Reverse the bytes in each quadlet in the specified region.</td>
</tr>
<tr>
<td>lwflips</td>
<td>( qaddr len -- )</td>
<td>Swap the doublets in each quadlet in specified region.</td>
</tr>
<tr>
<td>lpeek</td>
<td>( qaddr -- false</td>
<td>quad true )</td>
</tr>
<tr>
<td>lpoke</td>
<td>( q qaddr -- okay? )</td>
<td>Attempt to store the quadlet 8 at qaddr. Return true if the access was successful. Return false if a write access error occurred.</td>
</tr>
<tr>
<td>move</td>
<td>( src-addr dest-addr len -- )</td>
<td>Copy len bytes from src-addr to dest-addr.</td>
</tr>
<tr>
<td>off</td>
<td>( a-addr -- )</td>
<td>Store false at a-addr.</td>
</tr>
<tr>
<td>on</td>
<td>( a-addr -- )</td>
<td>Store true at a-addr.</td>
</tr>
<tr>
<td>unaligned-l!</td>
<td>( q addr -- )</td>
<td>Store a quadlet q, any alignment</td>
</tr>
<tr>
<td>unaligned-l0</td>
<td>( addr -- q )</td>
<td>Fetch a quadlet q, any alignment.</td>
</tr>
<tr>
<td>unaligned-w!</td>
<td>( w addr -- )</td>
<td>Store a doublet w, any alignment.</td>
</tr>
<tr>
<td>unaligned-w@</td>
<td>( addr -- w )</td>
<td>Fetch a doublet w, any alignment.</td>
</tr>
<tr>
<td>w!</td>
<td>( w waddr -- )</td>
<td>Store a doublet w at waddr.</td>
</tr>
<tr>
<td>w@</td>
<td>( waddr -- w)</td>
<td>Fetch a doublet w from waddr.</td>
</tr>
<tr>
<td>&lt;w@</td>
<td>( waddr -- n )</td>
<td>Fetch doublet n from waddr, sign-extended.</td>
</tr>
<tr>
<td>wbflips</td>
<td>( waddr len -- )</td>
<td>Swap the bytes in each doublet in the specified region.</td>
</tr>
<tr>
<td>wpeek</td>
<td>( waddr -- false l w true )</td>
<td>Attempt to fetch the doublet w at waddr. Return the data and true if the access was successful. Return false if a read access error occurred.</td>
</tr>
<tr>
<td>wpoke</td>
<td>( w waddr -- okay? )</td>
<td>Attempt to store the doublet w to waddr. Return true if the access was successful. Return false if a write access error occurred.</td>
</tr>
</tbody>
</table>
The memory access commands listed in TABLE 4-12 are available only on 64-bit OpenBoot implementations.

**TABLE 4-12  64-Bit Memory Access Functions**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;l@</td>
<td>( qaddr -- n )</td>
<td>Fetch quadlet from qaddr, sign-extended.</td>
</tr>
<tr>
<td>x@</td>
<td>( oaddr -- o )</td>
<td>Fetch octlet from an octlet aligned address.</td>
</tr>
<tr>
<td>x!</td>
<td>( o oaddr -- )</td>
<td>Store octlet to an octlet aligned address.</td>
</tr>
<tr>
<td>xbflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the bytes in each octlet in the given region. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
<tr>
<td>xlflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the quadlets in each octlet in the given region. The bytes in each quadlet are not reversed. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
<tr>
<td>xwflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the doublets in each octlet in the given region. The bytes in each doublet are not reversed. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
</tbody>
</table>

The dump command is particularly useful. It displays a region of memory as both bytes and ASCII values. The example below displays the contents of 20 bytes of memory starting at virtual address 10000.

```
ok 10000 20 dump (Display 20 bytes of memory starting at virtual address 10000)
  \/ 1 2 3 4 5 6 7 8 9 a b c d e f v123456789abcdef
10000 05 75 6e 74 69 6c 00 40  4e d4 00 00 da 18 00 00 .until.@NT..Z...
10010 ce da 00 00 f4 f4 00 00  fe dc 00 00 d3 0c 00 00 NZ..tt~\..S...
ok
```

Some implementations support variants of dump that display memory as 16-, 32- and 64-bit values. You can use sifting dump (see “Searching the Dictionary” on page 64) to find out if your system has such variants.

If you try to access an invalid memory location (with @, for example), the operation may abort and display an error message, such as Data Access Exception or Bus Error.
TABLE 4-13 lists memory mapping commands.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>alloc-mem</td>
<td>(len -- a-addr)</td>
<td>Allocate len bytes of memory; return the virtual address.</td>
</tr>
<tr>
<td>free-mem</td>
<td>(a-addr len --)</td>
<td>Free memory allocated by alloc-mem.</td>
</tr>
</tbody>
</table>

The following screen is an example of the use of alloc-mem and free-mem.

- alloc-mem allocates 4000 bytes of memory, and the starting address (ef7a48) of the reserved area is displayed.
- dump displays the contents of 20 bytes of memory starting at ef7a48.
- This region of memory is then filled with the value 55.
- Finally, free-mem returns the 4000 allocated bytes of memory starting at ef7a48.
Device Registers

Device registers cannot be reliably accessed using the virtual memory access operators discussed in the last section. There are special operators for accessing device registers, and these operators require that the machine be properly set up prior to their use. For a detailed explanation of this topic, see Writing FCode 3.x Programs.

Using Defining Words

The dictionary contains all the available Forth words. Forth defining words create new Forth words.

Defining words require two stack diagrams. The first diagram shows the stack effect when the new word is created. The second (or “Execution:”) diagram shows the stack effect when that word is later executed.

TABLE 4-14 lists the defining words that you can use to create new Forth words.

If a Forth command is created with the same name as an existing command, the new command will be created normally. Depending on the implementation, a warning message "new-name isn’t unique" may be displayed. Previous uses of that command name will be unaffected. Subsequent uses of that command name will use the latest definition of that command name. (To correct the original definition such that all uses of the command name get the corrected behavior, make the correction with patch. (See <Red>INVALID XREF FORMAT. Change to SectionTitle&Page#)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>: name</td>
<td>( -- )</td>
<td>Begin creation of a colon definition.</td>
</tr>
<tr>
<td></td>
<td>(E: ... -- ???)</td>
<td></td>
</tr>
<tr>
<td>;</td>
<td>( -- )</td>
<td>End creation of a colon definition.</td>
</tr>
<tr>
<td>alias</td>
<td>( -- )</td>
<td>Create new-name with the same behavior as old-name.</td>
</tr>
<tr>
<td>new-name</td>
<td>(E: ... -- ???)</td>
<td></td>
</tr>
<tr>
<td>old-name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>buffer:</td>
<td>( size -- )</td>
<td>Create a named data buffer. name returns a-addr.</td>
</tr>
<tr>
<td>name</td>
<td>(E: -- a-addr )</td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>( x -- )</td>
<td>Create a constant (for example, 3 constant bar).</td>
</tr>
<tr>
<td>name</td>
<td>(E: -- x )</td>
<td></td>
</tr>
<tr>
<td>2constant</td>
<td>( x1 x2 -- )</td>
<td>Create a 2-number constant.</td>
</tr>
<tr>
<td>name</td>
<td>(E: -- x1 x2 )</td>
<td></td>
</tr>
</tbody>
</table>
value lets you create a name for a numerical value that can be changed. Later execution of that name leaves the assigned value on the stack. The following example creates a word named foo with an initial value of 22, and then calls foo to use its value in an arithmetic operation.

```
ok 22 value foo
ok foo 3 + .
25
ok
```

The value can be changed with the word to. For example:

```
ok 43 value thisval
ok thisval .
43
ok 10 to thisval
ok thisval .
10
ok
```

Words created with value are convenient, because you do not have to use @ to retrieve their values.
The defining word **variable** creates a name with an associated one-cell memory location. Later execution of that name leaves the address of the memory on the stack. @ and ! are used to read or write to that address. For example:

```
ok variable bar
ok 33 bar !
ok bar @ 2 + .
35
ok
```

The defining word **defer** creates a word whose behavior can be changed later, by creating a slot which can be loaded with different behaviors at different times. For example:

```
ok hex
ok defer printit
ok ['] .d to printit
ok ff printit
255
ok : myprint ( n -- ) ." It is " .h
[ ." in hex " ;
ok ['] myprint to printit
ok ff printit
It is ff in hex
ok
```
Searching the Dictionary

The dictionary contains all the available Forth words. TABLE 4-15 lists some useful tools you can use to search the dictionary. Please note that some of these tools work only with methods or commands while others work with all types of words (including, for example, variables and values).

TABLE 4-15  Dictionary Searching Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>' name</td>
<td>( -- xt )</td>
<td>Find the named word in the dictionary. Returns the execution token. Use outside definitions.</td>
</tr>
<tr>
<td>['] name</td>
<td>( -- xt )</td>
<td>Similar to ‘ but is used either inside or outside definitions.</td>
</tr>
<tr>
<td>.calls</td>
<td>( xt -- )</td>
<td>Display a list of all commands which use the execution token xt.</td>
</tr>
<tr>
<td>$find</td>
<td>( str len -- xt true</td>
<td>str len false )</td>
</tr>
<tr>
<td>find</td>
<td>( pstr -- xt n</td>
<td>pstr false )</td>
</tr>
<tr>
<td>see thisword</td>
<td>( -- )</td>
<td>Decompile the specified word.</td>
</tr>
<tr>
<td>(see)</td>
<td>( xt -- )</td>
<td>Decompile the word whose execution token is xt.</td>
</tr>
<tr>
<td>$sift</td>
<td>( text-addr text-len -- )</td>
<td>Display all command names containing text-string.</td>
</tr>
<tr>
<td>sifting text</td>
<td>( -- )</td>
<td>Display all command names containing text. text contains no spaces.</td>
</tr>
<tr>
<td>words</td>
<td>( -- )</td>
<td>Display the names of words in the dictionary as described below.</td>
</tr>
</tbody>
</table>

Before you can understand the operation of the dictionary searching tools, you need to understand how words become visible. If there is an active package at the time a word is defined, the new word becomes a method of the active package, and is visible only when that package is the active package. The commands dev and find-device can be used to select or change the active package. The command device-end deselects the currently active package leaving no active package.
If there is no active package at the time a word is defined, the word is *globally visible* (i.e. not specific to a particular package and always available).

The dictionary searching commands first search through the words of the active package, if there is one, and then through the globally visible words.

**Note** – The Forth commands *only* and *also* will affect which words are visible.

`.calls` can be used to locate all of the Forth commands that use a specified word in their definition. `.calls` takes an execution token from the stack and searches the entire dictionary to produce a listing of the names and addresses of every Forth command which uses that execution token. For example:

```forth
ok ' input .calls
   Called from input at 1e248d8
   Called from io at 1e24ac0
   Called from install-console at 1e33598
   Called from install-console at 1e33678
ok
```

`see`, used in the form:

```forth
see thisword
```

displays a “pretty-printed” listing of the source for *thisword* (without the comments, of course). For example:

```forth
ok see see
: see
   ' ['] (see) catch if
      drop
   then
; ok
```

For more details on the use of `see`, refer to “Using the Forth Language Decompiler” on page 93.
sifting takes a string from the input stream and searches vocabularies in the dictionary search order to find every command name that contains the specified string as shown in the following screen.

```plaintext
Ok sifting input

In vocabulary options
(1e333f8) input-device
In vocabulary forth
(1e2476c) input(1e0a9b4) set-input(1e0a978) restore-input
(1e0a940) save-input(1e0a7f0) more-input?(1e086cc) input-file
Ok
```

words displays all the visible word names in the dictionary, starting with the most recent definition. If a node is currently selected (as with dev), the list produced by words is limited to the words in that selected node.

---

**Compiling Data Into the Dictionary**

The commands listed in TABLE 4-16 control the compilation of data into the dictionary.

### TABLE 4-16  Dictionary Compilation Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>,</td>
<td>( n -- )</td>
<td>Place a number in the dictionary.</td>
</tr>
<tr>
<td>c,</td>
<td>( byte -- )</td>
<td>Place a byte in the dictionary.</td>
</tr>
<tr>
<td>w,</td>
<td>( word -- )</td>
<td>Place a 16-bit number in the dictionary.</td>
</tr>
<tr>
<td>l,</td>
<td>( quad -- )</td>
<td>Place a 32-bit number in the dictionary.</td>
</tr>
<tr>
<td>[</td>
<td>( -- )</td>
<td>Begin interpreting.</td>
</tr>
<tr>
<td>]</td>
<td>( -- )</td>
<td>End interpreting, resume compilation.</td>
</tr>
<tr>
<td>allot</td>
<td>( n -- )</td>
<td>Allocate n bytes in the dictionary.</td>
</tr>
<tr>
<td>&gt;body</td>
<td>( xt -- a-addr )</td>
<td>Find the data field address from the execution token.</td>
</tr>
<tr>
<td>body&gt;</td>
<td>( a-addr -- xt )</td>
<td>Find the execution token from the data field address.</td>
</tr>
<tr>
<td>compile</td>
<td>( -- )</td>
<td>Compile the next word at run time. (Recommend using postpone instead.)</td>
</tr>
</tbody>
</table>
The dictionary compilation commands listed in TABLE 4-17 are available only on 64-bit OpenBoot implementations.

### TABLE 4-16  Dictionary Compilation Commands (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[compile] name</td>
<td>( -- )</td>
<td>Compile the next (immediate) word. (Recommend using postpone instead.)</td>
</tr>
<tr>
<td>here</td>
<td>( -- addr )</td>
<td>Address of top of dictionary.</td>
</tr>
<tr>
<td>immediate</td>
<td>( -- )</td>
<td>Mark the last definition as immediate.</td>
</tr>
<tr>
<td>to name</td>
<td>( n -- )</td>
<td>Install a new action in a defer word or value.</td>
</tr>
<tr>
<td>literal</td>
<td>( n -- )</td>
<td>Compile a number.</td>
</tr>
<tr>
<td>origin</td>
<td>( -- addr )</td>
<td>Return the address of the start of the Forth system.</td>
</tr>
<tr>
<td>patch new-word old-word word-to-patch</td>
<td>( -- )</td>
<td>Replace old-word with new-word in word-to-patch.</td>
</tr>
<tr>
<td>(patch)</td>
<td>( new-n old-n xt -- )</td>
<td>Replace old-n with new-n in word indicated by xt.</td>
</tr>
<tr>
<td>postpone name</td>
<td>( -- )</td>
<td>Delay the execution of the word name.</td>
</tr>
<tr>
<td>recurse</td>
<td>( ... -- ???)</td>
<td>Compile a recursive call to the word being compiled.</td>
</tr>
<tr>
<td>recursive</td>
<td>( -- )</td>
<td>Make the name of the colon definition being compiled visible in the dictionary, and thus allow the name of the word to be used recursively in its own definition.</td>
</tr>
<tr>
<td>state</td>
<td>( -- addr )</td>
<td>Variable that is non-zero in compile state.</td>
</tr>
</tbody>
</table>

The dictionary compilation commands listed in TABLE 4-17 are available only on 64-bit OpenBoot implementations.

### TABLE 4-17  64-Bit Dictionary Compilation Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>x,</td>
<td>( o -- )</td>
<td>Compile an octlet, o, into the dictionary (doublet-aligned).</td>
</tr>
</tbody>
</table>
Displaying Numbers

Basic commands to display stack values are shown in TABLE 4-18.

### TABLE 4-18  Basic Number Display

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.</td>
<td>( n -- )</td>
<td>Display a number in the current base.</td>
</tr>
<tr>
<td>.r</td>
<td>( n size -- )</td>
<td>Display a number in a fixed width field.</td>
</tr>
<tr>
<td>.s</td>
<td>( -- )</td>
<td>Display contents of data stack.</td>
</tr>
<tr>
<td>showstack</td>
<td>( ??? -- ??? )</td>
<td>Execute .s automatically before each ok prompt.</td>
</tr>
<tr>
<td>no-showstack</td>
<td>( ??? -- ??? )</td>
<td>Turn off automatic display of the stack before each ok prompt</td>
</tr>
<tr>
<td>u.</td>
<td>( u -- )</td>
<td>Display an unsigned number.</td>
</tr>
<tr>
<td>u.r</td>
<td>( u size -- )</td>
<td>Display an unsigned number in a fixed width field.</td>
</tr>
</tbody>
</table>

The .s command displays the entire stack contents without disturbing them. It can usually be used safely for debugging purposes. (This is the function that showstack performs automatically.)

Changing the Number Base

You can print numbers in a specific number base or change the operating number base using the commands in TABLE 4-19.

### TABLE 4-19  Changing the Number Base

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.d</td>
<td>( n -- )</td>
<td>Display n in decimal without changing base.</td>
</tr>
<tr>
<td>.h</td>
<td>( n -- )</td>
<td>Display n in hex without changing base.</td>
</tr>
<tr>
<td>base</td>
<td>( -- addr )</td>
<td>Variable containing number base.</td>
</tr>
<tr>
<td>decimal</td>
<td>( -- )</td>
<td>Set the number base to 10.</td>
</tr>
</tbody>
</table>
The \texttt{d#} and \texttt{h#} commands are useful when you want to input a number in a specific base without explicitly changing the current base. For example:

\begin{verbatim}
ok decimal       (Changes base to decimal)
ok 4 h# ff 17 2
4 255 17 2 ok
\end{verbatim}

The \texttt{.d} and \texttt{.h} commands act like \texttt{"."} but display the value in decimal or hexadecimal, respectively, regardless of the current base setting. For example:

\begin{verbatim}
ok hex
ok ff . ff .d
ff 255
\end{verbatim}

\section*{Controlling Text Input and Output}

This section describes text and character input and output commands.

TABLE 4-20 lists commands to control text input.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|}
\hline
Command & Stack Diagram & Description \\
\hline
\texttt{( ccc )} & ( -- ) & Create a comment. Conventionally used for stack diagrams. \\
\texttt{\ rest-of-line} & ( -- ) & Treat the rest of the line as a comment. \\
\texttt{ascii ccc} & ( -- char ) & Get numerical value of first ASCII character of next word. \\
\texttt{accept} & ( addr len1 -- len2 ) & Get a line of edited input from the console input device; store at \texttt{addr}. len1 is the maximum allowed length. len2 is the actual length received. \\
\hline
\end{tabular}
\end{table}
Comments are used with Forth source code (generally in a text file) to describe the function of the code. The ( (open parenthesis) is the Forth word that begins a comment. Any character up to the closing parenthesis ) is ignored by the Forth interpreter. Stack diagrams are one example of comments using (.

\ (backslash) indicates a comment terminated by the end of the line of text.

key waits for a key to be pressed, then returns the ASCII value of that key on the stack.

ascii, used in the form ascii x, returns on the stack the numerical code of the character x.

key? looks at the keyboard to see whether the user has recently typed any key. It returns a flag on the stack: true if a key has been pressed and false otherwise. See “Conditional Flags” on page 77 for a discussion on the use of flags.

TABLE 4-21 lists general-purpose text display commands.

**TABLE 4-21  Displaying Text Output**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.&quot; ccc&quot;</td>
<td>( -- )</td>
<td>Compile a string for later display.</td>
</tr>
<tr>
<td>(cr</td>
<td>( -- )</td>
<td>Move the output cursor back to the beginning of the current line.</td>
</tr>
<tr>
<td>cr</td>
<td>( -- )</td>
<td>Terminate a line on the display and go to the next line.</td>
</tr>
</tbody>
</table>
cr sends a carriage-return/linefeed sequence to the console output device. For example:

\begin{verbatim}
ok 3 . 44 . cr 5 .
3 44
5
ok
\end{verbatim}

emit displays the letter whose ASCII value is on the stack.

\begin{verbatim}
ok ascii a
61 ok 42
61 42 ok emit emit
Ba
ok
\end{verbatim}

TABLE 4-22 shows commands used to manipulate text strings.

\begin{table}[h]
\centering
\begin{tabular}{lll}
\hline
\textbf{Command} & \textbf{Stack Diagram} & \textbf{Description} \\
\hline
emit & (char --) & Display the character. \\
exit? & (-- flag) & Enable the scrolling control prompt: More [<space>,<cr>,q] ? The return flag is true if the user wants the output to be terminated. \\
space & (--) & Display a space character. \\
spaces & (+n --) & Display +n spaces. \\
type & (addr +n --) & Display the +n characters beginning at addr. \\
\hline
\end{tabular}
\caption{Manipulating Text Strings}
\end{table}

TABLE 4-21 Displaying Text Output (Continued)
TABLE 4-22  Manipulating Text Strings (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bl</td>
<td>( -- char )</td>
<td>ASCII code for the space character; decimal 32.</td>
</tr>
<tr>
<td>count</td>
<td>( pstr -- addr +n )</td>
<td>Unpack a packed string.</td>
</tr>
<tr>
<td>lcc</td>
<td>( char -- lowercase-char )</td>
<td>Convert a character to lowercase.</td>
</tr>
<tr>
<td>left-parse-string</td>
<td>( addr len char -- addrR lenR addrL lenL )</td>
<td>Split a string at char (which is discarded).</td>
</tr>
<tr>
<td>pack</td>
<td>( addr len pstr -- pstr )</td>
<td>Store the string addr,len as a packed string at pstr.</td>
</tr>
<tr>
<td>upc</td>
<td>( char -- uppercase-char )</td>
<td>Convert a character to uppercase.</td>
</tr>
</tbody>
</table>

Some string commands specify an address (the location in memory where the characters reside) and a length (the number of characters in the string). Other commands use a packed string or `pstr`, which is a location in memory containing a byte for the length, immediately followed by the characters. The stack diagram for the command indicates which form is used. For example, `count` converts a packed string to an address-length string.

The command `"` is used in the form: `" string"`. It outputs text immediately when it is encountered by the interpreter. A `"` (double quotation mark) marks the end of the text string. For example:

```
ok  : testing 34 . " This is a test" 55 . ;
ok
ok testing
34 This is a test55
ok
```

When `"` is used outside a colon definition, only two interpreted strings of up to 80 characters each can be assembled concurrently. This limitation does not apply in colon definitions.

---

Redirecting Input and Output

Normally, OpenBoot uses a keyboard for command input, and a frame buffer with a connected display screen for display output. (Server systems may use an ASCII terminal connected to a serial port. For more information on how to connect a
terminal to your system, see your system’s installation manual.) You can redirect the input, the output, or both, to a serial port. This may be useful, for example, when debugging a frame buffer.

TABLE 4-23 lists commands you can use to redirect input and output.

**TABLE 4-23  I/O Redirection Commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>input</td>
<td>( device -- )</td>
<td>Select device, for example ttya, keyboard, or device-specifier, for subsequent input.</td>
</tr>
<tr>
<td>io</td>
<td>( device -- )</td>
<td>Select device for subsequent input and output.</td>
</tr>
<tr>
<td>output</td>
<td>( device -- )</td>
<td>Select device, for example ttya, keyboard, or device-specifier, for subsequent output.</td>
</tr>
</tbody>
</table>

The commands input and output temporarily change the current devices for input and output. The change takes place as soon as you enter a command; you do not have to reset your system. A system reset or power cycle causes the input and output devices to revert to the default settings specified in the NVRAM configuration variables input-device and output-device. These variables can be modified, if needed (see Chapter 3).

input must be preceded by one of the following: keyboard, ttya, ttyb, or device-specifier text string. For example, if input is currently accepted from the keyboard, and you want to make a change so that input is accepted from a terminal connected to the serial port ttya, type:

```
ok ttya input
ok
```

At this point, the keyboard becomes nonfunctional (except perhaps for Stop-A), but any text entered from the terminal connected to ttya is processed as input. All commands are executed as usual.

To resume using the keyboard as the input device, use the terminal keyboard to type:

```
ok keyboard input
ok
```
Similarly, output must be preceded by one of the following: screen, ttya, or ttyb or *device-specifier*. For example, if you want to send output to a serial port instead of the normal display screen, type:

```
ok ttya output
ok
```

The screen does *not* show the answering ok prompt, but the terminal connected to the serial port shows the ok prompt and all further output as well.

io is used in the same way, except that it changes both the input and output to the specified place. For example:

```
ok ttya io
ok
```

Generally, the argument to input, output, and io is a *device-specifier*, which can be either a device path name or a device alias. The *device must be specified as a Forth string, using double quotation marks ("), as shown in the two examples below:

```
ok " /sbus/cgsix" output
```

or:

```
ok " screen" output
```

In the preceding examples, keyboard, screen, ttya, and ttyb are predefined Forth words that put their corresponding device alias string on the stack.

---

**Command Line Editor**

OpenBoot implements a command line editor (similar to EMACS, a common text editor), some optional extensions and an optional history mechanism for the User Interface. You use these tools to re-execute previous commands without retyping them, to edit the current command line to fix typing errors, or to recall and change previous commands.
TABLE 4-24 lists line-editing commands available at the ok prompt.

**TABLE 4-24**  Required Command Line Editor Keystroke Commands

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return (Enter)</td>
<td>Finishes editing of the line and submits the entire visible line to the interpreter regardless of the current cursor position.</td>
</tr>
<tr>
<td>Control-B</td>
<td>Moves backward one character.</td>
</tr>
<tr>
<td>Escape B</td>
<td>Moves backward one word.</td>
</tr>
<tr>
<td>Control-F</td>
<td>Moves forward one character.</td>
</tr>
<tr>
<td>Escape F</td>
<td>Moves forward one word.</td>
</tr>
<tr>
<td>Control-A</td>
<td>Moves backward to beginning of line.</td>
</tr>
<tr>
<td>Control-E</td>
<td>Moves forward to end of line.</td>
</tr>
<tr>
<td>Delete</td>
<td>Erases previous character.</td>
</tr>
<tr>
<td>Backspace</td>
<td>Erases previous character.</td>
</tr>
<tr>
<td>Control-H</td>
<td>Erases previous character.</td>
</tr>
<tr>
<td>Escape H</td>
<td>Erases from beginning of word to just before the cursor, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-W</td>
<td>Erases from beginning of word to just before the cursor, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-D</td>
<td>Erases next character.</td>
</tr>
<tr>
<td>Escape D</td>
<td>Erases from cursor to end of the word, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-K</td>
<td>Erases from cursor to end of line, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-U</td>
<td>Erases entire line, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-R</td>
<td>Retypes the line.</td>
</tr>
<tr>
<td>Control-Q</td>
<td>Quotes next character (allows you to insert control characters).</td>
</tr>
<tr>
<td>Control-Y</td>
<td>Inserts the contents of the save buffer before the cursor.</td>
</tr>
</tbody>
</table>
The command line history extension saves previously-typed commands in an
EMACS-like command history ring that contains at least 8 entries. Commands may
be recalled by moving either forward or backward around the ring. Once recalled, a
command may be edited and/or resubmitted (by typing the Return key). The
command line history extension keys are:

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-P</td>
<td>Selects and displays the previous command in the command history ring.</td>
</tr>
<tr>
<td>Control-N</td>
<td>Selects and displays the next command in the command history ring.</td>
</tr>
<tr>
<td>Control-L</td>
<td>Displays the entire command history ring.</td>
</tr>
</tbody>
</table>

The command completion extension enables the system to complete long Forth word
names by searching the dictionary for one or more matches based on the already-
typed portion of a word. When you type a portion of a word followed by the
command completion keystroke, Control-Space, the system behaves as follows:

- If the system finds exactly one matching word, the remainder of the word is
  automatically displayed.
- If the system finds several possible matches, the system displays all of the
  characters that are common to all of the possibilities.
- If the system cannot find a match for the already-typed characters, the system
  deletes characters from the right until there is at least one match for the remaining
  characters.
- The system beeps if it cannot determine an unambiguous match.

The command completion extension keys are:

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-Space</td>
<td>Complete the name of the current word.</td>
</tr>
<tr>
<td>Control-?</td>
<td>Display all possible matches for the current word.</td>
</tr>
<tr>
<td>Control-/</td>
<td>Display all possible matches for the current word.</td>
</tr>
</tbody>
</table>
Conditional Flags

Forth conditionals use flags to indicate true/false values. A flag can be generated in several ways, based on testing criteria. The flag can then be displayed from the stack with the word “." or it can be used as input to a conditional control command. Control commands can cause one behavior if a flag is true and another behavior if the flag is false. Thus, execution can be altered based on the result of a test.

A 0 value indicates that the flag value is false. A -1 or any other nonzero number indicates that the flag value is true.

TABLE 4-27 lists commands that perform relational tests, and leave a true or false flag result on the stack.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
<td>(n1 n2 -- flag)</td>
<td>True if n1 &lt; n2.</td>
</tr>
<tr>
<td>&lt;=</td>
<td>(n1 n2 -- flag)</td>
<td>True if n1 &lt;= n2.</td>
</tr>
<tr>
<td>&lt;&gt;</td>
<td>(n1 n2 -- flag)</td>
<td>True if n1 is not equal to n2.</td>
</tr>
<tr>
<td>=</td>
<td>(n1 n2 -- flag)</td>
<td>True if n1 = n2.</td>
</tr>
<tr>
<td>&gt;</td>
<td>(n1 n2 -- flag)</td>
<td>True if n1 &gt; n2.</td>
</tr>
<tr>
<td>&gt;=</td>
<td>(n1 n2 -- flag)</td>
<td>True if n1 &gt;= n2.</td>
</tr>
<tr>
<td>0&lt;</td>
<td>(n -- flag)</td>
<td>True if n &lt; 0.</td>
</tr>
<tr>
<td>0&lt;=</td>
<td>(n -- flag)</td>
<td>True if n &lt;= 0.</td>
</tr>
<tr>
<td>0&lt;&gt;</td>
<td>(n -- flag)</td>
<td>True if n &lt;&gt; 0.</td>
</tr>
<tr>
<td>0=</td>
<td>(n -- flag)</td>
<td>True if n = 0 (also inverts any flag).</td>
</tr>
<tr>
<td>0&gt;</td>
<td>(n -- flag)</td>
<td>True if n &gt; 0.</td>
</tr>
<tr>
<td>0&gt;=</td>
<td>(n -- flag)</td>
<td>True if n &gt;= 0.</td>
</tr>
<tr>
<td>between</td>
<td>(n min max -- flag)</td>
<td>True if min &lt;= n &lt;= max.</td>
</tr>
<tr>
<td>false</td>
<td>(- 0 )</td>
<td>The value FALSE, which is 0.</td>
</tr>
<tr>
<td>true</td>
<td>(- -1 )</td>
<td>The value TRUE, which is -1.</td>
</tr>
<tr>
<td>u&lt;</td>
<td>(u1 u2 -- flag)</td>
<td>True if u1 &lt; u2, unsigned.</td>
</tr>
<tr>
<td>u&lt;=</td>
<td>(u1 u2 -- flag)</td>
<td>True if u1 &lt;= u2, unsigned.</td>
</tr>
</tbody>
</table>
> takes two numbers from the stack, and returns true (-1) on the stack if the first number was greater than the second number, or returns false (0) otherwise. An example follows:

```further
ok 3 6 > .
0 (3 is not greater than 6)
ok
```

0= takes one item from the stack, and returns true if that item was 0 or returns false otherwise. This word inverts any flag to its opposite value.

### Control Commands

The following sections describe words used in a Forth program to control the flow of execution.

#### The if-else-then Structure

The commands if, else and then provide a simple control structure.

The commands listed in Table 4-28 control the flow of conditional execution.

### Table 4-28  if...else...then Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>if</td>
<td>( flag -- )</td>
<td>Execute the following code when flag is true.</td>
</tr>
<tr>
<td>else</td>
<td>( -- )</td>
<td>Execute the following code when flag is false.</td>
</tr>
<tr>
<td>then</td>
<td>( -- )</td>
<td>Terminate if...else...then.</td>
</tr>
</tbody>
</table>
The format for using these commands is:

```
flag if
   (do this if true)
then
   (continue normally)
```

or

```
flag if
   (do this if true)
else
   (do this if false)
then
   (continue normally)
```

The if command consumes a flag from the stack. If the flag is true (nonzero), the commands following the if are performed. Otherwise, the commands (if any) following the else are performed.

```
ok : testit ( n -- )
] 5 > if ." good enough "
] else ." too small "
] then
] ." Done. " ;
ok
ok 8 testit
good enough Done.
ok 2 testit
too small Done.
ok
```

**Note** – The ] prompt reminds you that you are part way through creating a new colon definition. It reverts to ok after you finish the definition with a semicolon.

**The case Statement**

A high-level case command is provided for selecting alternatives with multiple possibilities. This command is easier to read than deeply-nested if...then commands.
TABLE 4-29 lists the conditional case commands.

**TABLE 4-29** case Statement Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>case</td>
<td>( selector -- selector )</td>
<td>Begin a case...endcase conditional.</td>
</tr>
<tr>
<td>endcase</td>
<td>( selector -- )</td>
<td>Terminate a case...endcase conditional.</td>
</tr>
<tr>
<td>endof</td>
<td>( -- )</td>
<td>Terminate an of...endof clause in a case...endcase</td>
</tr>
<tr>
<td>of</td>
<td>( selector test-value -- selector</td>
<td>{empty}</td>
</tr>
</tbody>
</table>

Here is a simple example of a case command:

```
ok : testit ( testvalue -- )
] case
] 0 of " It was zero " endof
] 1 of " It was one " endof
] ff of " Correct " endof
] -2 of " It was minus-two "endof
] ( default ) " It was this value: " dup ." All done." ;
ok
ok 1 testit
It was one All done.
ok ff testit
Correct All done.
ok 4 testit
It was this value: 4 All done.
ok
```

**Note** – The (optional) default clause can use the test value which is still on the stack, but should *not* remove it (use the phrase “dup .” instead of “.”). A successful of clause automatically removes the test value from the stack.

**The begin Loop**

A begin loop executes the same commands repeatedly until a certain condition is satisfied. Such a loop is also called a conditional loop.
TABLE 4-30 lists commands to control the execution of conditional loops.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>again</td>
<td>( -- )</td>
<td>End a begin...again infinite loop.</td>
</tr>
<tr>
<td>begin</td>
<td>( -- )</td>
<td>Begin a begin...while...repeat, begin...until, or begin...again loop.</td>
</tr>
<tr>
<td>repeat</td>
<td>( -- )</td>
<td>End a begin...while...repeat loop.</td>
</tr>
<tr>
<td>until</td>
<td>( flag -- )</td>
<td>Continue executing a begin...until loop until flag is true.</td>
</tr>
<tr>
<td>while</td>
<td>( flag -- )</td>
<td>Continue executing a begin...while...repeat loop while flag is true.</td>
</tr>
</tbody>
</table>

There are two general forms:

```
begin any commands...flag until
```

and

```
begin any commands...flag while
   more commands repeat
```

In both cases, the commands in the loop are executed repeatedly until the proper flag value causes the loop to be terminated. Then execution continues normally with the command following the closing command word (until or repeat).

In the begin...until case, until removes a flag from the top of the stack and inspects it. If the flag is false, execution continues just after the begin, and the loop repeats. If the flag is true, the loop is exited.

In the begin...while...repeat case, while removes a flag from the top of the stack and inspects it. If the flag is true, the loop continues by executing the commands just after the while. The repeat command automatically sends control back to begin to continue the loop. If the flag is false when while is encountered, the loop is exited immediately; control goes to the first command after the closing repeat.

An easy mnemonic for either of these loops is: If true, fall through.
A simple example follows.

```
ok begin 4000 c@ . key? until  (repeat until any key is pressed)
43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43
ok
```

The loop starts by fetching a byte from location 4000 and displaying the value. Then, the key? command is called, which leaves a true on the stack if the user has pressed any key, and false otherwise. This flag is consumed by until and, if the value is false, then the loop continues. Once a key is pressed, the next call to key? returns true, and the loop terminates.

Unlike many versions of Forth, the User Interface allows the interactive use of loops and conditionals — that is, without first creating a definition.

### The do Loop

A do loop (also called a counted loop) is used when the number of iterations of the loop can be calculated in advance. A do loop normally exits just before the specified ending value is reached.

TABLE 4-31 lists commands to control the execution of counted loops.

**TABLE 4-31  do (Counted) Loop Commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+loop</td>
<td>( n -- )</td>
<td>End a do...+loop construct; add n to loop index and return to do (if n &lt; 0, index goes from start to end inclusive).</td>
</tr>
<tr>
<td>?do</td>
<td>( end start -- )</td>
<td>Begin ?do...loop to be executed 0 or more times. Index goes from start to end-1 inclusive. If end = start, loop is not executed.</td>
</tr>
<tr>
<td>?leave</td>
<td>( flag -- )</td>
<td>Exit from a do...loop if flag is non-zero.</td>
</tr>
<tr>
<td>do</td>
<td>( end start -- )</td>
<td>Begin a do...loop. Index goes from start to end-1 inclusive. Example: 10 0 do i . loop (prints 0 1 2...d e f).</td>
</tr>
<tr>
<td>i</td>
<td>( -- n )</td>
<td>Leaves the loop index on the stack.</td>
</tr>
<tr>
<td>j</td>
<td>( -- n )</td>
<td>Leaves the loop index of the next outer enclosing loop on the stack.</td>
</tr>
<tr>
<td>leave</td>
<td>( -- )</td>
<td>Exit from do...loop.</td>
</tr>
<tr>
<td>loop</td>
<td>( -- )</td>
<td>End of do...loop.</td>
</tr>
</tbody>
</table>
The following screen shows several examples of how loops are used.

```
ok 10 5 do i . loop
5 6 7 8 9 a b c d e f
ok
ok 2000 1000 do i . i c@ . cr i c@ ff = if leave then 4 +loop
1000 23
1004 0
1008 fe
100c 0
1010 78
1014 ff
ok
: scan ( byte -- )
] 6000 5000    (Scan memory 5000 - 6000 for bytes not equal to the specified byte)
] do dup i c@ <> ( byte error? )
]    if i . then ( byte )
]    loop
]    drop ( the original byte was still on the stack, discard it )
] ;
ok 55 scan
5005 5224 5f99
ok 6000 5000 do i i c! loop    (Fill a region of memory with a stepped pattern)
ok
ok 500 value testloc
ok : test16 ( -- ) 1.0000 0 ( do 0-ffff )    (Write different 16-bit values to a location)
]    do i testloc w! testloc w@ i <> ( error? )    (Also check the location)
]        if ." Error - wrote " i ." read " testloc w@ . cr
]        leave ( exit after first error found )    (This line is optional)
]    then
]    loop
] ;
ok test16
ok 6000 to testloc
ok test16
Error - wrote 200 read 300
ok
```
Additional Control Commands

TABLE 4-32 contains descriptions of additional program execution control commands.

**TABLE 4-32  Program Execution Control Commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abort</td>
<td>( -- )</td>
<td>Abort current execution and interpret keyboard commands.</td>
</tr>
<tr>
<td>abort&quot; ccc&quot;</td>
<td>( abort? -- )</td>
<td>If abort? is true, abort and display message.</td>
</tr>
<tr>
<td>eval</td>
<td>( addr len -- )</td>
<td>Interpret Forth source from addr len.</td>
</tr>
<tr>
<td>execute</td>
<td>( xt -- )</td>
<td>Execute the word whose execution token is on the stack.</td>
</tr>
<tr>
<td>exit</td>
<td>( -- )</td>
<td>Return from the current word. (Cannot be used in counted loops.)</td>
</tr>
<tr>
<td>quit</td>
<td>( -- )</td>
<td>Same as abort, but leave stack intact.</td>
</tr>
</tbody>
</table>

*abort* causes immediate termination and returns control to the keyboard. *abort" is similar to abort but is different in two respects. *abort" removes a flag from the stack and only aborts if the flag is true. Also, *abort" prints any desired message when the abort takes place.*

eval takes a string from the stack (specified as an address and a length). The characters in that string are then interpreted as if they were entered from the keyboard. If a Forth text file has been loaded into memory (see "<Red>INVALID XREF FORMAT. Change to ChapterNumber"), then eval can be used to compile the definitions contained in the file.
Loading and Executing Programs

The User Interface provides several methods for loading and executing a program on the machine. These methods load a file into memory from Ethernet, a hard disk, a floppy disk, or a serial port, and support the execution of Forth, FCode and binary executable programs.

Most of these methods require the file to have a Client program header; see IEEE 1275.1-1994 Standard for Boot (Initialization Configuration) Firmware for a description. This header is similar to the a.out header used by many UNIX systems. Sun’s FCode tokenizer generates files with the Client program header.

OpenBoot commands for loading files from various sources are listed in TABLE 5-1.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boot [device-specifier] [arguments]</td>
<td>( -- )</td>
<td>Depending on the values of various configuration variables and the optional arguments, determine the file and device to be used. Reset the machine, load the identified program from the identified device, and execute the program.</td>
</tr>
<tr>
<td>byte-load</td>
<td>( addr xt -- )</td>
<td>Interpret FCode beginning at addr. If xt is 1 (the usual case), use rb@ to read the FCode. Otherwise, use the access routine whose execution token is xt.</td>
</tr>
<tr>
<td>dl</td>
<td>( -- )</td>
<td>Load a Forth source text file over a serial line until Control-D is detected and then interpret. Using tip as an example, type: ~C cat filename Control-D</td>
</tr>
<tr>
<td>dlbin</td>
<td>( -- )</td>
<td>Load a binary file over a serial line. Using tip as an example, type: ~C cat filename</td>
</tr>
<tr>
<td>dload filename</td>
<td>( addr -- )</td>
<td>Load the specified file over Ethernet at the given address.</td>
</tr>
</tbody>
</table>
Using boot

Although boot is normally used to boot the operating system, it can be used to load and execute any client program. Although booting usually happens automatically, the user can also initiate booting from the User Interface.

The boot process is as follows:

- The machine may be reset if a client program has been executed since the last reset. (The execution of a reset is implementation dependent.)
- A device is selected by parsing the boot command line to determine the boot device and the boot arguments to use. Depending on the form of the boot command, the boot device and/or argument values may be obtained from configuration variables.
- The bootpath and bootargs properties in the /chosen node of the device tree are set with the selected values.
- The selected program is loaded into memory using a protocol that depends on the type of the selected device. For example, a disk boot might read a fixed number of blocks from the beginning of the disk, while a tape boot might read a particular tape file.
- The loaded program is executed. The behavior of the program may be further controlled by the argument string (if any) that was either contained within the selected configuration variable or was passed to the boot command on the command line.
boot has the following general format:

\[ \text{boot} \ [\text{device-specifier}] \ [\text{arguments}] \]

where device-specifier and arguments are optional. For a complete discussion of the use of the boot command, see “Booting for the Expert User” on page 15.

### Using dl to Load Forth Text Files Over Serial Port A

Forth programs loaded with dl must be ASCII files.

To load a file over the serial line, connect the test system’s serial port A to a machine that is able to transfer a file on request (in other words, a server). Start a terminal emulator on the server, and use that terminal emulator to download the file using dl.

The following example assumes the use of the Solaris terminal emulator tip. (See Appendix A”, for information on this procedure.)

1. **At the ok prompt of the test system, type:**

\[ \text{ok} \ \text{dl} \]

2. **In the tip window of the server, type:**

\[ \~\text{C} \]

   to obtain a command line with which to issue a Solaris command on the server.

---

**Note** – The C is case-sensitive and must be capitalized.

**Note** – tip will only recognize the ~ as a tip command if it is the first character on the command line. If tip fails to recognize the ~C, type Enter in the tip window and repeat ~C.
3. At the local command prompt, use `cat` to send the file.

   `-C (local command) cat filename
   (Away two seconds)
   Control-D`

4. When `tip` displays a message of the form (Away \( n \) seconds), type:

   `Control-D`

   in the `tip` window to signal `dl` that the end of the file has been reached.

   `dl` then automatically interprets the file, and the `ok` prompt reappears on the screen of the test system.

**Using `load`**

The syntax and behavior of `load` are similar to `boot` except that the program is only loaded and not executed. `load` also does not do a machine reset prior to loading as may `boot`.

The general form of the `load` command is:

```
load [device-specifier] [arguments]
```

The parsing of the `load` command’s parameters is affected by the same configuration variables as `boot`, and `load`’s `device-specifier` and `arguments` are identified by the same process. (See “Boot for the Expert User” on page 15 for the details.)

Once the `device-specifier` and `arguments` are identified, loading proceeds as follows:

1. The `device-specifier` and `arguments` are saved in the `bootpath` and `bootargs` properties, respectively, of the `/chosen node.

2. If the `device-specifier` was obtained from a configuration variable, its value may be a list of devices. If the list contains only a single entry, that entry is used by `load` as the `device-specifier`.  
Note – If the list contains more than one entry, an attempt is made to open each listed device, beginning with the first entry, and continuing until the next to last entry. If the system successfully opens a device, that device is closed and is used by load as the device-specifier. If none of these devices can be opened, the last device in the list is used by load as the device-specifier.

3. load attempts to open the device specified by device-specifier. If the device cannot be opened, loading is terminated.

4. If the device is successfully opened, the device’s load method is invoked to load the specified program from the specified device at the system’s default load address.

5. If load is successful, and if the beginning of the loaded image is a valid client program header for the system:
   a. Memory is allocated at the address and of the size specified in that header.
   b. The loaded image is moved from the default load address to the newly allocated memory.
   c. The system is initialized such that a subsequent go command will begin the execution of the loaded program.

Using dlbin to Load FCode or Binary Executables Over Serial Port A

FCode or binary programs loaded with dlbin must be Client program header files. dlbin loads the files at the entry point indicated in the Client program header. Link binary files for 4000 (hex). Recent versions of the FCode Tokenizer create a Client program header file with entry point 4000.

To load a file over the serial line, connect the test system’s serial port A to a machine that is able to transfer a file on request (i.e. a server). Start a terminal emulator on the server, and use that terminal emulator to download the file using dlbin.

The following example assumes the use of the Solaris terminal emulator tip. (See Appendix A", for information on this procedure.)

1. At the test system’s ok prompt, type:

   ok dlbin
In the `tip` window of the server, type:

```
~c
```

to obtain a command line with which to issue a Solaris command on the server.

**Note** – The `C` is case-sensitive and must be capitalized.

**Note** – `tip` will only recognize the `~` as a `tip` command if it is the first character on the command line. If `tip` fails to recognize the `~C`, press Return in the `tip` window and repeat `~C` again.

1. At the “local command” prompt, use `cat` to send the file.

```
-C (local command) cat filename
(Away two seconds)
```

When `tip` completes the download, it displays a message of the form `(Away n seconds)`, and the `ok` prompt reappears on the screen of the test system.

To execute an FCode program, type:

```
ok 4000 1 byte-load
```

To execute the downloaded program, type:

```
ok go
```

---

**Using `dload` to Load From Ethernet**

`dload` loads files over Ethernet at a specified address, as shown below.

```
ok 4000 dload filename
```
In the above example, *filename* must be relative to the server’s root. Use 4000 (hex) as the address for dload input. dload uses the trivial file transfer protocol (TFTP), so the server may need to have its permissions adjusted for this to work.

**Forth Programs**

Forth programs loaded with dload must be ASCII files beginning with the two characters “\ ” (backslash and space). To execute the loaded Forth program, type:

```
ok 4000 file-size @ eval
```

In the above example, *file-size* contains the size of the loaded image.

**FCode Programs**

FCode programs loaded with dload must be Client program header files. To execute the loaded FCode program, type:

```
ok 4000 1 byte-load
```

*byte-load* is used by OpenBoot to interpret FCode programs on expansion boards such as SBuses. The 1 in the example is a specific value of a parameter that specifies the separation between FCode bytes in the general case. Since dload loads into system memory, 1 is the correct spacing.

**Binary Executables**

dload requires binary programs to be in Client program header.Executable binary programs loaded must be either linked to dload's input address (e.g., 4000) or be position independent. To execute the binary program, type:

```
ok go
```

To run the program again, type:

```
ok init-program go
```
dlload does not use intermediate booters (unlike the boot command). Thus, any symbol information included in the Client program header file is available to the User Interface's symbolic debugging capability. (See Chapter 6 for more information on symbolic debugging.)

Using ?go

Once a program has been loaded into the system, ?go can be used to execute that program regardless of the type of the program.

?go examines the start of the loaded image. If the image begins with the string \\
(backslash and space), the image is assumed to be Forth text. The Forth interpreter is invoked to interpret the image.
Debugging

OpenBoot provides debugging tools that include a Forth language decompiler, a machine language disassembler, register display commands, a symbolic debugger, breakpoint commands, a Forth source-level debugger, a high-level language patching facility, and exception tracing. This chapter describes the capabilities specified by IEEE Standard 1275-1994.

Using the Forth Language Decompiler

The built-in Forth language decompiler can be used to recreate the source code for any previously-defined Forth word. The command:

```
ok see old-name
```

displays a listing of the source for old-name (without the source comments, of course).

A companion to see is (see) which is used to decompile the Forth word whose execution token is taken from the stack. For example:

```
ok ' old-name (see)
```

(see) produces a listing in a format identical to see.
The preceding listing shows that:

- \textit{see} itself is composed only of Forth source words that were compiled as external or as headers with \texttt{fcode-debug?} set to true.
- \texttt{(see)} is a defer word. \texttt{(see)} also contains words that were compiled as headerless and are, consequently, displayed as hex addresses surrounded by parentheses.
- Decompiling a word with \texttt{(see)} produces a listing identical to that produced by \texttt{see}.

For words implemented in Forth assembler language, \texttt{see} displays a Forth assembler listing. For example, decompiling \texttt{dup} displays:

\begin{verbatim}
ok see dup
code dup
f0008c98 sub %g7, 8, %g7
f0008c9c stx %g4, [%g0 + %g7]
f0008ca0 ld [%g5], %10
f0008ca4 jmp %10, %g2, %g0
f0008ca8 add %g5, 4, %g5
\end{verbatim}
Using the Disassembler

The built-in disassembler translates the contents of memory into equivalent assembly language.

TABLE 6-1 lists commands that disassemble memory into equivalent opcodes.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+dis</td>
<td>( -- )</td>
<td>Continue disassembling where the last disassembly left off.</td>
</tr>
<tr>
<td>dis</td>
<td>( addr -- )</td>
<td>Begin disassembling at the specified address.</td>
</tr>
</tbody>
</table>

dis begins to disassemble the data content of any desired location. The system pauses when:
- Any key is pressed while disassembly is taking place.
- The disassembler output fills the display screen.
- A call or jump opcode is encountered.

Disassembly can then be stopped or the +dis command can be used to continue disassembling at the location where the last disassembly stopped.

Memory addresses are normally shown in hexadecimal. However, if a symbol table is present, memory addresses are displayed symbolically whenever possible.

Displaying Registers

You can enter the User Interface from the middle of an executing program as a result of a program crash, a user abort, or an encountered breakpoint. (Breakpoints are discussed on page 97.) In all these cases, the User Interface automatically saves all the CPU data register values in a buffer area. These values can then be inspected or altered for debugging purposes.
**SPARC Registers**

TABLE 6-2 lists the SPARC register commands.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>%g0 through %g7</td>
<td>( -- value )</td>
<td>Return the value in the specified global register.</td>
</tr>
<tr>
<td>%i0 through %i7</td>
<td>( -- value )</td>
<td>Return the value in the specified input register.</td>
</tr>
<tr>
<td>%l0 through %l7</td>
<td>( -- value )</td>
<td>Return the value in the specified local register.</td>
</tr>
<tr>
<td>%o0 through %o7</td>
<td>( -- value )</td>
<td>Return the value in the specified output register.</td>
</tr>
<tr>
<td>%pc %npc %y</td>
<td>( -- value )</td>
<td>Return the value in the specified register.</td>
</tr>
<tr>
<td>%f0 through %f31</td>
<td>( -- value )</td>
<td>Return the value in the specified floating point register.</td>
</tr>
<tr>
<td>.fregisters</td>
<td>( -- )</td>
<td>Display the values in %f0 through %f31.</td>
</tr>
<tr>
<td>.locals</td>
<td>( -- )</td>
<td>Display the values in the i, l and o registers.</td>
</tr>
<tr>
<td>.registers</td>
<td>( -- )</td>
<td>Display values in processor registers.</td>
</tr>
<tr>
<td>.window</td>
<td>( window# -- )</td>
<td>Same as w .locals; display the desired window.</td>
</tr>
<tr>
<td>ctrace</td>
<td>( -- )</td>
<td>Display the return stack showing C subroutines.</td>
</tr>
<tr>
<td>set-pc</td>
<td>( new-value --)</td>
<td>Set %pc to new-value, and set %npc to (new-value+4).</td>
</tr>
<tr>
<td>to regname</td>
<td>( new-value --)</td>
<td>Change the value stored in any of the above registers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use in the form: new-value to regname.</td>
</tr>
<tr>
<td>w</td>
<td>( window# -- )</td>
<td>Set the current window for displaying %ix, %lx, or %ox.</td>
</tr>
</tbody>
</table>
The values of all of these registers are saved and can be altered with \texttt{to}. After the values have been inspected and/or modified, program execution can be continued with the \texttt{go} command. The saved (and possibly modified) register values are copied back into the CPU, and execution resumes at the location specified by the saved program counter.

If you change \%pc with \texttt{to}, you should also change \%npc. (It is easier to use set-pc, which changes both registers automatically.)

On SPARC V9 systems, if N is the current window, N-1 specifies the window for the caller, N-2 specifies the caller’s caller, etc.

### Breakpoints

The User Interface provides a breakpoint capability to assist in the development and debugging of stand-alone programs. (Programs that run over the operating system generally do not use this OpenBoot feature, but use other debuggers designed to run with the operating system.) The breakpoint feature lets you stop the program under
test at desired points. After program execution has stopped, registers or memory can be inspected or changed, and new breakpoints can be set or cleared. You can resume program execution with the go command.

TABLE 6-4 lists the breakpoint commands that control and monitor program execution.

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+bp</td>
<td>( addr -- )</td>
<td>Add a breakpoint at the specified address.</td>
</tr>
<tr>
<td>-bp</td>
<td>( addr -- )</td>
<td>Remove the breakpoint at the specified address.</td>
</tr>
<tr>
<td>--bp</td>
<td>( -- )</td>
<td>Remove the most-recently-set breakpoint.</td>
</tr>
<tr>
<td>.bp</td>
<td>( -- )</td>
<td>Display all currently set breakpoints.</td>
</tr>
<tr>
<td>.breakpoint</td>
<td>( -- )</td>
<td>Perform a specified action when a breakpoint occurs. This word can be altered to perform any desired action. For example, to display registers at every breakpoint, type: [''].registers to .breakpoint. The default behavior is .instruction. To perform multiple behaviors, create a single definition which calls all desired behaviors, then load that word into .breakpoint.</td>
</tr>
<tr>
<td>.instruction</td>
<td>( -- )</td>
<td>Display the address, opcode for the last-encountered breakpoint.</td>
</tr>
<tr>
<td>.step</td>
<td>( -- )</td>
<td>Perform a specified action when a single step occurs (see .breakpoint).</td>
</tr>
<tr>
<td>bpoff</td>
<td>( -- )</td>
<td>Remove all breakpoints.</td>
</tr>
<tr>
<td>finish-loop</td>
<td>( -- )</td>
<td>Execute until the end of this loop.</td>
</tr>
<tr>
<td>go</td>
<td>( -- )</td>
<td>Continue from a breakpoint. This can be used to go to an arbitrary address by setting up the processor’s program counter before issuing go.</td>
</tr>
<tr>
<td>gos</td>
<td>( n -- )</td>
<td>Execute go n times.</td>
</tr>
<tr>
<td>hop</td>
<td>( -- )</td>
<td>(Like the step command.) Treat a subroutine call as a single instruction.</td>
</tr>
<tr>
<td>hops</td>
<td>( n -- )</td>
<td>Execute hop n times.</td>
</tr>
<tr>
<td>return</td>
<td>( -- )</td>
<td>Execute until the end of this subroutine.</td>
</tr>
<tr>
<td>returnl</td>
<td>( -- )</td>
<td>Execute until the end of this leaf subroutine.</td>
</tr>
<tr>
<td>skip</td>
<td>( -- )</td>
<td>Skip (do not execute) the current instruction.</td>
</tr>
<tr>
<td>step</td>
<td>( -- )</td>
<td>Single-step one instruction.</td>
</tr>
<tr>
<td>steps</td>
<td>( n -- )</td>
<td>Execute step n times.</td>
</tr>
<tr>
<td>till</td>
<td>( addr -- )</td>
<td>Execute until the given address is encountered. Equivalent to +bp go.</td>
</tr>
</tbody>
</table>
To debug a program using breakpoints, use the following procedure.

1. **Load the test program into memory.**
2. See Chapter 5 for more information. The register values are initialized automatically.
3. (Optional) Disassemble the downloaded program to verify a properly-loaded file.
4. Begin single-stepping the test program using the `step` command.
5. You can also set a breakpoint, then execute (for example, using the commands `addr +bp` and `go`) or perform other variations.

---

**The Forth Source-Level Debugger**

The Forth source-level Debugger allows single-stepping and tracing of Forth programs. Each step represents the execution of one Forth word.

The debugger commands are shown in **TABLE 6-5**.

**TABLE 6-5  Forth Source-level Debugger Commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>“Continue”. Switch from stepping to tracing, thus tracing the remainder of the execution of the word being debugged.</td>
</tr>
<tr>
<td>d</td>
<td>“Down a level”. Mark for debugging the word whose name was just displayed, then execute it.</td>
</tr>
<tr>
<td>u</td>
<td>“Up a level”. Un-mark the word being debugged, mark its caller for debugging, and finish executing the word that was previously being debugged.</td>
</tr>
<tr>
<td>f</td>
<td>Start a subordinate Forth interpreter with which Forth commands can be executed normally. When that interpreter is terminated (with <code>resume</code>), control returns to the debugger at the place where the <code>f</code> command was executed.</td>
</tr>
<tr>
<td>g</td>
<td>“Go.” Turn off the debugger and continue execution.</td>
</tr>
<tr>
<td>q</td>
<td>“Quit”. Abort the execution of the word being debugged and all its callers and return to the command interpreter.</td>
</tr>
<tr>
<td>s</td>
<td>“see”. Decompile the word being debugged.</td>
</tr>
<tr>
<td>$</td>
<td>Display the address,len on top of the stack as a text string.</td>
</tr>
<tr>
<td>h</td>
<td>“Help”. Display symbolic debugger documentation.</td>
</tr>
<tr>
<td>?</td>
<td>“Short Help”. Display brief symbolic debugger documentation.</td>
</tr>
</tbody>
</table>
Every Forth word is defined as a series of one or more words that could be called “component” words. While debugging a specified word, the debugger displays information about the contents of the stack while executing each of the word’s “component” words. Immediately before executing each component word, the debugger displays the contents of the stack and the name of the component word that is about to be executed.

In trace mode, that component word is then executed, and the process continues with the next component word.

In step mode (the default), the user controls the debugger’s execution behavior. Before the execution of each component word, the user is prompted for one of the keystrokes specified in TABLE 6-5.

### Using `patch` and `(patch)`

OpenBoot provides the ability to change the definition of a previously compiled Forth word using high-level Forth language. While the changes will typically be made in the appropriate source code, the `patch` facility provides a means of quickly correcting errors uncovered during debugging.

`patch` reads the input stream for the following information:
The name of the new code to be inserted.
The name of the old code to be replaced.
The name of the word containing the old code.

For example, consider the following example in which the word `test` is replaced with the number 555:

```plaintext
ok : patch-me test 0 do i . cr loop ;
ok patch 555 test patch-me
ok see patch-me
    : patch-me
        h# 555 0 do
        i . cr
        loop
    ;
```

When using `patch`, some care must be taken to select the right word to replace. This is especially true if the word you are replacing is used several times within the target word and the occurrence of the word that you want to replace is not the first occurrence within the target word. In such a case, some subterfuge is required.

```plaintext
ok : patch-me2 dup dup dup ( This third dup should be drop) ;
ok : xx dup ;
ok patch xx dup patch-me2
ok patch xx dup patch-me2
ok patch drop dup patch-me2
ok see patch-me2
    : patch-me2
        xx xx drop
    ;
```

Another use for `patch` is the case where the word to be patched contains some functionality that needs to be completely discarded. In this case, the word `exit` should be patched over the first word whose functionality is to be eliminated. For example, consider a word whose definition is:

```plaintext
ok : foo good bad unneeded ;
```

In this example, the functionality of `bad` is incorrect and the functionality of `unneeded` should be discarded. A first attempt to patch `foo` might be:

```plaintext
ok : right this that exit ;
ok patch right bad foo
```
on the expectation that the use of exit in the word right would prevent the execution of unneeded. Unfortunately, exit terminates the execution of the word which contains it, in this case right. The correct way to patch foo is:

```
ok : right this that ;
ok patch right bad foo
ok patch exit unneeded foo
```

(patch) is similar to patch except that (patch) obtains its arguments from the stack. The stack diagram for (patch) is:

```
( new-n1 num1? old-n2 num2? xt -- )
```

where:

- new-n1 and old-n2 can be either execution tokens or literal numbers.
- num1? and num2? are flags indicating whether new-n1 or old-n2, respectively, are numbers.
- xt is the execution token of the word to be patched.

For example, consider the following example in which we reverse the affect of our first patch example by replacing the number 555 with test:

```
ok see patch-me
: patch-me
  h# 555 0 do
  i . cr
  loop
;
ok ['] test false 555 true ['] patch-me (patch)
ok see patch-me
: patch-me
  test 0 do
  i . cr
  loop
;
```
Using ftrace

The ftrace command shows the sequence of Forth words that were being executed at the time of the last exception. An example of ftrace follows.

```
ok : test1 1 ! ;
ok : test2 1 test1 ;
ok test2
Memory address not aligned
ok ftrace
! Called from test1 at ffeacc5c
test1 Called from test2 at ffeacc6a
(ffe8b574) Called from (interpret at ffe8b6f8
execute Called from catch at ffe8a8ba
    ffeff0
    0
ffefebdc
catch Called from (fload) at ffe8ced8
    0
(fload) Called from interact at ffe8cf74
execute Called from catch at ffe8a8ba
    ffefed4
    0
ffefebdc
catch Called from (quit at ffe8cf98
```

In this example, test2 calls test1, which tries to store a value to an unaligned address. This results in the exception: Memory address not aligned.

The first line of ftrace’s output shows the last command that caused the exception to occur. The next lines show locations from which the subsequent commands were being called.

The last few lines are usually the same in any ftrace output, because that is the calling sequence in effect when the Forth interpreter interprets a word from the input stream.
Setting Up a TIP Connection

You can use the TTYA or TTYB ports on your SPARC system to connect to a second Sun workstation. By connecting two systems in this way, you can use a shell window on the Sun workstation as a terminal to your SPARC system. (See the tip man page for detailed information about terminal connection to a remote host.)

The TIP method is preferable to simply connecting to a dumb termina, since it lets you use windowing and operating system features when working with the boot PROM. A communications program or another non-Sun computer can be used in the same way, if the program can match the output baud rate used by the PROM TTY port.

Note – In the following pages, “SPARC system” refers to your system, and “Sun workstation” refers to the system you are connecting to your system.

Use the following procedure to set up the TIP connection.

1. Connect the Sun workstation TTYB serial port to your SPARC system TTYA serial port using a serial connection cable. Use a 3-wire Null Modem Cable, and connect wires 3-2, 2-3, and 7-7. (Refer to your system installation manual for specifications on null modem cables.)
2. At the Sun workstation, add the following lines to the /etc/remote file.
   If you are running a pre-Solaris 2.0 version of the operating environment, type:

   ```
   hardwire:\
     :dv=/dev/ttyb:br#9600:el=~C~S~Q~U~D:ie=\$:oe=\D:
   ```

   If you are running version 2.x of the Solaris operating environment, type:

   ```
   hardwire:\
     :dv=/dev/term/b:br#9600:el=~C~S~Q~U~D:ie=\$:oe=\D:
   ```

3. In a Shell Tool window on the Sun workstation, type:

   ```
   hostname% tip hardwire
   connected
   ```

   The Shell Tool window is now a TIP window directed to the Sun workstation TTYB.

   **Note** – Use a Shell Tool, not a Command Tool; some TIP commands may not work properly in a Command Tool window.

4. At your SPARC system, enter the Forth Monitor so that the **ok** prompt is displayed.

   **Note** – If you do not have a video monitor attached to your SPARC system, connect the SPARC system TTYA to the Sun workstation TTYB and turn on the power to your SPARC system. Wait for a few seconds, and press Stop-Auto interrupt the power-on sequence and start the Forth Monitor. Unless the system is completely inoperable, the Forth Monitor is enabled, and you can continue with the next step in this procedure.

5. If you need to redirect the standard input and output to TTYA, type:

   ```
   ok ttya io
   ```

   There will be no echoed response.

6. Press Return on the Sun workstation keyboard. The

   ```
   ok
   ```
7. **prompt shows in the TIP window.**

Typing `~#` in the TIP window is equivalent to pressing Stop-A at the SPARC system.

---

**Note** – *Do not* type Stop-A from a Sun workstation being used as a TIP window to your SPARC system. Doing so will abort the operating system on the workstation. (If you accidentally type `Stop-A`, you can recover by immediately typing `go` at the `ok` prompt.)

---

8. When you are finished using the TIP window, end your TIP session and exit the window:

9. Redirect the input and output to the screen and keyboard, if needed, by typing:

```
ok screen output keyboard input
```

---

**Note** – When entering `~` (tilde character) commands in the TIP window, `~` must be the first character entered on the line. To ensure that you are at the start of a new line, press Return first.

---

### Common Problems With TIP

This section describes solutions for TIP problems occurring in pre-Solaris 2.0 operating environments.

Problems with TIP may occur if:

- The lock directory is missing or incorrect.

  There should be a directory named `/usr/spool/uucp`. The owner should be `uucp` and the mode should be `drwxr-sr-x`.

- TTYB is enabled for logins.

  The status field for TTYB (or the serial port you are using) must be set to `off` in `/etc/ttytab`. Be sure to execute `kill -HUP 1` (see `init(8)`) as root if you have to change this entry.

- `/dev/ttyb` is inaccessible.

  Sometimes, a program will have changed the protection of `/dev/ttyb` (or the serial port you are using) so that it is no longer accessible. Make sure that `/dev/ttyb` has the mode set to `crw-rw-rw-`. 
The serial line is in tandem mode.

If the TIP connection is in tandem mode, the operating system sometimes sends XON (^S) characters (particularly when programs in other windows are generating lots of output). The XON characters are detected by the Forth word key?, and can cause confusion. The solution is to turn off tandem mode with the ~s !tandem TIP command.

The .cshrc file generates text.

TIP opens a sub-shell to run cat, thus causing text to be attached to the beginning of your loaded file. If you use dl and see any unexpected output, check your .cshrc file.
Building a Bootable Floppy Disk

This appendix outlines the steps necessary to create a bootable floppy disk. Information about the OS commands can be found in the man pages. Refer to the specific OS release for information about particular files and their locations within the file system.

1. **Format the diskette.**
   The fdformat command is an example of a utility for formatting floppy disks.

2. **Create the diskette’s file systems.**
   If available, you can use the newfs command.

3. **Mount the diskette to a temporary partition.**
   If available, you can use the mount command to do this.

4. **Copy the second-level disk booter to the diskette, using the cp command.**
   boot and ufsboot are examples of second-level booters.

5. **Install a boot block on the floppy.**
   If available, you can use the installboot command.

6. **Copy the file that you want to boot to the mounted diskette, using the cp command.**

7. **Unmount the diskette, using umount, if available.**

8. **You can now remove the diskette from the drive.**
   Use eject floppy, if it’s available.
Troubleshooting Guide

What do you do if your system fails to boot properly? This appendix discusses some common failures and ways to alleviate them.

Power-on Initialization Sequence

Familiarize yourself with the system power-on initialization messages. You can then identify problems more accurately because these messages show you the types of functions the system performs at various stages of system startup. They also show the transfer of control from POST to OpenBoot to the Booter to the kernel.

The example that follows shows the OpenBoot initialization sequence in a Sun Ultra™ 1 system. The messages before the banner appear on TTYA only if the diag-switch? parameter is true.
Note – The actual OpenBoot initialization sequence is system dependent. The messages on your system may be different.

CODE EXAMPLE C-1  OpenBoot Initialization Sequence

...ttya initialized  (At this point, POST has finished execution and has transferred control to OpenBoot)
Probing Memory Bank #0 16 + 16 : 32 Megabytes (Probe memory)
Probing Memory Bank #1 0 + 0 : 0 Megabytes
Probing Memory Bank #2 0 + 0 : 0 Megabytes
Probing Memory Bank #3 0 + 0 : 0 Megabytes
  (If use-nvramrc? is true, the firmware executes NVRAMRC commands. The firmware then checks for Stop-X commands, and probes the devices. The Keyboard LEDs are then flashed.)
Probing UPA Slot at le,0 Nothing there (Probe devices)
Probing /sbus@1f,0 at 0,0 cgsix
Probing /sbus@1f,0 at 1,0 Nothing there
Probing /sbus@1f,0 at 2,0 Nothing there
Sun Ultra 1 UPA/SBus (UltraSPARC 167 MHz), Keyboard Present (Display the banner)
OpenBoot 3.0, 32 MB memory installed, Serial #7570016
Ethernet address 8:0:20:73:82:60, Host ID: 80738260.
ok boot disk3
Boot device: /sbus/esp@ma@e,8400000/esp@e,8800000/sd@3,0 (The firmware is TFTP-ing the boot program)
sd@3,0 File and args:  (Control is transferred to the booter after this message is displayed)
FCode UFS Reader 1.8 01 Feb 1995 17:07:00, IEEE 1275 Client Interface. (Booter starts executing)
Loading: /platform/sun4u/ufsboot
cpu0: SUNW, UltraSPARC (upaid 0 impl 0x0 ver 0x0 clock 143 MHz)
SunOS Release 5.5 Version quick_gate_build:04/13/95 (UNIX(R) System V Release 4.0) (Control is passed to the kernel after this message is displayed)
Copyright (c) 1983-1995, Sun Microsystems, Inc. (The kernel starts to execute)
DEBUG enabled  (More kernel messages)

Emergency Procedures

Some OpenBoot systems provide the capability of commanding OpenBoot by means of depressing a combination of keys on the system’s keyboard (i.e. a “keyboard chord”).
TABLE C-1 describes the keyboard chords provided by SPARC-compatible systems. When issuing any of these commands, hold down the keys immediately after turning on the power to the SPARC system, and keep them pressed for a few seconds until the keyboard LEDs flash.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>Bypass POST. This command does not depend on security-mode. (Note: some systems bypass POST as a default; in such cases, use Stop-D to start POST.)</td>
</tr>
<tr>
<td>Stop-A</td>
<td>Abort.</td>
</tr>
<tr>
<td>Stop-D</td>
<td>Enter diagnostic mode (set diag-switch? to true).</td>
</tr>
<tr>
<td>Stop-F</td>
<td>Enter Forth on TTYA instead of probing. Use fexit to continue with the initialization sequence. Useful if hardware is broken.</td>
</tr>
<tr>
<td>Stop-N</td>
<td>Reset NVRAM contents to default values.</td>
</tr>
</tbody>
</table>

**Note** – These commands are disabled if the PROM security is on. Also, if your system has full security enabled, you cannot apply any of the suggested commands unless you have the password to get to the ok prompt.

---

### Preserving Data After a System Crash

The *sync* command forces any information on its way to the hard disk to be written out immediately. This is useful if the operating system has crashed, or has been interrupted without preserving all data first.

*sync* actually returns control to the operating system, which then performs the data saving operations. After the disk data has been synchronized, the operating system begins to save a core image of itself. If you do not need this core dump, you can interrupt the operation with the Stop-A key sequence.

---

### Common Failures

This section describes some common failures and how you can fix them.
Blank Screen —No Output

Problem: Your system screen is blank and does not show any output.

Here are possible causes for this problem:

- Hardware has failed.

Refer to your system documentation.

- Keyboard is not attached.

If the keyboard is not plugged in, the output goes to TTYA instead. To fix this problem, power down the system, plug in the keyboard, and power on again.

- Monitor is not turned on or is not plugged in.

Check the power cable on the monitor. Make sure the monitor cable is plugged into the system frame buffer; then turn the monitor on.

- output-device is set to TTYA or TTYB.

This means the NVRAM parameter output-device is set to ttya or ttyb instead of being set to screen. Connect a terminal to TTYA and reset the system. After getting to the ok prompt on the terminal, type: screen output to send output to the frame buffer. Use setenv to change the default display device, if needed.

- System has multiple frame buffers.

If your system has several plugged-in frame buffers, or it has a built-in frame buffer and one or more plugged-in frame buffers, then it is possible that the wrong frame buffer is being used as the console device. See “Setting the Console to a Specific Monitor” on page 117.

System Boots From the Wrong Device

Problem: Your system is supposed to boot from the disk; instead, it boots from the net.

There are two possible causes for this:

- The diag-switch? NVRAM parameter is set to true.

Interrupt the booting process with Stop-A. Type the following commands at the ok prompt:

```
ok setenv diag-switch? false
ok boot
```

The system should now start booting from the disk.
The `boot-device` NVRAM parameter is set to `net` instead of `disk`.

Interrupt the booting process with `Stop-A`. Type the following commands at the `ok` prompt:

```
ok setenv boot-device disk
ok boot
```

Note that the preceding commands cause the system to boot from the disk defined as `disk` in the device aliases list. If you want to boot from another service, set `boot-device` accordingly.

Problem: Your system is booting from a disk instead of from the net.

- `boot-device` is not set to `net`.

Interrupt the booting process with `Stop-A`. Type the following commands at the `ok` prompt:

```
ok setenv boot-device net
ok boot
```

Problem: Your system is booting from the wrong disk. (For example, you have more than one disk in your system. You want the system to boot from `disk2`, but the system is booting from `disk1` instead.)

- `boot-device` is not set to the correct disk.

Interrupt the booting process with `Stop-A`. Type the following commands at the `ok` prompt:

```
ok setenv boot-device disk2
ok boot
```

System Will Not Boot From Ethernet

Problem: Your system fails to boot from the net.

The problem could be one of the following:

- NIS maps are out-of-date.

Report the problem to your system administrator.

- Ethernet cable is not plugged in.
Plug in the ethernet cable. The system should continue with the booting process.
- Server is not responding: no carrier messages.

Report the problem to your system administrator.
- tpe-link-test is disabled.

Refer to the troubleshooting information in your system documentation. (Note: systems that do not have Twisted Pair Ethernet will not have the tpe-link-test parameter.)

System Will Not Boot From Disk

Problem: You are booting from a disk and the system fails with the message: The file just loaded does not appear to be executable.
- The boot block is missing or corrupted.

Install a new boot block.

Problem: You are booting from a disk and the system fails with the message: Can’t open boot device.
- The disk may be powered down (especially if it is an external disk).

Turn on power to the disk, and make sure the SCSI cable is connected to the disk and the system.

SCSI Problems

Problem: Your system has more than one disk installed, and you get SCSI-related errors.
- Your system might have duplicate SCSI target number settings.

Try the following procedure:

1. Unplug all but one of the disks.

2. At the ok prompt, type:

   ```
   ok probe-scsi
   ```

   Note the target number and its corresponding unit number.

1. Plug in another disk and perform Step b again.
2. If you get an error, change the target number of this disk to be one of the unused target numbers.

3. Repeat Steps b, c, and d until all the disks are plugged back in.

**Setting the Console to a Specific Monitor**

Problem: You have more than one monitor attached to the system, and the console is not set to the intended monitor.

- If you have more than one monitor attached to the system, OpenBoot always assigns the console to the frame buffer specified by the `output-device` NVRAM parameter. The default value of `output-device` is `screen`, which is an alias for one of the frame buffers found by the firmware.

A common way to change this default is to change `output-device` to the appropriate frame buffer:

```
ok nvalias myscreen /sbus/cgsix
ok setenv output-device myscreen
ok reset-all
```

Another way of setting the console to a specific monitor is to change the `sbus-probe-list` NVRAM parameter.

```
ok show sbus-probe-list  (Display the current and default values)
```

If the frame buffer that you are choosing as the console is in slot 2, change `sbus-probe-list` to probe slot 2 first:

```
ok setenv sbus-probe-list 2013
ok reset-all
```

If a non-SBus frame buffer is installed, this second method may not work.
Sun Ultra 5/10 UPA/PCI System

This appendix describes some information that is different in this PCI-bus-based system than in an Sbus-based Sun system.

---

**PCI-Based System**

The banner output is as follows, indicating that it is a PCI-based system by showing "UPA/PCI" in banner

```
ok banner
Sun Ultra 5/10 UPA/PCI (UltraSPARC-IIi 300MHz), Keyboard Present
OpenBoot 3.11, 32 MB memory installed, Serial #8812498.
Ethernet address 8:0:20:86:77:d2, Host ID: 808677d2.
```

Note that the output of `show-devs` command shows some PCI-based nodes. Also, PCI-based systems use generic names for devices. On-board network is named "network", and internal disks are named "diskn", n representing the scsi target number for that disk.
Plug in PCI cards with their own FC0dePROM may or may not be using generic names. For details on generic names, see Recommended Practices available on homepage for Open Firmware Working Group at:
http://playground.sun.com/1275

```
ok show-devs
/SUNW,UltraSPARC-IIi@0,0
/pci@1f,0
/virtual-memory
/memory@0,0
/aliases
/options
/openprom
/chosen
/packages
/pci@1f,0/pci@0
/pci@1f,0/pci@0,1
/pci@1f,0/pci@0,1/ide@3
/pci@1f,0/pci@0,1/SUNW,m64B@2
/pci@1f,0/pci@0,1/network@0,1
/pci@1f,0/pci@0,1/ebus@1
/pci@1f,0/pci@0,1/ide@3/cdrom
/pci@1f,0/pci@0,1/ide@3/disk
/pci@1f,0/pci@0,1/ebus@1/SUNW,CS4231@14,200000
/pci@1f,0/pci@0,1/ebus@1/flashprom@10,0
/pci@1f,0/pci@0,1/ebus@1/eeprom@14,0
/pci@1f,0/pci@0,1/ebus@1/fdthree@14,3023f0
/pci@1f,0/pci@0,1/ebus@1/ecpp@14,3043bc
/pci@1f,0/pci@0,1/ebus@1/su@14,3062f8
/pci@1f,0/pci@0,1/ebus@1/su@14,3083f8
/pci@1f,0/pci@0,1/ebus@1/se@14,400000
/pci@1f,0/pci@0,1/ebus@1/SUNW,pll@14,504000
/pci@1f,0/pci@0,1/ebus@1/power@14,724000
/pci@1f,0/pci@0,1/ebus@1/auxio@14,726000
/openprom/client-services
/packages/sun-keyboard
/packages/SUNW,builtin-drivers
/packages/disk-label
/packages/obp-tftp
/packages/deblocker
/packages/terminal-emulator
```
The following shows the output of the `devalias` command on the Sun Ultra 5/10 UPA/PCI system:

```
ok devalias
screen     /pci@1f,0/pci@1,1/SUNW,m64B@2
net        /pci@1f,0/pci@1,1/network@1,1
cdrom      /pci@1f,0/pci@1,1/ide@3/cdrom@2,0:f
disk       /pci@1f,0/pci@1,1/ide@3/disk@0,0
disk3      /pci@1f,0/pci@1,1/ide@3/disk@3,0
disk2      /pci@1f,0/pci@1,1/ide@3/disk@2,0
disk1      /pci@1f,0/pci@1,1/ide@3/disk@1,0
disk0      /pci@1f,0/pci@1,1/ide@3/disk@0,0
ide        /pci@1f,0/pci@1,1/ide@3
floppy     /pci@1f,0/pci@1,1/ebus@1/fdthree
ttyb       /pci@1f,0/pci@1,1/ebus@1/se:b
ttya       /pci@1f,0/pci@1,1/ebus@1/se:a
keyboard!  /pci@1f,0/pci@1,1/ebus@1/su@14,3083f8:forcemode
keyboard   /pci@1f,0/pci@1,1/ebus@1/su@14,3083f8
mouse      /pci@1f,0/pci@1,1/ebus@1/su@14,3062f8
name       aliases
```

The command `.speed` shows the speed for the processor and busses attached to the system:

```
ok .speed
CPU Speed : 300.00MHz
UPA Speed : 100.00MHz
PCI Bus A : 33MHz
PCI Bus B : 33MHz
```
pcia and pcib PCI Busses

The Sun Ultra 5/10 UPA/PCI system has two PCI busses, pcia & pcib. The probing of slots for those busses are controlled by the following two NVRAM configuration variables.

**TABLE D-1** PCI Slots

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pcia-probe-list</td>
<td>1, 2, 3, 4</td>
<td>Controls probe order of plug-in devices under pcia</td>
</tr>
<tr>
<td>pcib-probe-list</td>
<td>1, 2, 3</td>
<td>Controls probe order of plug-in devices under pcib</td>
</tr>
</tbody>
</table>
Sun Ultra 30 UPA/PCI System

This appendix describes some information that is different in this PCI-bus-based system than in an Sbus-based Sun system.

PCI-Based System

The banner output is as follows, indicating that it is a PCI-based system by showing "UPA/PCI" in banner

```
ok banner
Sun Ultra 30 UPA/PCI (UltraSPARC 200MHz), Keyboard Present
OpenBoot 3.9, 64 MB memory installed, Serial #8431666
Ethernet address 8:0:20:80:a8:32, Host ID: 8080a832
```

Note that the output of show-devs command shows some PCI-based nodes. Also, PCI-based systems use generic names for devices. On-board network is named "network", and internal disks are named "diskn", representing the scsi target number for that disk.
Plug in PCI cards with their own FCodPROM may or may not be using generic names. For details on generic names, see Recommended Practices available on homepage for Open Firmware Working Group at: http://playground.sun.com/1275

ok  show-devs
/SUNW,ffb@le,0
/SUNW, UltraSPARC@0,0
/counter-timer@lf,1c00
/pci@lf,2000
/pci@lf,4000
/virtual-memory
/memory@0,60000000
/aliases
/options
/openprom
/chosen
/packages
/pci@lf,4000/usb@5
/pci@lf,4000/SUNW,m64B@2
/pci@lf,4000/scsi@3
/pci@lf,4000/network@1,1
/pci@lf,4000/ebus@1
/pci@lf,4000/scsi@3/tape
/pci@lf,4000/scsi@3/disk
/pci@lf,4000/ebus@1/SUNW,CS4231@14,200000
/pci@lf,4000/ebus@1/flashprom@10,0
/pci@lf,4000/ebus@1/eeprom@14,0
/pci@lf,4000/ebus@1/fdthree@14,3023f0
/pci@lf,4000/ebus@1/ecpp@14,3043bc
/pci@lf,4000/ebus@1/su@14,3062f8
/pci@lf,4000/ebus@1/su@14,3083f8
/pci@lf,4000/ebus@1/se@14,400000
/pci@lf,4000/ebus@1/sc@14,500000
/pci@lf,4000/ebus@1/SUNW,p11@14,504000
/pci@lf,4000/ebus@1/power@14,724000
/pci@lf,4000/ebus@1/auxio@14,726000
/openprom/client-services
/packages/sun-keyboard
/packages/SUNW,builtin-drivers
/packages/disk-label
/packages/obp-tftp
/packages/deblocker
/packages/terminal-emulator
The following shows the output of the `devalias` command on the Sun Ultra 30UPA/PCI system:

```
ok devalias

screen                   /SUNW,ffb@1e,0
net                      /pci@1f,4000/network@1,1
disk                     /pci@1f,4000/scsi@3/disk@0,0
cdrom                    /pci@1f,4000/scsi@3/disk@6,0:f
tape                     /pci@1f,4000/scsi@3/tape@4,0
tape1                    /pci@1f,4000/scsi@3/tape@5,0
tape0                    /pci@1f,4000/scsi@3/tape@4,0
disk6                    /pci@1f,4000/scsi@3/disk@6,0
disk5                    /pci@1f,4000/scsi@3/disk@5,0
disk4                    /pci@1f,4000/scsi@3/disk@4,0
disk3                    /pci@1f,4000/scsi@3/disk@3,0
disk2                    /pci@1f,4000/scsi@3/disk@2,0
disk1                    /pci@1f,4000/scsi@3/disk@1,0
disk0                    /pci@1f,4000/scsi@3/disk@0,0
scsi                     /pci@1f,4000/scsi@3
floppy                   /pci@1f,4000/ebus@1/fdthree
ttyb                     /pci@1f,4000/ebus@1/se:b
ttya                     /pci@1f,4000/ebus@1/se:a
keyboard!                /pci@1f,4000/ebus@1/su@14,3083f8:forcemode
keyboard                 /pci@1f,4000/ebus@1/su@14,3083f8
mouse                    /pci@1f,4000/ebus@1/su@14,3062f8
```
When you look at properties for the device node of a PCI device, you will see few properties that are unique to PCI devices and few properties has a different format than that of a SBus device. For example, the output of .properties for a PCI device is:

```
ok cd /pci@1f,4000/scsi@3
ok .properties
interrupts               0000020
assigned-addresses       81001810 00000000 00000400 00000000 00000100
                        82001814 00000000 00010000 00000000 00001000
                        82001818 00000000 00011000 00000000 00001000
device_type              scsi-2
clock-frequency          02625a00
reg                      0001800 00000000 00000000 00000000 00000000
                        01001810 00000000 00000000 00000000 00000100
                        02001814 00000000 00000000 00000000 00000100
                        02001818 00000000 00000000 00000000 00000100
model                    Symbios,53C875
compatible               gl
name                     scsi
devsel-speed             00000001
class-code               00010000
max-latency              00000400
min-grant                0000011
revision-id              0000003
device-id                000000f
vendor-id                00001000
```

### Generic Names

The following example shows generic names for devices under `/pci@1f,4000/scsi@3`:

```
ok ls
f00809d8 tape
f007ecdc disk
```
The command `.speed` shows the speed for the processor and busses attached to the system:

```
ok .speed
CPU Speed : 200.00MHz
UPA Speed : 100.00MHz
PCI Bus A : 66Mhz
PCI Bus B : 33Mhz
```

**pcia and pcib PCI Busses**

The Sun Ultra 30 UPA/PCI system has two PCI busses, pcia & pcib. The probing of slots for those busses are controlled by the following two NVRAM configuration variables.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pcia-probe-list</td>
<td>1,2</td>
<td>Controls probe order of plug-in devices under pcia</td>
</tr>
<tr>
<td>pcib-probe-list</td>
<td>3,2,4,5</td>
<td>Controls probe order of plug-in devices under pcib</td>
</tr>
</tbody>
</table>

**TABLE E-1**    
PCI Slots

**pcia-probe-list** corresponds to devices under `/pci@1f,2000` and **pcib-probe-list** corresponds to devices under `/pci@1f,4000`.

**pcia** supports one plug-in client (slot 1, marked as "PCI 1, 66") It can support a device which is 64 bits wide and runs up to 66Mhz. Even though there is no client/slot under pcia corresponding to value 2, 2 is included in pcia-probe-list default value for historical reasons.

**pcib** supports three plug-in clients (slot 2, 4, and 5; marked as "PCI 2", "PCI 3", and "PCI 4" respectively). pcib can support devices which are 64 bits wide and run up to 33Mhz.
Sun Ultra 60 UPA/PCI System

This appendix describes some information that is different in this PCI-bus-based system than in an Sbus-based Sun system.

PCI-Based System

The banner output is as follows, indicating that it is a PCI-based system by showing "UPA/PCI" in banner

```
ok banner
Sun Ultra 60 UPA/PCI (UltraSPARC-II 296MHz), No Keyboard
OpenBoot 3.11, 256 MB memory installed, Serial #9241373.
Ethernet address 8:0:20:8d:3:1d, Host ID: 808d031d.
```

Note that the output of show-devs command shows some PCI-based nodes. Also, PCI-based systems use generic names for devices. On-board network is named "network", and internal disks are named "diskn", n representing the scsi target number for that disk.
Plug in PCI cards with their own FCodePROM may or may not be using generic names. For details on generic names, see Recommended Practices available on homepage for Open Firmware Working Group at:
http://playground.sun.com/1275

```
ok show-devs
/SUNW,UltraSPARC-II@0,0
/counter-timer@1f,1c00
/pci@1f,2000
/pci@1f,4000
/virtual-memory
/memory@0,a0000000
/aliases
/options
/openprom
/chosen
/packages
/pci@1f,4000/scsi@3,1
/pci@1f,4000/scsi@3
/pci@1f,4000/network@1,1
/pci@1f,4000/ebus@1
/pci@1f,4000/scsi@3,1/tape
/pci@1f,4000/scsi@3,1/disk
/pci@1f,4000/scsi@3/tape
/pci@1f,4000/scsi@3/disk
/pci@1f,4000/ebus@1/SUNW,CS4231@14,200000
/pci@1f,4000/ebus@1/flashprom@10,0
/pci@1f,4000/ebus@1/eeprom@14,0
/pci@1f,4000/ebus@1/fdthree@14,3023f0
/pci@1f,4000/ebus@1/ecpp@14,3043bc
/pci@1f,4000/ebus@1/su@14,3062f8
/pci@1f,4000/ebus@1/su@14,3083f8
/pci@1f,4000/ebus@1/se@14,400000
/pci@1f,4000/ebus@1/sc@14,500000
/pci@1f,4000/ebus@1/SUNW,p11@14,504000
/pci@1f,4000/ebus@1/power@14,724000
/pci@1f,4000/ebus@1/auxio@14,726000
/openprom/client-services
/packages/sun-keyboard
/packages/SUNW,builtin-drivers
/packages/disk-label
/packages/obp-tftp
/packages/deblocker
/packages/terminal-emulator
```
The following shows the output of the `devalias` command on the Sun Ultra 30UPA/PCI system:

```
ok  devalias
screen       /SUNW,ffb@1e,0
net          /pci@0f,4000/network@1,1
disk         /pci@0f,4000/scsi@3/disk00,0
cdrom        /pci@0f,4000/scsi@3/disk06,0:f
tape         /pci@0f,4000/scsi@3/tape04,0
tape1        /pci@0f,4000/scsi@3/tape05,0
tape0        /pci@0f,4000/scsi@3/tape04,0
disk6        /pci@0f,4000/scsi@3/disk06,0
disk5        /pci@0f,4000/scsi@3/disk05,0
disk4        /pci@0f,4000/scsi@3/disk04,0
disk3        /pci@0f,4000/scsi@3/disk03,0
disk2        /pci@0f,4000/scsi@3/disk02,0
disk1        /pci@0f,4000/scsi@3/disk01,0
disk0        /pci@0f,4000/scsi@3/disk00,0
scsi         /pci@0f,4000/scsi@3
floppy       /pci@0f,4000/ebus@1/fdthree
ttyb         /pci@0f,4000/ebus@1/se:b
ttysa        /pci@0f,4000/ebus@1/se:a
keyboard!    /pci@0f,4000/ebus@1/su@14,3083f8:forcemode
keyboard     /pci@0f,4000/ebus@1/su@14,3083f8
mouse        /pci@0f,4000/ebus@1/su@14,3062f8
name         aliases
```
When you look at properties for the device node of a PCI device, you will see few properties that are unique to PCI devices and few properties has a different format than that of a SBus device. For example, the output of .properties for a PCI device is:

```
ok cd /pci@1f,4000/scsi@3
ok .properties
assigned-addresses 81001810 00000000 00000400 00000000 00001000
                    82001814 00000000 00100000 00000000 00001000
                    82001818 00000000 00110000 00000000 00010000
device_type         scsi-2
clock-frequency     02625a00
reg                 00001800 00000000 00000000 00000000 00000100
                    01001810 00000000 00000000 00000000 00000100
                    02001814 00000000 00000000 00000000 00000100
                    02001818 00000000 00000000 00000000 00001000
model               Symbios,53C875
compatible          glm
name                scsi
devsel-speed        00000001
class-code          00010000
interrupts         00000001
max-latency         00000040
min-grant           00000011
revision-id         00000014
device-id           0000000f
vendor-id           00001000
```

---

**Generic Names**

The following example shows generic names for devices under /pci@1f,4000/scsi@3:

```
ok ls
f007ae2c tape
f00797f4 disk
```
The command `.speed` shows the speed for the processor and busses attached to the system:

```
ok .speed
CPU  Speed : 296.00MHz
UPA  Speed : 098.66MHz
PCI  Bus A : 66Mhz
PCI  Bus B : 33Mhz
```

**pcia and pcib PCI Busses**

The Sun Ultra 60 UPA/PCI system has two PCI busses, `pcia` & `pcib`. The probing of slots for those busses are controlled by the following two NVRAM configuration variables.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pcia-probe-list</td>
<td>1,2</td>
<td>Controls probe order of plug-in devices under <code>pcia</code></td>
</tr>
<tr>
<td>pcib-probe-list</td>
<td>3,2,4,5</td>
<td>Controls probe order of plug-in devices under <code>pcib</code></td>
</tr>
</tbody>
</table>

`pcia-probe-list` corresponds to devices under `/pci@1f,2000` and `pcib-probe-list` corresponds to devices under `/pci@1f,4000`.

`pcia` supports one plug-in client (slot 1, marked as "PCI 1, 66"). It can support a device which is 64 bits wide and runs up to 66Mhz. Even though there is no client/slot under `pcia` corresponding to value 2, 2 is included in `pcia-probe-list` default value for historical reasons.

`pcib` supports three plug-in clients (slot 2,4, and 5; marked as "PCI 2", "PCI 3", and "PCI 4" respectively). `pcib` can support devices which are 64 bits wide and run up to 33Mhz.
Sun Ultra 250 UPA/PCI System

This appendix describes information that is different in this PCI-bus-based system than that in an Sbus-based Sun system.

Banner Command Output

The output of the banner command appears as follows, indicating that it is a PCI-based system.

```
ok banner
Sun (TM) Enterprise 250 UPA/PCI (UltraSPARC-II 296MHz), No Keyboard
OpenBoot 3.7, 128 MB memory installed, Serial #8941639.
Ethernet address 8:0:20:88:70:47, Host ID: 80887047.
```

Generic Names

Note that the output of the `show-devs` command shows some PCI-based nodes. PCI-based systems use generic names for devices. That is, the on-board network is named "network", and internal disks are named "diskn", with n representing the scsi target number for that disk, ("disk" with no number refers to "disk0"). Plug in PCI cards with their own FCode PROM may or may not be using generic names.
For details on generic names, see *Recommended Practices* available on the homepage for the Open Firmware Working Group at: http://playground.sun.com

```
ok show-devs
/SUNW,UltraSPARC-II@0,0
/mc@0,0
/rsc
/pci@1f,2000
/pci@1f,4000
/counter-timer@1f,1c00
/associations
/virtual-memory
/memory@0,0
/aliases
/options
/openprom
/chosen
/packages
/mc@0,0/bank@0,60000000
/mc@0,0/bank@0,40000000
/mc@0,0/bank@0,20000000
/mc@0,0/bank@0,0
/mc@0,0/bank@0,0/dimm@0,3
/mc@0,0/bank@0,0/dimm@0,2
/mc@0,0/bank@0,0/dimm@0,1
/mc@0,0/bank@0,0/dimm@0,0/pci@1f,4000/scsi@3,1
/pci@1f,4000/scsi@3
/pci@1f,4000/network@1,1
/pci@1f,4000/ebus@1
/pci@1f,4000/scsi@3,1/tape
/pci@1f,4000/scsi@3,1/disk
/pci@1f,4000/scsi@3/tape
/pci@1f,4000/scsi@3/disk
/pci@1f,4000/ebus@1/SUNW,envctrltwo@14,600000
/pci@1f,4000/ebus@1/flashprom@10,0
/pci@1f,4000/ebus@1/eprom@14,0
/pci@1f,4000/ebus@1/fdthree@14,3023f0
/pci@1f,4000/ebus@1/ecpp@14,3043bc
/pci@1f,4000/ebus@1/su@14,3062f8
/pci@1f,4000/ebus@1/su@14,3083f8
/pci@1f,4000/ebus@1/se@14,200000
/pci@1f,4000/ebus@1/se@14,400000
/pci@1f,4000/ebus@1/sc@14,500000
/pci@1f,4000/ebus@1/SUNW,pl1014,504000
/pci@1f,4000/ebus@1/power@14,724000
/pci@1f,4000/ebus@1/auxio@14,726000
```
SCSI Internal Busses

For Ultra 250 systems, there are two internal SCSI busses. The device "scsi" refers to the internal SCSI I/O bus for internal disk.

/associations/slot2dev
/associations/slot2disk
/openprom/client-services
/packages/obdiag
/packages/disk-label
/packages/obp-tftp
/packages/deblocker
/packages/terminal-emulator
The following shows the output of a `devalias` command on a Sun Ultra 250 UPA/PCI system.

```
ok  devalias
  disk5    /pci@1f,4000/scsi@3/disk@c,0
  disk4    /pci@1f,4000/scsi@3/disk@b,0
  disk3    /pci@1f,4000/scsi@3/disk@a,0
  disk2    /pci@1f,4000/scsi@3/disk@9,0
  disk1    /pci@1f,4000/scsi@3/disk@8,0
  disk0    /pci@1f,4000/scsi@3/disk@0,0
  disk     /pci@1f,4000/scsi@3/disk@0,0
  scsi     /pci@1f,4000/scsi@3
  cdrom    /pci@1f,4000/scsi@3/disk@6,0:f
  tape     /pci@1f,4000/scsi@3/tape@4,0
  pcia      /pci@1f,2000
  pcib      /pci@1f,4000
  pci0      /pci@1f,4000
  flash     /pci@1f,4000/ebus@1/flashprom@10,0
  nvram     /pci@1f,4000/ebus@1/eeprom@14,0
  parallel  /pci@1f,4000/ebus@1/ecpp@14,3043bc
  net       /pci@1f,4000/network@1,1
  ebus      /pci@1f,4000/ebus@1
  i2c        /pci@1f,4000/ebus@1/SUNW,envctrltwo
  floppy    /pci@1f,4000/ebus@1/fdthree
  tty       /pci@1f,4000/ebus@1/se@14,400000
  ttya      /pci@1f,4000/ebus@1/se@14,400000:a
  ttyb      /pci@1f,4000/ebus@1/se@14,400000:b
  rscctl    /pci@1f,4000/ebus@1/se@14,200000:sspctl
  rsc       /pci@1f,4000/ebus@1/se@14,200000:ssp
  ttyc      /pci@1f,4000/ebus@1/se@14,200000:ssp
  ttyd      /pci@1f,4000/ebus@1/se@14,200000:sspctl
  keyboard! /pci@1f,4000/ebus@1/su@14,3083f8:forcemode
  keyboard  /pci@1f,4000/ebus@1/su@14,3083f8
  mouse     /pci@1f,4000/ebus@1/su@14,3083f8
  name      aliases
```
.properties for a PCI Device

When you look at properties for a device node of a PCI device, you will see a few properties that are unique to PCI devices and a few properties that have a different format than that of a SBus device. For example, the output of .properties for a PCI device:

```
ok cd /pci@1f,4000/scsi@3
ok .properties
  target6-scsi-options     00 00 05 f8
  target5-scsi-options     00 00 05 f8
  target4-scsi-options     00 00 05 f8
  target3-scsi-options     00 00 05 f8
  target2-scsi-options     00 00 05 f8
  target1-scsi-options     00 00 05 f8
  latency-timer            00000011
  assigned-addresses       81001810 00000000 00000400 00000000 00001000
                           82001814 00000000 00010000 00000000 00000100
                           82001818 00000000 00011000 00000000 00000100
  device_type              scsi-2
  fru                      motherboard
  clock-frequency          02625a00
  reg                      00001800 00000000 00000000 00000000 00000000
                           01001810 00000000 00000000 00000000 00000100
                           02001814 00000000 00000000 00000000 00001000
                           02001818 00000000 00000000 00000000 00000100
  model                    Symbios,53C875
  compatible               70 63 69 31 30 30 2c 66 00 67 6c 6d 00 70 63
  name                     scsi
  devsel-speed             00000001
  class-code               00010000
  interrupts              00000020
  max-latency              00000040
  min-grant                00000011
  revision-id              00000014
  device-id                0000000f
  vendor-id                00001000
```
The following example shows generic names for devices under `/pci@1f,4000/scsi@3`:

```
ok ls
f008bc60 tape
f007a51c disk
```

**.speed Command**

The command `.speed` shows the speed for both processors and busses attached to the system, as follows:

```
ok .speed
CPU Speed : 296.00MHz
UPA Speed : 098.66MHz
PCI Bus A at UPA node 1f: 66Mhz
PCI Bus B at UPA node 1f: 33Mhz
```

**Probing of Slots For PCI Busses**

The Sun Ultra 250 UPA/PCI system has four PCI plug-in slots, distributed across a single PCI bus. Probing of slots for those busses is controlled by the following two NVRAM configuration variables:

<table>
<thead>
<tr>
<th>TABLE G-1 NVRAM Configuration Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable Name</strong></td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td><code>pci0-probe-list</code></td>
</tr>
<tr>
<td><code>pci-slot-skip-list</code></td>
</tr>
</tbody>
</table>

`pci0-probe-list` specifies the device probe order on the "B" bus of the 1F PCI Controller. Device 3 is the motherboard 876 UltraSCSI bus (internal disks), while devices 2, 4, and 5 are open 33MHz 32-bit slots for plug-in cards.
pci-slot-skip-list is a list (0 to 3) of PCI slots that should not be probed. The values "0" to "3" correspond to the backpanel PCI slots, from bottom to top.

The Ultra 250 systems provide 4 PCI plug-in slots, numbered from 0 to 3, bottom-to-top (accessible and labeled from the back of the system):

<table>
<thead>
<tr>
<th>PCI Slot</th>
<th>PCI Bus</th>
<th>PCI Device</th>
<th>Width</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>pci0</td>
<td>/pci@1f,2000/xxx@1</td>
<td>32 bit</td>
<td>33 MHz</td>
</tr>
<tr>
<td>2</td>
<td>pci0</td>
<td>/pci@1f,4000/xxx@2</td>
<td>32 bit</td>
<td>33 MHz</td>
</tr>
<tr>
<td>1</td>
<td>pci0</td>
<td>/pci@1f,4000/xxx@4</td>
<td>32 bit</td>
<td>33 MHz</td>
</tr>
<tr>
<td>0</td>
<td>pci0</td>
<td>/pci@1f,4000/xxx@5</td>
<td>32 bit</td>
<td>33 MHz</td>
</tr>
</tbody>
</table>

where the xxx will correspond to the particular PCI card plugged into that slot. For example, plugging an 875/glm SCSI controller card into slot 0 will yield /pci@1f,4000/scsi@5, while plugging an 876 dual-SCSI card into slot 3 will yield two separate "devices" /pci@1f,2000/scsi@1 and /pci@1f,2000/scsi@1,1.

---

**Probe SCSI Command**

The following is a sample output of the probe-scsi command showing the two internal SCSI busses.

```
ok probe-scsi
This command may hang the system if a Stop-A or halt command has been executed. Please type reset-all to reset the system before executing this command.
Do you wish to continue? (y/n) y
Target 8
  Unit 0  Disk       SEAGATE ST32171W SUN2.1G8254
```
This appendix describes information that is different in this PCI-bus-based system than that in an Sbus-based Sun system.

Banner Command Output

The output of the banner command appears as follows, indicating that it is a PCI-based system.

```
ok banner
Sun Ultra 450 (3 X UltraSPARC-II 248MHz), Keyboard Present
OpenBoot 3.5, 256 MB memory installed, Serial #8525185
Ethernet address 8:0:20:82:a5:81, Host ID: 80821581
```
ok show-devs
pci@6,2000
pci@6,4000
pci@4,2000
pci@4,4000
SUNW,ffb@1d,0
SUNW,UltraSPARC-II@1,0
mc@0,0
pci@1f,2000
pci@1f,4000
counter-timer@1f,1c00
associations
virtual-memory
memory@0,0
aliases
options
openprom
chosen
packages
pci@6,4000/scsi@4,1
pci@6,4000/scsi@4
pci@6,4000/scsi@3,1
pci@6,4000/scsi@3
pci@6,4000/scsi@4,1/tape
pci@6,4000/scsi@4,1/disk
pci@6,4000/scsi@4/tape
pci@6,4000/scsi@4/disk
pci@6,4000/scsi@3,1/tape
pci@6,4000/scsi@3,1/disk
pci@6,4000/scsi@3/tape
pci@6,4000/scsi@3/disk
mc@0,0/bank@0,c0000000
mc@0,0/bank@0,8000000
mc@0,0/bank@0,4000000
mc@0,0/bank@0,0
mc@0,0/bank@0,40000000/dimm@0,3
mc@0,0/bank@0,40000000/dimm@0,2
mc@0,0/bank@0,40000000/dimm@0,1
mc@0,0/bank@0,40000000/dimm@0,0
mc@0,0/bank@0,0/dimm@0,3
mc@0,0/bank@0,0/dimm@0,2
mc@0,0/bank@0,0/dimm@0,1
mc@0,0/bank@0,0/dimm@0,0
SCSI Internal Busses

For Ultra 450 systems, there are two internal SCSI busses. The device "scsi" refers to the internal SCSI I/O bus for internal disks, while device "scsix" refers to the removeable-media and external (connector on back panel) internal SCSI bus.
The following shows the output of a `devalias` command on a Sun Ultra 450 UPA/PCI system.

```
ok  devalias
screen   /SUNW,ffb@1d,0
disk     /pci@1f,4000/scsi@3/disk@0,0
disk0    /pci@1f,4000/scsi@3/disk@0,0
disk1    /pci@1f,4000/scsi@3/disk@1,0
disk2    /pci@1f,4000/scsi@3/disk@2,0
disk3    /pci@1f,4000/scsi@3/disk@3,0
scsi     /pci@1f,4000/scsi@3
diskx0   /pci@1f,4000/scsi@2/disk@0,
diskx1   /pci@1f,4000/scsi@2/disk@1,0
diskx2   /pci@1f,4000/scsi@2/disk@2,0
diskx3   /pci@1f,4000/scsi@2/disk@3,0
cdrom    /pci@1f,4000/scsi@2/disk@6,0:f
tape     /pci@1f,4000/scsi@2/tape@4,0
scsix    /pci@1f,4000/scsi@2
pci      /pci@1f,4000
pcia     /pci@1f,2000
pcib     /pci@1f,4000
pci0     /pci@1f,4000
pci1     /pci@1f,2000
pci2     /pci@4,4000
pci3     /pci@4,2000
pci4     /pci@6,4000
pci5     /pci@6,2000
flash    /pci@1f,4000/ebus@1/flashprom@10,0
nvram    /pci@1f,4000/ebus@1/eeprom@14,0
parallel /pci@1f,4000/ebus@1/ecpp@14,3043bc
net      /pci@1f,4000/network@1,1
ebus     /pci@1f,4000/ebus@1
i2c      /pci@1f,4000/ebus@1/SUNW,envctrl
floppy   /pci@1f,4000/ebus@1/fdthree
tty      /pci@1f,4000/ebus@1/se
ttyb     /pci@1f,4000/ebus@1/se:b
ttya     /pci@1f,4000/ebus@1/se:a
keyboard! /pci@1f,4000/ebus@1/su@14,3083f8:forcemode
keyboard  /pci@1f,4000/ebus@1/su@14,3083f8
mouse    /pci@1f,4000/ebus@1/su@14,3062f8
```
.properties for a PCI Device

When you look at properties for a device node of a PCI device, you will see a few properties that are unique to PCI devices and a few properties that have a different format than that of a SBus device. For example, the output of .properties for a PCI device:

```
ok  cd /pci@1f,4000/scsi@3
ok  .properties
interrupts           00000020
assigned-addresses   81001810 00000000 00000400 00000000 00000100
                      82001814 00000000 00100000 00000000 00000100
                      82001818 00000000 00110000 00000000 00001000
device_type          scsi-2
clock-frequency      02625a00
reg                  00001800 00000000 00000000 00000000 00000100
                      01001810 00000000 00000000 00000000 00000100
                      02001814 00000000 00000000 00000000 00001000
                      02001818 00000000 00000000 00000000 00001000
model                Symbios,53C875
compatible           glm
name                 scsi
devsel-speed         00000001
class-code           00010000
max-latency          00000040
min-grant            00000011
revision-id          00000003
device-id            0000000f
vendor-id            00001000
```

The following example shows generic names for devices under `/pci@1f,4000/scsi@3`:

```
ok  ls
f00809d8 tape
f007ecdc disk
```
.speed Command

The command .speed shows the speed for both processors and busses attached to
the system, as follows:

```
ok .speed
CPU Speed : 248.00MHz
UPA Speed : 082.66MHz
PCI Bus A at UPA node 1f: 66Mhz
PCI Bus B at UPA node 1f: 33Mhz
PCI Bus A at UPA node 6: 66Mhz
PCI Bus B at UPA node 6: 33Mhz
PCI Bus A at UPA node 4: 66Mhz
PCI Bus B at UPA node 4: 33Mhz
```

Probing of Slots For PCI Busses

The Sun Ultra 450 UPA/PCI system has ten PCI plug-in slots, distributed across six
PCI busses, called pci0 to pci5; probing of slots for those busses is controlled by the
following two NVRAM configuration variables:

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pci0-probe-list</td>
<td>3,2,4</td>
<td>Controls probe order of plug-in devices under pci</td>
</tr>
<tr>
<td>pci-slot-skip-list</td>
<td>none</td>
<td>Controls skipping of PCI plug-in slots</td>
</tr>
</tbody>
</table>

pci0-probe-list specifies the device probe order on the "B" bus of the 1F PCI Controller.
Device 3 is the motherboard 875 UltraSCSI bus (internal disks), device 2 is the
motherboard 875 for removeable media and backpanel external connections (two
motherboard 875 chips), while device 4 is an open 33MHz 32-bit slot for plug-in
cards.

The remaining 5 PCI busses (pci1 to pci5) probe device slots in ascending numerical
order, which order cannot be changed.
pci-slot-skip-list is a list (1 to 10) of PCI slots that should not be probed. The values "1" to "10" correspond to the backpanel PCI slots, from bottom to top.

The Ultra 450 systems provide 10 PCI plug-in slots, numbered from 1 to 10, bottom-to-top (accessible and labeled from the back of the system). The 10 PCI slots correspond to the six PCI busses as follows:

<table>
<thead>
<tr>
<th>PCI Slot</th>
<th>PCI Bus</th>
<th>PCI Device</th>
<th>Width</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>pci0</td>
<td>/pci@1f,4000/xxx@4</td>
<td>32 Bit</td>
<td>33 MHz</td>
</tr>
<tr>
<td>9</td>
<td>pci2</td>
<td>/pci@4,4000/xxx@2</td>
<td>32 Bit</td>
<td>33 MHz</td>
</tr>
<tr>
<td>8</td>
<td>pci2</td>
<td>/pci@4,4000/xxx@3</td>
<td>32 Bit</td>
<td>33 MHz</td>
</tr>
<tr>
<td>7</td>
<td>pci2</td>
<td>/pci@4,4000/xxx@4</td>
<td>64 Bit</td>
<td>33MHz</td>
</tr>
<tr>
<td>6</td>
<td>pci3</td>
<td>/pci@4,2000/xxx@1</td>
<td>64 Bit</td>
<td>66MHz</td>
</tr>
<tr>
<td>5</td>
<td>pci1</td>
<td>/pci@1f,2000/xxx@1</td>
<td>64 Bit</td>
<td>66MHz</td>
</tr>
<tr>
<td>4</td>
<td>pci5</td>
<td>/pci@6,2000/xxx@1</td>
<td>64 Bit</td>
<td>66MHz</td>
</tr>
<tr>
<td>3</td>
<td>pci4</td>
<td>/pci@6,4000/xxx@2</td>
<td>64 Bit</td>
<td>33MHz</td>
</tr>
<tr>
<td>2</td>
<td>pci4</td>
<td>/pci@6,4000/xxx@3</td>
<td>64 Bit</td>
<td>33MHz</td>
</tr>
<tr>
<td>1</td>
<td>pci4</td>
<td>/pci@6,4000/xxx@4</td>
<td>64 Bit</td>
<td>33MHz</td>
</tr>
</tbody>
</table>

where the xxx will correspond to the particular PCI card plugged into that slot. For example, plugging an 875/glml SCSI controller card into slot 8 will yield /pci@4,4000/scsi@3, while plugging an 876 dual-SCSI card into slot 5 will yield two separate "devices" /pci@1f,2000/scsi@1 and /pci@1f,2000/scsi@1,1. Inserting a PCI-to-PCI card (such as used for a PCI bus expansion box, or as used on some multi-function PCI cards like the Sun Swift PCI card) into slot 4 will yield a device name /pci@6,2000/pci@1, and will subsequently have further devices created "underneath" this node, such as /pci@6,2000/pci@1/SUNW,hme@0,1.

Some of these slots are unavailable if certain graphics options are plugged-in. For example, installing the second FFB graphics card will occupy the physical space of PCI slots 10, 9, and 8. Other graphics options may use up the space occupied by PCI slots 10 to 4.
Probe SCSI Command

The following is a sample output of the `probe-scsi` command showing the two internal SCSI busses.

```plaintext
ok probe-scsi
Primary UltraSCSI bus:
Target 0
  Unit 0  Disk  SEAGATE ST34371W SUN4.2G8254
Target 1
  Unit 0  Disk  SEAGATE ST34371W SUN4.2G8254
Target 2
  Unit 0  Disk  SEAGATE ST34371W SUN4.2G8254
Target 3
  Unit 0  Disk  SEAGATE ST34371W SUN4.2G8254

Removeable-Media/External SCSI bus:
Target 3
  Unit 0  Removable Tape  ARCHIVE VIPER 150  21531-004  SUN-04.00.0
Target 4
  Unit 0  Removable Tape  EXABYTE EXB-8500SMBANXH10458
Target 5
  Unit 0  Removable Tape  EXABYTE EXB-8200  263H
Target 6
  Unit 0  Removable Read Only device  TOSHIBA XM-5401TASUN4XCD3485
```
Forth Word Reference

This appendix contains the Forth commands supported by OpenBoot.

For the most part, the commands are listed in the order in which they were introduced in the chapters. Some of the tables in this appendix show commands that are not listed elsewhere in this manual. These additional commands (such as memory mapping or output display primitives, or machine-specific register commands) are also part of the set of words in the OpenBoot implementation of Forth; they are included with relevant groups of commands.
# Stack Item Notation

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>`</td>
<td>`</td>
</tr>
<tr>
<td>`</td>
<td>`</td>
</tr>
<tr>
<td><code>???</code></td>
<td>Unknown stack item(s).</td>
</tr>
<tr>
<td><code>...</code></td>
<td>Unknown stack item(s). If used on both sides of a stack comment, means the same stack items are present on both sides.</td>
</tr>
<tr>
<td><code>&lt; &gt; &lt;space&gt;</code></td>
<td>Space delimiter. Leading spaces are ignored.</td>
</tr>
<tr>
<td><code>a-addr</code></td>
<td>Variable-aligned address.</td>
</tr>
<tr>
<td><code>addr</code></td>
<td>Memory address (generally a virtual address).</td>
</tr>
<tr>
<td><code>addr len</code></td>
<td>Address and length for memory region</td>
</tr>
<tr>
<td><code>byte bxxx</code></td>
<td>8-bit value (low order byte in a 32-bit word).</td>
</tr>
<tr>
<td><code>char</code></td>
<td>7-bit value (low order byte), high bit unspecified.</td>
</tr>
<tr>
<td><code>cnt len size</code></td>
<td>Count or length.</td>
</tr>
<tr>
<td><code>dxxx</code></td>
<td>Double (extended-precision) numbers. 2 stack items, most significant cell on top of stack.</td>
</tr>
<tr>
<td><code>&lt;eol&gt;</code></td>
<td>End-of-line delimiter.</td>
</tr>
<tr>
<td><code>false</code></td>
<td>0 (false flag).</td>
</tr>
<tr>
<td><code>ihandle</code></td>
<td>Pointer for an instance of a package.</td>
</tr>
<tr>
<td><code>n n1 n2 n3</code></td>
<td>Normal signed values (32-bit).</td>
</tr>
<tr>
<td><code>nu nu1</code></td>
<td>Signed or unsigned values (32-bit).</td>
</tr>
<tr>
<td><code>&lt;nothing&gt;</code></td>
<td>Zero stack items.</td>
</tr>
<tr>
<td><code>phandle</code></td>
<td>Pointer for a package.</td>
</tr>
<tr>
<td><code>phys</code></td>
<td>Physical address (actual hardware address).</td>
</tr>
<tr>
<td><code>phys.lo phys.hi</code></td>
<td>Lower/upper cell of physical address</td>
</tr>
<tr>
<td><code>pstr</code></td>
<td>Packed string.</td>
</tr>
<tr>
<td><code>quad qxxx</code></td>
<td>Quadlet (32-bit value).</td>
</tr>
<tr>
<td><code>qaddr</code></td>
<td>Quadlet (32-bit) aligned address.</td>
</tr>
</tbody>
</table>
### TABLE I-1  Stack Item Notation (Continued)

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>{text}</td>
<td>Optional text. Causes default behavior if omitted.</td>
</tr>
<tr>
<td>&quot;text&lt;delim&gt;&quot;</td>
<td>Input buffer text, parsed when command is executed. Text delimiter is enclosed in &lt;&gt;</td>
</tr>
<tr>
<td>[text&lt;delim&gt;]</td>
<td>Text immediately following on the same line as the command, parsed immediately. Text delimiter is enclosed in &lt;&gt;</td>
</tr>
<tr>
<td>true</td>
<td>-1 (true flag).</td>
</tr>
<tr>
<td>uxxx</td>
<td>Unsigned value, positive values (32-bit).</td>
</tr>
<tr>
<td>virt</td>
<td>Virtual address (address used by software).</td>
</tr>
<tr>
<td>waddr</td>
<td>Doublet (16-bit) aligned address</td>
</tr>
<tr>
<td>word wxxxx</td>
<td>Doublet (16-bit value, low order two bytes in a 32-bit word).</td>
</tr>
<tr>
<td>x xl</td>
<td>Arbitrary stack item.</td>
</tr>
<tr>
<td>x.lo x.hi</td>
<td>Low/high significant bits of a data item</td>
</tr>
<tr>
<td>xt</td>
<td>Execution token.</td>
</tr>
<tr>
<td>xxx?</td>
<td>Flag. Name indicates usage (e.g. done? ok? error?).</td>
</tr>
<tr>
<td>xyz-str xyz-len</td>
<td>Address and length for unpacked string.</td>
</tr>
<tr>
<td>xyz-sys</td>
<td>Control-flow stack items, implementation-dependent.</td>
</tr>
<tr>
<td>( C: -- )</td>
<td>Compilation stack diagram.</td>
</tr>
<tr>
<td>( -- ) ( E: -- )</td>
<td>Execution stack diagram.</td>
</tr>
<tr>
<td>( R: -- )</td>
<td>Return stack diagram.</td>
</tr>
</tbody>
</table>
# Commands for Browsing the Device Tree

## TABLE I-2  Commands for Browsing the Device Tree

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.properties</td>
<td>Display the names and values of the current node’s properties.</td>
</tr>
<tr>
<td>dev device-path</td>
<td>Choose the specified device node, making it the current node.</td>
</tr>
<tr>
<td>dev node-name</td>
<td>Search for a node with the specified name in the subtree below the current node, and choose the first such node found.</td>
</tr>
<tr>
<td>dev ..</td>
<td>Choose the device node that is the parent of the current node.</td>
</tr>
<tr>
<td>dev /</td>
<td>Choose the root machine node.</td>
</tr>
<tr>
<td>device-end</td>
<td>Leave the device tree.</td>
</tr>
<tr>
<td>“device-path” find-device</td>
<td>Choose the specified device node, similar to dev.</td>
</tr>
<tr>
<td>ls</td>
<td>Display the names of the current node’s children.</td>
</tr>
<tr>
<td>pwd</td>
<td>Display the device path name that names the current node.</td>
</tr>
<tr>
<td>see wordname</td>
<td>Decompile the specified word.</td>
</tr>
<tr>
<td>show-devs [device-path]</td>
<td>Display all the devices known to the system directly beneath a given device in the device hierarchy. show-devs used by itself shows the entire device tree.</td>
</tr>
<tr>
<td>words</td>
<td>Display the names of the current node’s methods.</td>
</tr>
<tr>
<td>“device-path” select-dev</td>
<td>Select the specified device and make it the active node.</td>
</tr>
</tbody>
</table>

## Common Options for the boot

...
Command

**TABLE I-3**  Common Options for the `boot` Command

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boot [device-specifier] [filename] [options]</code></td>
<td></td>
</tr>
<tr>
<td><code>[device-specifier]</code></td>
<td>The name (full path name or alias) of the boot device. Typical values include:</td>
</tr>
<tr>
<td></td>
<td><code>cdrom</code> (CD-PROM drive)</td>
</tr>
<tr>
<td></td>
<td><code>disk</code> (hard disk)</td>
</tr>
<tr>
<td></td>
<td><code>floppy</code> (3-1/2&quot; diskette drive)</td>
</tr>
<tr>
<td></td>
<td><code>net</code> (Ethernet)</td>
</tr>
<tr>
<td></td>
<td><code>tape</code> (SCSI tape)</td>
</tr>
<tr>
<td><code>[filename]</code></td>
<td>The name of the program to be booted (for example, <code>stand/diag</code>). <code>filename</code> is relative to</td>
</tr>
<tr>
<td></td>
<td>the root of the selected device and partition (if specified). If <code>filename</code> is not specified,</td>
</tr>
<tr>
<td></td>
<td>the boot program uses the value of the <code>boot-file</code> NVRAM parameter (see Chapter 3).</td>
</tr>
<tr>
<td><code>[options]</code></td>
<td>(These options are specific to the operating system, and may differ from system to system.)</td>
</tr>
</tbody>
</table>

**System Information Display Commands**

**TABLE I-4**  System Information Display Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>banner</code></td>
<td>Display power-on banner.</td>
</tr>
<tr>
<td><code>show-sbus</code></td>
<td>Display list of installed and probed SBus devices.</td>
</tr>
<tr>
<td><code>.enet-addr</code></td>
<td>Display current Ethernet address.</td>
</tr>
<tr>
<td><code>.idprom</code></td>
<td>Display ID PROM contents, formatted.</td>
</tr>
<tr>
<td><code>.traps</code></td>
<td>Display a list of SPARC trap types.</td>
</tr>
<tr>
<td><code>.version</code></td>
<td>Display version and date of the boot PROM.</td>
</tr>
<tr>
<td><code>.speed</code></td>
<td>Display CPU and bus speeds.</td>
</tr>
<tr>
<td><code>show-devs</code></td>
<td>Display all installed and probed devices.</td>
</tr>
</tbody>
</table>
Viewing or Changing Configuration Variables

**TABLE I-5** Viewing or Changing Configuration Variables

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>printenv</td>
<td>Display all current parameters and current default values. (Numbers are usually shown as decimal values.) printenv parameter shows the current value of the named parameter.</td>
</tr>
<tr>
<td>setenv parameter</td>
<td>Set parameter to the specified decimal or text value. (Changes are permanent, but usually only take effect after a reset.)</td>
</tr>
<tr>
<td>set-default</td>
<td>Reset the value of the named parameter to the factory default.</td>
</tr>
<tr>
<td>set-defaults</td>
<td>Reset parameter values to the factory defaults.</td>
</tr>
<tr>
<td>password</td>
<td>Set security-password.</td>
</tr>
</tbody>
</table>

**NVRAMRC Editor Commands**

**TABLE I-6** NVRAMRC Editor Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>nvalias alias</td>
<td>Store the command &quot;devalias alias device-path&quot; in NVRAMRC. The alias persists until the nvunalias or set-defaults commands are executed.</td>
</tr>
<tr>
<td>nvalias device-path</td>
<td></td>
</tr>
<tr>
<td>nvedit</td>
<td>Enter the NVRAMRC editor. If data remains in the temporary buffer from a previous nvedit session, resume editing those previous contents. If not, read the contents of NVRAMRC into the temporary buffer and begin editing it.</td>
</tr>
<tr>
<td>nvquit</td>
<td>Discard the contents of the temporary buffer, without writing it to NVRAMRC. Prompt for confirmation.</td>
</tr>
<tr>
<td>nvrecover</td>
<td>Recover the contents of NVRAMRC if they have been lost as a result of the execution of set-defaults; then enter the editor as with nvedit. nvrecover fails if nvedit is executed between the time that the NVRAMRC contents were lost and the time that nvrecover is executed.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>nvrun</td>
<td>Execute the contents of the temporary buffer.</td>
</tr>
<tr>
<td>nvstore</td>
<td>Copy the contents of the temporary buffer to NVRAMRC; discard the contents of the temporary buffer.</td>
</tr>
<tr>
<td>nvunalias alias</td>
<td>Delete the corresponding alias from NVRAMRC.</td>
</tr>
</tbody>
</table>
## NVRAM Script Editor Keystroke Commands

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-B</td>
<td>Moves backward one character.</td>
</tr>
<tr>
<td>Escape B</td>
<td>Moves backward one word.</td>
</tr>
<tr>
<td>Control-F</td>
<td>Moves forward one character.</td>
</tr>
<tr>
<td>Escape F</td>
<td>Moves forward one word.</td>
</tr>
<tr>
<td>Control-A</td>
<td>Moves backward to beginning of the line.</td>
</tr>
<tr>
<td>Control-E</td>
<td>Moves forward to end of the line.</td>
</tr>
<tr>
<td>Control-N</td>
<td>Moves to the next line of the script editing buffer.</td>
</tr>
<tr>
<td>Control-P</td>
<td>Moves to the previous line of the script editing buffer.</td>
</tr>
<tr>
<td>Return (Enter)</td>
<td>Inserts a newline at the cursor position and advances to the next line.</td>
</tr>
<tr>
<td>Control-O</td>
<td>Inserts a newline at the cursor position and stays on the current line.</td>
</tr>
<tr>
<td>Control-K</td>
<td>Erases from the cursor position to the end of the line, storing the erased characters in a save buffer. If at the end of a line, joins the next line to the current line (i.e. deletes the newline).</td>
</tr>
<tr>
<td>Delete</td>
<td>Erases the previous character.</td>
</tr>
<tr>
<td>Backspace</td>
<td>Erases the previous character.</td>
</tr>
<tr>
<td>Control-H</td>
<td>Erases the previous character.</td>
</tr>
<tr>
<td>Escape H</td>
<td>Erases from beginning of word to just before the cursor, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-W</td>
<td>Erases from beginning of word to just before the cursor, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-D</td>
<td>Erases the next character.</td>
</tr>
<tr>
<td>Escape D</td>
<td>Erases from the cursor to the end of the word, storing the erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-U</td>
<td>Erases the entire line, storing the erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-Y</td>
<td>Inserts the contents of the save buffer before the cursor.</td>
</tr>
<tr>
<td>Control-Q</td>
<td>Quotes the next character (i.e. allows you to insert control characters).</td>
</tr>
</tbody>
</table>
### TABLE I-7  NVRAM Script Editor Keystroke Commands (Continued)

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-R</td>
<td>Retypes the line.</td>
</tr>
<tr>
<td>Control-L</td>
<td>Displays the entire contents of the editing buffer.</td>
</tr>
<tr>
<td>Control-C</td>
<td>Exits the script editor, returning to the OpenBoot command interpreter. The temporary buffer is preserved, but is not written back to the script. (Use <code>nvstore</code> afterwards to write it back.)</td>
</tr>
</tbody>
</table>
# Stack Manipulation Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear</td>
<td>( ??? -- )</td>
<td>Empty the stack.</td>
</tr>
<tr>
<td>depth</td>
<td>( -- u )</td>
<td>Return the number of items on the stack.</td>
</tr>
<tr>
<td>drop</td>
<td>( x -- )</td>
<td>Remove top item from the stack.</td>
</tr>
<tr>
<td>2drop</td>
<td>( x1 x2 -- )</td>
<td>Remove 2 items from the stack.</td>
</tr>
<tr>
<td>3drop</td>
<td>( x1 x2 x3 -- )</td>
<td>Remove 3 items from the stack.</td>
</tr>
<tr>
<td>dup</td>
<td>( x -- x x )</td>
<td>Duplicate the top stack item.</td>
</tr>
<tr>
<td>2dup</td>
<td>( x1 x2 -- x1 x2 x1 x2 )</td>
<td>Duplicate 2 stack items.</td>
</tr>
<tr>
<td>3dup</td>
<td>( x1 x2 x3 -- x1 x2 x3 x1 x2 x3 )</td>
<td>Duplicate 3 stack items.</td>
</tr>
<tr>
<td>?dup</td>
<td>( x -- x x</td>
<td>0 )</td>
</tr>
<tr>
<td>nip</td>
<td>( x1 x2 -- x2 )</td>
<td>Discard the second stack item.</td>
</tr>
<tr>
<td>over</td>
<td>( x1 x2 -- x1 x2 x1 )</td>
<td>Copy second stack item to top of stack.</td>
</tr>
<tr>
<td>2over</td>
<td>( x1 x2 x3 x4 -- x1 x2 x3 x4 x1 x2 )</td>
<td>Copy second 2 stack items.</td>
</tr>
<tr>
<td>pick</td>
<td>( xu ... x1 x0 u -- xu ... x1 x0 xu )</td>
<td>Copy u-th stack item (1 pick = over).</td>
</tr>
<tr>
<td>&gt;r</td>
<td>( x -- ) (R: -- x )</td>
<td>Move a stack item to the return stack.</td>
</tr>
<tr>
<td>r&gt;</td>
<td>( -- x ) (R: x -- )</td>
<td>Move a return stack item to the stack.</td>
</tr>
<tr>
<td>r@</td>
<td>( -- x ) (R: x -- x )</td>
<td>Copy the top of the return stack to the stack.</td>
</tr>
<tr>
<td>roll</td>
<td>( xu ... x1 x0 u -- xu-1 ... x1 x0 xu )</td>
<td>Rotate u stack items (2 roll = rot).</td>
</tr>
<tr>
<td>rot</td>
<td>( x1 x2 x3 -- x2 x3 x1 )</td>
<td>Rotate 3 stack items.</td>
</tr>
<tr>
<td>-rot</td>
<td>( x1 x2 x3 -- x3 x1 x2 )</td>
<td>Inversely rotate 3 stack items.</td>
</tr>
<tr>
<td>2rot</td>
<td>( x1 x2 x3 x4 x5 x6 -- x3 x4 x5 x6 x1 x2 )</td>
<td>Rotate 3 pairs of stack items.</td>
</tr>
<tr>
<td>swap</td>
<td>( x1 x2 -- x2 x1 )</td>
<td>Exchange the top 2 stack items.</td>
</tr>
<tr>
<td>2swap</td>
<td>( x1 x2 x3 x4 -- x3 x4 x1 x2 )</td>
<td>Exchange 2 pairs of stack items.</td>
</tr>
<tr>
<td>tuck</td>
<td>( x1 x2 -- x2 x1 x2 )</td>
<td>Copy top stack item below second item.</td>
</tr>
</tbody>
</table>
## Single-Precision Arithmetic Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>( nu1 nu2 -- sum )</td>
<td>Add ( nu1 + nu2 ).</td>
</tr>
<tr>
<td>-</td>
<td>( nu1 nu2 -- diff )</td>
<td>Subtract ( nu1 - nu2 ).</td>
</tr>
<tr>
<td>*</td>
<td>( nu1 nu2 -- prod )</td>
<td>Multiply ( nu1 \times nu2 ).</td>
</tr>
<tr>
<td>*/</td>
<td>( nu1 nu2 nu3 -- quot )</td>
<td>Calculates ( nu1 \times nu2 / n3 ).</td>
</tr>
<tr>
<td>/</td>
<td>( n1 n2 -- quot )</td>
<td>Divide ( n1 ) by ( n2 ); remainder is discarded.</td>
</tr>
<tr>
<td>1+</td>
<td>( nu1 -- nu2 )</td>
<td>Add 1.</td>
</tr>
<tr>
<td>1-</td>
<td>( nu1 -- nu2 )</td>
<td>Subtract 1.</td>
</tr>
<tr>
<td>2+</td>
<td>( nu1 -- nu2 )</td>
<td>Add 2.</td>
</tr>
<tr>
<td>2-</td>
<td>( nu1 -- nu2 )</td>
<td>Subtract 2.</td>
</tr>
<tr>
<td>abs</td>
<td>( n -- u )</td>
<td>Absolute value.</td>
</tr>
<tr>
<td>bounds</td>
<td>( n count -- n+count n )</td>
<td>Prepare arguments for do or ?do loop.</td>
</tr>
<tr>
<td>even</td>
<td>( n -- n | n+1 )</td>
<td>Round to nearest even integer ( \geq n ).</td>
</tr>
<tr>
<td>max</td>
<td>( n1 n2 -- n1|n2 )</td>
<td>Return the maximum of ( n1 ) and ( n2 ).</td>
</tr>
<tr>
<td>min</td>
<td>( n1 n2 -- n1|n2 )</td>
<td>Return the minimum of ( n1 ) and ( n2 ).</td>
</tr>
<tr>
<td>mod</td>
<td>( n1 n2 -- rem )</td>
<td>Remainder of ( n1 ) ( / n2 ).</td>
</tr>
<tr>
<td>*/mod</td>
<td>( n1 n2 n3 -- rem quot )</td>
<td>Remainder, quotient of ( n1 \times n2 / n3 ).</td>
</tr>
<tr>
<td>/mod</td>
<td>( n1 n2 -- rem quot )</td>
<td>Remainder, quotient of ( n1 ) ( / n2 ).</td>
</tr>
<tr>
<td>negate</td>
<td>( n1 -- n2 )</td>
<td>Change the sign of ( n1 ).</td>
</tr>
<tr>
<td>u*</td>
<td>( u1 u2 -- uprod )</td>
<td>Multiply 2 unsigned numbers yielding an unsigned product.</td>
</tr>
<tr>
<td>u/mod</td>
<td>( u1 u2 -- urem uquot )</td>
<td>Divide unsigned number by an unsigned number; yield remainder and quotient.</td>
</tr>
</tbody>
</table>
Bit-wise Logical Operators

**TABLE I-10** Bit-wise Logical Operators

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2*</td>
<td>( x1 -- x2 )</td>
<td>Multiply by 2.</td>
</tr>
<tr>
<td>2/</td>
<td>( x1 -- x2 )</td>
<td>Divide by 2.</td>
</tr>
<tr>
<td>&gt;&gt;u</td>
<td>( x1 u -- x2 )</td>
<td>Arithmetic right-shift x1 by u bits.</td>
</tr>
<tr>
<td>and</td>
<td>( x1 x2 -- x3 )</td>
<td>Bitwise logical AND.</td>
</tr>
<tr>
<td>invert</td>
<td>( x1 -- x2 )</td>
<td>Invert all bits of x1.</td>
</tr>
<tr>
<td>lshift</td>
<td>( x1 u -- x2 )</td>
<td>Left-shift x1 by u bits. Zero-fill low bits.</td>
</tr>
<tr>
<td>or</td>
<td>( x1 x2 -- x3 )</td>
<td>Bitwise logical OR.</td>
</tr>
<tr>
<td>rshift</td>
<td>( x1 u -- x2 )</td>
<td>Right-shift x1 by u bits. Zero-fill high bits.</td>
</tr>
<tr>
<td>u2/</td>
<td>( x1 -- x2 )</td>
<td>Logical right shift 1 bit; zero shifted into high bit.</td>
</tr>
<tr>
<td>xor</td>
<td>( x1 x2 -- x3 )</td>
<td>Bitwise exclusive OR.</td>
</tr>
</tbody>
</table>

Double Number Arithmetic Functions

**TABLE I-11** Double Number Arithmetic Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>d+</td>
<td>(d1 d2 -- d.sum)</td>
<td>Add d1 to d2 yielding double number d.sum.</td>
</tr>
<tr>
<td>d-</td>
<td>(d1 d2 -- d.diff)</td>
<td>Subtract d2 from d1 yielding double number d.diff.</td>
</tr>
<tr>
<td>fm/mod</td>
<td>( d n -- rem quot)</td>
<td>Divide d by n.</td>
</tr>
<tr>
<td>m*</td>
<td>( n1 n2 -- d )</td>
<td>Signed multiply with double-number product.</td>
</tr>
<tr>
<td>s&gt;d</td>
<td>( n1 -- d1 )</td>
<td>Convert a number to a double number.</td>
</tr>
<tr>
<td>sm/rem</td>
<td>( d n -- rem quot)</td>
<td>Divide d by n, symmetric division.</td>
</tr>
<tr>
<td>um*</td>
<td>( u1 u2 -- ud )</td>
<td>Unsigned multiply yielding unsigned double number product.</td>
</tr>
<tr>
<td>um/mod</td>
<td>( ud u -- urem uprod)</td>
<td>Divide ud by u.</td>
</tr>
</tbody>
</table>
32-Bit Data Type Conversion Functions

**TABLE I-12** 32-Bit Data Type Conversion Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bljoin</td>
<td>( b.low b2 b3 b.hi -- quad )</td>
<td>Join four bytes to form a quadlet</td>
</tr>
<tr>
<td>bwjoin</td>
<td>( b.low b.hi -- word )</td>
<td>Join two bytes to form a doublet.</td>
</tr>
<tr>
<td>lbflip</td>
<td>( quad1 -- quad2 )</td>
<td>Reverse the bytes within a quadlet</td>
</tr>
<tr>
<td>lbsplit</td>
<td>( quad -- b.low b2 b3 b.hi )</td>
<td>Split a quadlet into four bytes.</td>
</tr>
<tr>
<td>lwflip</td>
<td>( quad1 -- quad2 )</td>
<td>Swap the doublets within a quadlet.</td>
</tr>
<tr>
<td>lwsplit</td>
<td>( quad -- w.low w.hi )</td>
<td>Split a quadlet into two doublets.</td>
</tr>
<tr>
<td>wbflip</td>
<td>( word1 -- word2 )</td>
<td>Swap the bytes within a doublet.</td>
</tr>
<tr>
<td>wbsplit</td>
<td>( word -- b.low b.hi )</td>
<td>Split a doublet into two bytes.</td>
</tr>
<tr>
<td>wljoin</td>
<td>( w.low w.hi -- quad )</td>
<td>Join two doublets to form a quadlet.</td>
</tr>
</tbody>
</table>

64-Bit Data Type Conversion Functions

**TABLE I-13** 64-Bit Data Type Conversion Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bxjoin</td>
<td>( b.lo b.2 b.3 b.4 b.5 b.6 b.7 b.hi -- o )</td>
<td>Join 8 bytes to form an octlet.</td>
</tr>
<tr>
<td>lxjoin</td>
<td>( quad.lo quad.hi -- o )</td>
<td>Join 2 quadlets to form an octlet.</td>
</tr>
<tr>
<td>wxjoin</td>
<td>( w.lo w.2 w.3 w.hi -- o )</td>
<td>Join four doublets to form an octlet.</td>
</tr>
<tr>
<td>xbflip</td>
<td>( oct1 -- oct2 )</td>
<td>Reverse the octets within an octlet.</td>
</tr>
<tr>
<td>xbflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the bytes within each octlet in the given region. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
<tr>
<td>xbsplit</td>
<td>( o -- b.lo b.2 b.3 b.4 b.5 b.6 b.7 b.hi )</td>
<td>Split an octlet into 8 bytes.</td>
</tr>
<tr>
<td>xlflip</td>
<td>( oct1 -- oct2 )</td>
<td>Reverse the quadlets within an octlet. The bytes within each quadlet are not reversed.</td>
</tr>
</tbody>
</table>
TABLE I-13  64-Bit Data Type Conversion Functions (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>xlflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the quadlets within each octlet in the given region. The bytes within each quadlet are not reversed. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
<tr>
<td>xlsplit</td>
<td>( o -- quad.lo quad.hi )</td>
<td>Split on octlet into 2 quadlets.</td>
</tr>
<tr>
<td>xwflip</td>
<td>( oct1 -- oct2 )</td>
<td>Reverse the doublets within an octlet. The bytes within each doublet are not reversed.</td>
</tr>
<tr>
<td>xwflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the doublets within each octlet in the given region. The bytes within each doublet are not reversed. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
<tr>
<td>xwsplit</td>
<td>( o -- w.lo w.2 w.3 w.hi )</td>
<td>Split an octlet into 4 doublets.</td>
</tr>
</tbody>
</table>
# Address Arithmetic Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>aligned</td>
<td>( n1 -- n1 \ a-addr)</td>
<td>Increase n1 if necessary to yield a variable aligned address.</td>
</tr>
<tr>
<td>/c</td>
<td>( -- n )</td>
<td>The number of address units to a byte: 1.</td>
</tr>
<tr>
<td>/c*</td>
<td>( nu1 -- nu2 )</td>
<td>Synonym for chars.</td>
</tr>
<tr>
<td>ca+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /c.</td>
</tr>
<tr>
<td>cal+</td>
<td>( addr1 -- addr2 )</td>
<td>Synonym for char+.</td>
</tr>
<tr>
<td>char+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /c.</td>
</tr>
<tr>
<td>cell+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /n.</td>
</tr>
<tr>
<td>chars</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /c.</td>
</tr>
<tr>
<td>cells</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /n.</td>
</tr>
<tr>
<td>/l</td>
<td>( -- n )</td>
<td>Number of address units to a quadlet; typically 4.</td>
</tr>
<tr>
<td>/l*</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /l.</td>
</tr>
<tr>
<td>la+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /l.</td>
</tr>
<tr>
<td>la1+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /l.</td>
</tr>
<tr>
<td>/n</td>
<td>( -- n )</td>
<td>Number of address units in a cell.</td>
</tr>
<tr>
<td>/n*</td>
<td>( nu1 -- nu2 )</td>
<td>Synonym for cells.</td>
</tr>
<tr>
<td>na+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /n.</td>
</tr>
<tr>
<td>nal+</td>
<td>( addr1 -- addr2 )</td>
<td>Synonym for cell+.</td>
</tr>
<tr>
<td>/w</td>
<td>( -- n )</td>
<td>Number of address units to a doublet; typically 2.</td>
</tr>
<tr>
<td>/w*</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of /w.</td>
</tr>
<tr>
<td>wa+</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of /w.</td>
</tr>
<tr>
<td>wal+</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of /w.</td>
</tr>
</tbody>
</table>
# 64-Bit Address Arithmetic Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( /x )</td>
<td>( -- n )</td>
<td>Number of address units in an octlet, typically 8.</td>
</tr>
<tr>
<td>( /x^* )</td>
<td>( nu1 -- nu2 )</td>
<td>Multiply nu1 by the value of ( /x ).</td>
</tr>
<tr>
<td>( xa^+ )</td>
<td>( addr1 index -- addr2 )</td>
<td>Increment addr1 by index times the value of ( /x ).</td>
</tr>
<tr>
<td>( xa1^+ )</td>
<td>( addr1 -- addr2 )</td>
<td>Increment addr1 by the value of ( /x ).</td>
</tr>
</tbody>
</table>

# Memory Access Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>!</td>
<td>( x a-addr -- )</td>
<td>Store a number at a-addr.</td>
</tr>
<tr>
<td>+!</td>
<td>( nu a-addr -- )</td>
<td>Add nu to the number stored at a-addr.</td>
</tr>
<tr>
<td>@</td>
<td>( a-addr -- x )</td>
<td>Fetch a number from a-addr.</td>
</tr>
<tr>
<td>2!</td>
<td>( x1 x2 a-addr -- )</td>
<td>Store 2 numbers at a-addr, x2 at lower address.</td>
</tr>
<tr>
<td>2@</td>
<td>( a-addr -- x1 x2 )</td>
<td>Fetch 2 numbers from a-addr, x2 from lower address.</td>
</tr>
<tr>
<td>blank</td>
<td>( addr len -- )</td>
<td>Set len bytes of memory beginning at addr to the space character (decimal 32).</td>
</tr>
<tr>
<td>c!</td>
<td>( byte addr -- )</td>
<td>Store byte at addr.</td>
</tr>
<tr>
<td>c@</td>
<td>( addr -- byte )</td>
<td>Fetch a byte from addr.</td>
</tr>
<tr>
<td>cpeek</td>
<td>( addr -- false</td>
<td>byte true )</td>
</tr>
<tr>
<td>cpoke</td>
<td>( byte addr -- okay? )</td>
<td>Attempt to store the byte to addr. Return true if the access was successful. Return false if a write access error occurred.</td>
</tr>
</tbody>
</table>
### TABLE I-16  Memory Access Commands (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>comp</td>
<td>( addr1 addr2 len -- diff? )</td>
<td>Compare two byte arrays. diff? is 0 if the arrays are identical, diff? is -1 if the first byte that is different is lesser in the string at addr1, diff? is 1 otherwise.</td>
</tr>
<tr>
<td>dump</td>
<td>( addr len -- )</td>
<td>Display len bytes of memory starting at addr.</td>
</tr>
<tr>
<td>erase</td>
<td>( addr len -- )</td>
<td>Set len bytes of memory beginning at addr to 0.</td>
</tr>
<tr>
<td>fill</td>
<td>( addr len byte -- )</td>
<td>Set len bytes of memory beginning at addr to the value byte.</td>
</tr>
<tr>
<td>l!</td>
<td>( quad qaddr -- )</td>
<td>Store a quadlet q at qaddr.</td>
</tr>
<tr>
<td>l@</td>
<td>( qaddr -- quad )</td>
<td>Fetch a quadlet q from qaddr.</td>
</tr>
<tr>
<td>lbflips</td>
<td>( qaddr len -- )</td>
<td>Reverse the bytes within each quadlet in the specified region.</td>
</tr>
<tr>
<td>lwflips</td>
<td>( qaddr len -- )</td>
<td>Swap the doublets within each quadlet in specified region.</td>
</tr>
<tr>
<td>lpeek</td>
<td>( qaddr -- false</td>
<td>quad true )</td>
</tr>
<tr>
<td>lpoke</td>
<td>( quad qaddr -- okay? )</td>
<td>Attempt to store the 32-bit quantity at qaddr. Return true if the access was successful. Return false if a write access error occurred.</td>
</tr>
<tr>
<td>move</td>
<td>( src-addr dest-addr len -- )</td>
<td>Copy len bytes from src-addr to dest-addr.</td>
</tr>
<tr>
<td>off</td>
<td>( a-addr -- )</td>
<td>Store false at a-addr.</td>
</tr>
<tr>
<td>on</td>
<td>( a-addr -- )</td>
<td>Store true at a-addr.</td>
</tr>
<tr>
<td>unaligned-l!</td>
<td>( quad addr -- )</td>
<td>Store a quadlet q, any alignment</td>
</tr>
<tr>
<td>unaligned-l@</td>
<td>( addr -- quad )</td>
<td>Fetch a quadlet q, any alignment.</td>
</tr>
<tr>
<td>unaligned-w!</td>
<td>( w addr -- )</td>
<td>Store a doublet w, any alignment.</td>
</tr>
<tr>
<td>unaligned-w@</td>
<td>( addr -- w )</td>
<td>Fetch a doublet w, any alignment.</td>
</tr>
<tr>
<td>w!</td>
<td>( w waddr -- )</td>
<td>Store a doublet w at waddr.</td>
</tr>
<tr>
<td>w@</td>
<td>( waddr -- w)</td>
<td>Fetch a doublet w from waddr.</td>
</tr>
<tr>
<td>&lt;w@</td>
<td>( waddr -- n )</td>
<td>Fetch doublet w from waddr, sign-extended.</td>
</tr>
</tbody>
</table>
**TABLE I-16**  Memory Access Commands (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>wbflips</td>
<td>( waddr len -- )</td>
<td>Swap the bytes within each doublet in the specified region.</td>
</tr>
<tr>
<td>wpeek</td>
<td>( waddr -- false</td>
<td>Attempt to fetch the 16-bit quantity at <em>waddr</em>. Return</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the data and <code>true</code> if the access was successful. Return <code>false</code> if a read access error occurred.</td>
</tr>
<tr>
<td>wpoke</td>
<td>( w waddr -- okay?)</td>
<td>Attempt to store the 16-bit quantity to <em>waddr</em>. Return</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>true</code> if the access was successful. Return <code>false</code> if a write access error occurred.</td>
</tr>
</tbody>
</table>
64-Bit Memory Access Functions

TABLE I-17  64-Bit Memory Access Functions

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;l@</td>
<td>( qaddr -- n )</td>
<td>Fetch quadlet from qaddr, sign-extended.</td>
</tr>
<tr>
<td>x,</td>
<td>( o -- )</td>
<td>Compile an octlet, o, into the dictionary (doublet-aligned).</td>
</tr>
<tr>
<td>x@</td>
<td>( oaddr -- o )</td>
<td>Fetch octlet from an octlet aligned address.</td>
</tr>
<tr>
<td>x!</td>
<td>( o oaddr -- )</td>
<td>Store octlet to an octlet aligned address.</td>
</tr>
<tr>
<td>xbflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the bytes within each octlet in the given region. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
<tr>
<td>xlflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the quadlets within each octlet in the given region. The bytes within each quadlet are not reversed. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
<tr>
<td>xwflips</td>
<td>( oaddr len -- )</td>
<td>Reverse the doublets within each octlet in the given region. The bytes within each doublet are not reversed. The behavior is undefined if len is not a multiple of /x.</td>
</tr>
</tbody>
</table>

Memory Mapping Commands

TABLE I-18  Memory Mapping Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>alloc-mem</td>
<td>( size -- virt )</td>
<td>Allocate and map size bytes of available memory; return the virtual address. Unmap with free-mem.</td>
</tr>
<tr>
<td>free-mem</td>
<td>( virt size -- )</td>
<td>Free memory allocated by alloc-mem.</td>
</tr>
<tr>
<td>map?</td>
<td>( virt -- )</td>
<td>Display memory map information for the virtual address.</td>
</tr>
</tbody>
</table>
## Defining Words

### TABLE I-19  Defining Words

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>: new-name</code></td>
<td>( -- )</td>
<td>Start a new colon definition of the word <code>new-name</code>.</td>
</tr>
<tr>
<td></td>
<td>(E: ... -- ???)</td>
<td></td>
</tr>
<tr>
<td><code>;</code></td>
<td>( -- )</td>
<td>End a colon definition.</td>
</tr>
<tr>
<td><code>alias new-name old-name</code></td>
<td>( -- )</td>
<td>Create <code>new-name</code> with the same behavior as <code>old-name</code>.</td>
</tr>
<tr>
<td></td>
<td>(E: ... -- ???)</td>
<td></td>
</tr>
<tr>
<td><code>buffer: name</code></td>
<td>( size -- )</td>
<td>Create a named array in temporary storage.</td>
</tr>
<tr>
<td></td>
<td>(E: -- a-addr)</td>
<td></td>
</tr>
<tr>
<td><code>constant name</code></td>
<td>( n -- )</td>
<td>Define a constant (for example, 3 constant <code>bar</code>).</td>
</tr>
<tr>
<td></td>
<td>(E: -- n)</td>
<td></td>
</tr>
<tr>
<td><code>2constant name</code></td>
<td>( n1 n2 -- )</td>
<td>Define a 2-number constant.</td>
</tr>
<tr>
<td></td>
<td>(E: -- n1 n2)</td>
<td></td>
</tr>
<tr>
<td><code>create name</code></td>
<td>( -- )</td>
<td>Generic defining word.</td>
</tr>
<tr>
<td></td>
<td>(E: -- a-addr)</td>
<td></td>
</tr>
<tr>
<td><code>defer name</code></td>
<td>( -- )</td>
<td>Define a word for forward references or execution vectors using execution token.</td>
</tr>
<tr>
<td></td>
<td>(E: ... -- ???)</td>
<td></td>
</tr>
<tr>
<td><code>does&gt;</code></td>
<td>( ... -- ... a-addr )</td>
<td>Start the run-time clause for defining words.</td>
</tr>
<tr>
<td></td>
<td>(E: ... -- ???)</td>
<td></td>
</tr>
<tr>
<td><code>field name</code></td>
<td>( offset size -- offset+size )</td>
<td>Create a named offset pointer.</td>
</tr>
<tr>
<td></td>
<td>(E: addr -- addr+offset)</td>
<td></td>
</tr>
<tr>
<td><code>struct</code></td>
<td>( -- 0 )</td>
<td>Initialize for <code>field</code> creation.</td>
</tr>
<tr>
<td><code>value name</code></td>
<td>( n -- )</td>
<td>Create a changeable, named quantity.</td>
</tr>
<tr>
<td></td>
<td>(E: -- n)</td>
<td></td>
</tr>
<tr>
<td><code>variable name</code></td>
<td>( -- )</td>
<td>Define a variable.</td>
</tr>
<tr>
<td></td>
<td>(E: -- a-addr)</td>
<td></td>
</tr>
</tbody>
</table>
## Dictionary Searching Commands

**TABLE I-20** Dictionary Searching Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>' name</td>
<td>( -- xt )</td>
<td>Find the named word in the dictionary. Returns the execution token. Use outside definitions.</td>
</tr>
<tr>
<td>['] name</td>
<td>( -- xt )</td>
<td>Similar to ' but is used either inside or outside definitions.</td>
</tr>
<tr>
<td>.calls</td>
<td>( xt -- )</td>
<td>Display a list of all words that call the word whose execution token is xt.</td>
</tr>
<tr>
<td>$find</td>
<td>( str len -- str len false</td>
<td>xt true )</td>
</tr>
<tr>
<td>find</td>
<td>( pstr -- pstr false</td>
<td>xt n )</td>
</tr>
<tr>
<td>see thisword</td>
<td>( -- )</td>
<td>Decompile the named command.</td>
</tr>
<tr>
<td>(see)</td>
<td>( xt -- )</td>
<td>Decompile the word indicated by the execution token.</td>
</tr>
<tr>
<td>sift</td>
<td>( pstr -- )</td>
<td>Display names of all dictionary entries containing the string pointed to by pstr.</td>
</tr>
<tr>
<td>sifting ccc</td>
<td>( -- )</td>
<td>Display names of all dictionary entries containing the sequence of characters. ccc contains no spaces.</td>
</tr>
<tr>
<td>words</td>
<td>( -- )</td>
<td>Display all visible words in the dictionary.</td>
</tr>
</tbody>
</table>

## Dictionary Compilation Commands

**TABLE I-21** Dictionary Compilation Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>,</td>
<td>( n -- )</td>
<td>Place a number in the dictionary.</td>
</tr>
<tr>
<td>c,</td>
<td>( byte -- )</td>
<td>Place a byte in the dictionary.</td>
</tr>
<tr>
<td>w,</td>
<td>( word -- )</td>
<td>Place a 16-bit number in the dictionary.</td>
</tr>
</tbody>
</table>
### TABLE I-21  Dictionary Compilation Commands (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,</td>
<td>( quad -- )</td>
<td>Place a 32-bit number in the dictionary.</td>
</tr>
<tr>
<td>[</td>
<td>( -- )</td>
<td>Enter interpretation state.</td>
</tr>
<tr>
<td>]</td>
<td>( -- )</td>
<td>End interpreting, enter compilation state.</td>
</tr>
<tr>
<td>allot</td>
<td>( n -- )</td>
<td>Allocate n bytes in the dictionary.</td>
</tr>
<tr>
<td>&gt;body</td>
<td>( xt -- a-addr )</td>
<td>Find the data field address from the execution token.</td>
</tr>
<tr>
<td>body&gt;</td>
<td>( a-addr -- xt )</td>
<td>Find the execution token from the data field address.</td>
</tr>
<tr>
<td>compile</td>
<td>( -- )</td>
<td>Compile the next word at run time. (Recommend using postpone instead.)</td>
</tr>
<tr>
<td>[compile] name</td>
<td>( -- )</td>
<td>Compile the next (immediate) word. (Recommend using postpone instead.)</td>
</tr>
<tr>
<td>forget name</td>
<td>( -- )</td>
<td>Remove word from dictionary and all subsequent words.</td>
</tr>
<tr>
<td>here</td>
<td>( -- addr )</td>
<td>Address of top of dictionary.</td>
</tr>
<tr>
<td>immediate</td>
<td>( -- )</td>
<td>Mark the last definition as immediate.</td>
</tr>
<tr>
<td>to name</td>
<td>( n -- )</td>
<td>Install a new action in a defer word or value.</td>
</tr>
<tr>
<td>literal</td>
<td>( n -- )</td>
<td>Compile a number.</td>
</tr>
<tr>
<td>origin</td>
<td>( -- addr )</td>
<td>Return the address of the start of the Forth system.</td>
</tr>
<tr>
<td>patch new-word old-word word-to-patch</td>
<td>( -- )</td>
<td>Replace old-word with new-word in word-to-patch.</td>
</tr>
<tr>
<td>(patch)</td>
<td>( new-n old-n xt -- )</td>
<td>Replace old-n with new-n in word indicated by xt.</td>
</tr>
<tr>
<td>postpone name</td>
<td>( -- )</td>
<td>Delay the execution of the word name.</td>
</tr>
<tr>
<td>recursive</td>
<td>( -- )</td>
<td>Make the name of the colon definition being compiled visible in the dictionary, and thus allow the name of the word to be used recursively in its own definition.</td>
</tr>
<tr>
<td>state</td>
<td>( -- addr )</td>
<td>Variable that is non-zero in compile state.</td>
</tr>
</tbody>
</table>
### Assembly Language Programming

**TABLE I-22** Assembly Language Programming

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>code <em>name</em></td>
<td>( -- code-sys )</td>
<td>Begin the creation of an assembly language routine called <em>name</em>. Commands that follow are interpreted as assembler mnemonics. Note that if the assembler is not installed, <code>code</code> is still present, except that machine code must be entered numerically (for example, in hex) with &quot;&quot;.</td>
</tr>
<tr>
<td>c;</td>
<td>( code-sys -- )</td>
<td>End the creation of an assembly language routine. Automatically assemble the Forth interpreter “next” function so that the created assembly-code word, when executed, returns control to the calling routine as usual.</td>
</tr>
<tr>
<td>label <em>name</em></td>
<td>( -- code-sys )</td>
<td>Begin the creation of an assembly language routine called <em>name</em>. Words created with <code>label</code> leave the address of the code on the stack when executed. The commands that follow are interpreted as assembler mnemonics. As with <code>code</code>, <code>label</code> is present even if the assembler is not installed.</td>
</tr>
<tr>
<td>end-code</td>
<td>( code-sys -- )</td>
<td>End the assembly language patch started with <code>label</code>.</td>
</tr>
</tbody>
</table>

### Basic Number Display

**TABLE I-23** Basic Number Display

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.</td>
<td>( n -- )</td>
<td>Display a number in the current base.</td>
</tr>
<tr>
<td>.r</td>
<td>( n size -- )</td>
<td>Display a number in a fixed width field.</td>
</tr>
<tr>
<td>.s</td>
<td>( -- )</td>
<td>Display contents of data stack.</td>
</tr>
<tr>
<td>showstack</td>
<td>( -- )</td>
<td>Execute .s automatically before each ok prompt.</td>
</tr>
<tr>
<td>noshowstack</td>
<td>( -- )</td>
<td>Turn off automatic display of the stack before each ok prompt.</td>
</tr>
<tr>
<td>u.</td>
<td>( u -- )</td>
<td>Display an unsigned number.</td>
</tr>
<tr>
<td>u.r</td>
<td>( u size -- )</td>
<td>Display an unsigned number in a fixed width field.</td>
</tr>
</tbody>
</table>
Changing the Number Base

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.d</td>
<td>( n -- )</td>
<td>Display $n$ in decimal without changing base.</td>
</tr>
<tr>
<td>.h</td>
<td>( n -- )</td>
<td>Display $n$ in hex without changing base.</td>
</tr>
<tr>
<td>base</td>
<td>( -- addr )</td>
<td>Variable containing number base.</td>
</tr>
<tr>
<td>decimal</td>
<td>( -- )</td>
<td>Set the number base to 10.</td>
</tr>
<tr>
<td>d# number</td>
<td>( -- n )</td>
<td>Interpret number in decimal; base is unchanged.</td>
</tr>
<tr>
<td>hex</td>
<td>( -- )</td>
<td>Set the number base to 16.</td>
</tr>
<tr>
<td>h# number</td>
<td>( -- n )</td>
<td>Interpret number in hex; base is unchanged.</td>
</tr>
</tbody>
</table>

Numeric Output Word Primitives

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>(+l1 -- +l2 )</td>
<td>Convert a digit in pictured numeric output.</td>
</tr>
<tr>
<td>#&gt;</td>
<td>( l-- addr +n )</td>
<td>End pictured numeric output.</td>
</tr>
<tr>
<td>&lt;#</td>
<td>( -- )</td>
<td>Initialize pictured numeric output.</td>
</tr>
<tr>
<td>(.)</td>
<td>( n -- )</td>
<td>Convert a number to a string.</td>
</tr>
<tr>
<td>(u.)</td>
<td>( -- addr len )</td>
<td>Convert unsigned to string.</td>
</tr>
<tr>
<td>digit</td>
<td>( char base -- digit true \ char false )</td>
<td>Convert a character to a digit.</td>
</tr>
<tr>
<td>hold</td>
<td>( char -- )</td>
<td>Insert the char in the pictured numeric output string.</td>
</tr>
<tr>
<td>$number</td>
<td>( addr len -- true \ n false )</td>
<td>Convert a string to a number.</td>
</tr>
<tr>
<td>#s</td>
<td>( l-- 0 )</td>
<td>Convert the rest of the digits in pictured numeric output.</td>
</tr>
<tr>
<td>sign</td>
<td>( n -- )</td>
<td>Set sign of pictured output.</td>
</tr>
</tbody>
</table>
Controlling Text Input

TABLE I-26  Controlling Text Input

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ccc )</td>
<td>( -- )</td>
<td>Begin a comment.</td>
</tr>
<tr>
<td>\ rest-of-line</td>
<td>( -- )</td>
<td>Skip the rest of the line.</td>
</tr>
<tr>
<td>ascii ccc</td>
<td>( -- char )</td>
<td>Get numerical value of first ASCII character of next word.</td>
</tr>
<tr>
<td>accept</td>
<td>( addr len1 -- len2 )</td>
<td>Get a line of edited input from the console input device; store at addr. len1 is the maximum allowed length. len2 is the actual length received.</td>
</tr>
<tr>
<td>expect</td>
<td>( addr len -- )</td>
<td>Get and display a line of input from the console; store at addr. (Recommend using accept instead.)</td>
</tr>
<tr>
<td>key</td>
<td>( -- char )</td>
<td>Read a character from the console input device.</td>
</tr>
<tr>
<td>key?</td>
<td>( -- flag )</td>
<td>True if a key has been typed on the console input device.</td>
</tr>
<tr>
<td>parse</td>
<td>( char -- str len )</td>
<td>Parse text from the input buffer delimited by char.</td>
</tr>
<tr>
<td>parse-word</td>
<td>( -- str len )</td>
<td>Skip leading spaces and parse text from the input buffer delimited by white space.</td>
</tr>
<tr>
<td>safe-parse-word</td>
<td>( -- str len )</td>
<td>Similar to parse-word but intended for use in cases where the null string as input is indicative of an error.</td>
</tr>
<tr>
<td>word</td>
<td>( char -- pstr )</td>
<td>Collect a string delimited by char from the input buffer and place it as a packed string in memory at pstr. (Recommend using parse instead.)</td>
</tr>
</tbody>
</table>

Displaying Text Output

TABLE I-27  Displaying Text Output

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>. &quot; ccc&quot;</td>
<td>( -- )</td>
<td>Compile a string for later display.</td>
</tr>
<tr>
<td>(cr)</td>
<td>( -- )</td>
<td>Move the output cursor back to the beginning of the current line.</td>
</tr>
<tr>
<td>cr</td>
<td>( -- )</td>
<td>Terminate a line on the display and go to the next line.</td>
</tr>
<tr>
<td>emit</td>
<td>( char -- )</td>
<td>Display the character.</td>
</tr>
<tr>
<td>Command</td>
<td>Stack Diagram</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>exit?</td>
<td>( -- flag )</td>
<td>Enable the scrolling control prompt: More [&lt;space&gt;,&lt;cr&gt;,q] ? The return flag is true if the user wants the output to be terminated.</td>
</tr>
<tr>
<td>space</td>
<td>( -- )</td>
<td>Display a space character.</td>
</tr>
<tr>
<td>spaces</td>
<td>( +n -- )</td>
<td>Display +n spaces.</td>
</tr>
<tr>
<td>type</td>
<td>( addr +n -- )</td>
<td>Display n characters.</td>
</tr>
</tbody>
</table>
Formatted Output

TABLE I-28  Formatted Output

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>#lines</td>
<td>( -- rows )</td>
<td>Value holding the number of lines on the output device.</td>
</tr>
<tr>
<td>#out</td>
<td>( -- a-addr )</td>
<td>Variable holding the column number on the output device.</td>
</tr>
</tbody>
</table>

Manipulating Text Strings

TABLE I-29  Manipulating Text Strings

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot; ,</td>
<td>( addr len -- )</td>
<td>Compile an array of bytes from addr of length len, at the top of the dictionary as a packed string.</td>
</tr>
<tr>
<td>&quot; ccc&quot;</td>
<td>( -- addr len )</td>
<td>Collect an input stream string, either interpreted or compiled. Within the string, &quot;(00, ff...) can be used to include arbitrary byte values.</td>
</tr>
<tr>
<td>. ( ccc)</td>
<td>( -- )</td>
<td>Display a string immediately.</td>
</tr>
<tr>
<td>-trailing</td>
<td>( addr +n1 -- addr +n2 )</td>
<td>Remove trailing spaces.</td>
</tr>
<tr>
<td>bl</td>
<td>( -- char )</td>
<td>ASCII code for the space character; decimal 32.</td>
</tr>
<tr>
<td>count</td>
<td>( pstr -- addr +n )</td>
<td>Unpack a packed string.</td>
</tr>
<tr>
<td>lcc</td>
<td>( char -- lowercase-char )</td>
<td>Convert a character to lowercase.</td>
</tr>
<tr>
<td>left-parse-string</td>
<td>( addr len char -- addrR lenR addrL lenL )</td>
<td>Split a string at char (which is discarded).</td>
</tr>
<tr>
<td>pack</td>
<td>( addr len pstr -- pstr )</td>
<td>Make a packed string from addr len; place it at pstr.</td>
</tr>
<tr>
<td>p&quot; ccc&quot;</td>
<td>( -- pstr )</td>
<td>Collect a string from the input stream; store as a packed string.</td>
</tr>
<tr>
<td>upc</td>
<td>( char -- uppercase-char )</td>
<td>Convert a character to uppercase.</td>
</tr>
</tbody>
</table>
I/O Redirection Commands

**TABLE I-30  I/O Redirection Commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>input</td>
<td>( device -- )</td>
<td>Select device (keyboard, or device-specifier) for subsequent input.</td>
</tr>
<tr>
<td>io</td>
<td>( device -- )</td>
<td>Select device for subsequent input and output.</td>
</tr>
<tr>
<td>output</td>
<td>( device -- )</td>
<td>Select device (screen, or device-specifier) for subsequent output.</td>
</tr>
</tbody>
</table>

ASCII Constants

**TABLE I-31  ASCII Constants**

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bell</td>
<td>( -- n )</td>
<td>ASCII code for the bell character; decimal 7.</td>
</tr>
<tr>
<td>bs</td>
<td>( -- n )</td>
<td>ASCII code for the backspace character; decimal 8.</td>
</tr>
</tbody>
</table>

Command Line Editor Keystroke Commands

**TABLE I-32  Command Line Editor Keystroke Commands**

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-B</td>
<td>Moves backward one character.</td>
</tr>
<tr>
<td>Escape B</td>
<td>Moves backward one word.</td>
</tr>
<tr>
<td>Control-F</td>
<td>Moves forward one character.</td>
</tr>
<tr>
<td>Escape F</td>
<td>Moves forward one word.</td>
</tr>
<tr>
<td>Control-A</td>
<td>Moves backward to beginning of line.</td>
</tr>
<tr>
<td>Keystroke</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Control-E</td>
<td>Moves forward to end of line.</td>
</tr>
<tr>
<td>Delete</td>
<td>Erases previous character.</td>
</tr>
<tr>
<td>Backspace</td>
<td>Erases previous character.</td>
</tr>
<tr>
<td>Control-H</td>
<td>Erases previous character.</td>
</tr>
<tr>
<td>Escape H</td>
<td>Erases from beginning of word to just before the cursor, storing erased</td>
</tr>
<tr>
<td></td>
<td>characters in a save buffer.</td>
</tr>
<tr>
<td>Control-W</td>
<td>Erases from beginning of word to just before the cursor, storing erased</td>
</tr>
<tr>
<td></td>
<td>characters in a save buffer.</td>
</tr>
<tr>
<td>Control-D</td>
<td>Erases next character.</td>
</tr>
<tr>
<td>Escape D</td>
<td>Erases from cursor to end of the word, storing erased characters in a save</td>
</tr>
<tr>
<td></td>
<td>buffer.</td>
</tr>
<tr>
<td>Control-K</td>
<td>Erases from cursor to end of line, storing erased characters in a save</td>
</tr>
<tr>
<td></td>
<td>buffer.</td>
</tr>
<tr>
<td>Control-U</td>
<td>Erases entire line, storing erased characters in a save buffer.</td>
</tr>
<tr>
<td>Control-R</td>
<td>Retypes the line.</td>
</tr>
<tr>
<td>Control-Q</td>
<td>Quotes next character (allows you to insert control characters).</td>
</tr>
<tr>
<td>Control-Y</td>
<td>Inserts the contents of the save buffer before the cursor.</td>
</tr>
<tr>
<td>Control-P</td>
<td>Selects and displays the previous line for subsequent editing.</td>
</tr>
<tr>
<td>Control-N</td>
<td>Selects and displays the next line for subsequent editing.</td>
</tr>
<tr>
<td>Control-L</td>
<td>Displays the entire contents of the editing buffer.</td>
</tr>
</tbody>
</table>
Command Completion Keystroke Commands

**TABLE I-33** Command Completion Keystroke Commands

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-Space</td>
<td>Complete the name of the current word.</td>
</tr>
<tr>
<td>Control-/</td>
<td>Display all possible matches for the current word.</td>
</tr>
</tbody>
</table>

Comparison Commands

**TABLE I-34** Comparison Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
<td>( n1 n2 -- flag )</td>
<td>True if $n1 &lt; n2$.</td>
</tr>
<tr>
<td>&lt;=</td>
<td>( n1 n2 -- flag )</td>
<td>True if $n1 \leq n2$.</td>
</tr>
<tr>
<td>&lt;&gt;</td>
<td>( n1 n2 -- flag )</td>
<td>True if $n1 \neq n2$.</td>
</tr>
<tr>
<td>=</td>
<td>( n1 n2 -- flag )</td>
<td>True if $n1 = n2$.</td>
</tr>
<tr>
<td>&gt;</td>
<td>( n1 n2 -- flag )</td>
<td>True if $n1 &gt; n2$.</td>
</tr>
<tr>
<td>&gt;=</td>
<td>( n1 n2 -- flag )</td>
<td>True if $n1 \geq n2$.</td>
</tr>
<tr>
<td>0&lt;</td>
<td>( n -- flag )</td>
<td>True if $n &lt; 0$.</td>
</tr>
<tr>
<td>0&lt;=</td>
<td>( n -- flag )</td>
<td>True if $n \leq 0$.</td>
</tr>
<tr>
<td>0&lt;&gt;</td>
<td>( n -- flag )</td>
<td>True if $n \neq 0$.</td>
</tr>
<tr>
<td>0=</td>
<td>( n -- flag )</td>
<td>True if $n = 0$ (also inverts any flag).</td>
</tr>
<tr>
<td>0&gt;</td>
<td>( n -- flag )</td>
<td>True if $n &gt; 0$.</td>
</tr>
<tr>
<td>0&gt;=</td>
<td>( n -- flag )</td>
<td>True if $n \geq 0$.</td>
</tr>
<tr>
<td>between</td>
<td>( n min max -- flag )</td>
<td>True if $min \leq n \leq max$.</td>
</tr>
<tr>
<td>false</td>
<td>( -- 0 )</td>
<td>The value FALSE, which is 0.</td>
</tr>
<tr>
<td>true</td>
<td>( -- -1 )</td>
<td>The value TRUE, which is -1.</td>
</tr>
<tr>
<td>u&lt;</td>
<td>( u1 u2 -- flag )</td>
<td>True if $u1 &lt; u2$, unsigned.</td>
</tr>
<tr>
<td>Command</td>
<td>Stack Diagram</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>u&lt;=</td>
<td>( u1 u2 -- flag )</td>
<td>True if u1 &lt;= u2, unsigned.</td>
</tr>
<tr>
<td>u&gt;</td>
<td>( u1 u2 -- flag )</td>
<td>True if u1 &gt; u2, unsigned.</td>
</tr>
<tr>
<td>u&gt;=</td>
<td>( u1 u2 -- flag )</td>
<td>True if u1 &gt;= u2, unsigned.</td>
</tr>
<tr>
<td>within</td>
<td>( n min max -- flag )</td>
<td>True if min &lt;= n &lt; max.</td>
</tr>
</tbody>
</table>
if-else-then Commands

**TABLE I-35** if-else-then Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>if</td>
<td>( flag -- )</td>
<td>Execute the following code when flag is true.</td>
</tr>
<tr>
<td>else</td>
<td>( -- )</td>
<td>Execute the following code when flag is false.</td>
</tr>
<tr>
<td>then</td>
<td>( -- )</td>
<td>Terminate if...then...else.</td>
</tr>
</tbody>
</table>

case Statement Commands

**TABLE I-36** case Statement Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>case</td>
<td>( selector -- selector )</td>
<td>Begin a case...endcase conditional.</td>
</tr>
<tr>
<td>endcase</td>
<td>( selector</td>
<td>{empty} -- )</td>
</tr>
<tr>
<td>endof</td>
<td>( -- )</td>
<td>Terminate an of...endof clause within a case...endcase</td>
</tr>
<tr>
<td>of</td>
<td>( selector test-value -- selector</td>
<td>{empty} )</td>
</tr>
</tbody>
</table>

begin (Conditional) Loop Commands

**TABLE I-37** begin (Conditional) Loop Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>again</td>
<td>( -- )</td>
<td>End a begin...again infinite loop.</td>
</tr>
<tr>
<td>begin</td>
<td>( -- )</td>
<td>Begin a begin...while...repeat, begin...until, or begin...again loop.</td>
</tr>
</tbody>
</table>
**TABLE I-37** begin (Conditional) Loop Commands (*Continued*)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>repeat</td>
<td>( -- )</td>
<td>End a begin...while...repeat loop.</td>
</tr>
<tr>
<td>until</td>
<td>( flag -- )</td>
<td>Continue executing a begin...until loop until flag is true.</td>
</tr>
<tr>
<td>while</td>
<td>( flag -- )</td>
<td>Continue executing a begin...while...repeat loop while flag is true.</td>
</tr>
</tbody>
</table>
do (Counted) Loop Commands

TABLE I-38  do (Counted) Loop Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+loop</td>
<td>( n -- )</td>
<td>End a do...+loop construct; add n to loop index and return to do (if n &lt; 0, index goes from start to end, inclusive).</td>
</tr>
<tr>
<td>?do</td>
<td>( end start -- )</td>
<td>Begin ?do...loop to be executed 0 or more times. Index goes from start to end-1, inclusive. If end = start, loop is not executed.</td>
</tr>
<tr>
<td>?leave</td>
<td>( flag -- )</td>
<td>Exit from a do...loop if flag is non-zero.</td>
</tr>
<tr>
<td>do</td>
<td>( end start -- )</td>
<td>Begin a do...loop. Index goes from start to end-1, inclusive. Example: 10 0 do i . loop (prints 0 1 2...d e f).</td>
</tr>
<tr>
<td>i</td>
<td>( -- n )</td>
<td>Leaves the loop index on the stack.</td>
</tr>
<tr>
<td>j</td>
<td>( -- n )</td>
<td>Leaves the loop index for next outer enclosing loop.</td>
</tr>
<tr>
<td>leave</td>
<td>( -- )</td>
<td>Exit from do...loop.</td>
</tr>
<tr>
<td>loop</td>
<td>( -- )</td>
<td>End of do...loop.</td>
</tr>
</tbody>
</table>

Program Execution Control Commands

TABLE I-39  Program Execution Control Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abort</td>
<td>( -- )</td>
<td>Abort current execution and interpret keyboard commands.</td>
</tr>
<tr>
<td>abort&quot; ccc&quot;</td>
<td>( abort? -- )</td>
<td>If abort? is true, abort and display message.</td>
</tr>
<tr>
<td>eval</td>
<td>( ... str len -- ??? )</td>
<td>Synonym for evaluate.</td>
</tr>
<tr>
<td>evaluate</td>
<td>( ... str len -- ??? )</td>
<td>Interpret Forth source text from the specified string.</td>
</tr>
<tr>
<td>execute</td>
<td>( xt -- )</td>
<td>Execute the word whose execution token is on the stack.</td>
</tr>
<tr>
<td>exit</td>
<td>( -- )</td>
<td>Return from the current word. (Cannot be used in counted loops.)</td>
</tr>
<tr>
<td>quit</td>
<td>( -- )</td>
<td>Same as abort, but leave stack intact.</td>
</tr>
</tbody>
</table>
File Loading Commands

TABLE I-40  File Loading Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>?go</td>
<td>( -- )</td>
<td>Execute Forth, FCode, or binary programs.</td>
</tr>
<tr>
<td>boot [specifiers] -h</td>
<td>( -- )</td>
<td>Load file from specified source.</td>
</tr>
<tr>
<td>byte-load</td>
<td>( addr span -- )</td>
<td>Interpret loaded FCode binary file. span is usually 1.</td>
</tr>
<tr>
<td>dl</td>
<td>( -- )</td>
<td>Load a Forth file over a serial line with tip and interpret. Type: ~C cat filename ^-D</td>
</tr>
<tr>
<td>dlbin</td>
<td>( -- )</td>
<td>Load a binary file over a serial line with tip. Type: ~C cat filename</td>
</tr>
<tr>
<td>dload filename</td>
<td>( addr -- )</td>
<td>Load the specified file over Ethernet at the given address.</td>
</tr>
<tr>
<td>eval</td>
<td>( addr len -- )</td>
<td>Interpret loaded Forth text file.</td>
</tr>
<tr>
<td>go</td>
<td>( -- )</td>
<td>Begin executing a previously-loaded binary program, or resume executing an interrupted program.</td>
</tr>
<tr>
<td>init-program</td>
<td>( -- )</td>
<td>Initialize to execute a binary file.</td>
</tr>
<tr>
<td>load device-specifier argument</td>
<td>( -- )</td>
<td>Load data from specified device into memory at the address given by load-base.</td>
</tr>
<tr>
<td>load-base</td>
<td>( -- addr )</td>
<td>Address at which load places the data it reads from a device.</td>
</tr>
</tbody>
</table>

Disassembler Commands

TABLE I-41  Disassembler Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+dis</td>
<td>( -- )</td>
<td>Continue disassembling where the last disassembly left off.</td>
</tr>
<tr>
<td>dis</td>
<td>( addr -- )</td>
<td>Begin disassembling at the specified address.</td>
</tr>
</tbody>
</table>
# Breakpoint Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+bp</td>
<td>( addr -- )</td>
<td>Add a breakpoint at the given address.</td>
</tr>
<tr>
<td>-bp</td>
<td>( addr -- )</td>
<td>Remove the breakpoint at the given address.</td>
</tr>
<tr>
<td>--bp</td>
<td>( -- )</td>
<td>Remove the most-recently-set breakpoint.</td>
</tr>
<tr>
<td>.bp</td>
<td>( -- )</td>
<td>Display all currently set breakpoints.</td>
</tr>
</tbody>
</table>
| .breakpoint | ( -- )    | Perform a specified action when a breakpoint occurs. This word can be altered to perform any desired action. For example, to display registers at every breakpoint, type: 
```
[''] .registers is .breakpoint. The default behavior is .instruction. To perform multiple behaviors, create a single definition which calls all desired behaviors, then load that word into .breakpoint.
```
| .instruction | ( -- )       | Display the address, opcode for the last-encountered breakpoint. |
| .step      | ( -- )       | Perform a specified action when a single step occurs. (See .breakpoint). |
| bpooff    | ( -- )       | Remove all breakpoints. |
| finish-loop | ( -- )     | Execute until the end of this loop. |
| go        | ( -- )       | Continue from a breakpoint. This can be used to go to an arbitrary address by setting up the processor’s program counter before issuing go. |
| gos       | ( n -- )     | Execute go n times. |
| hop       | ( -- )       | (Like the step command.) Treat a subroutine call as a single instruction. |
| hops      | ( n -- )     | Execute hop n times. |
| return    | ( -- )       | Execute until the end of this subroutine. |
| returnl   | ( -- )       | Execute until the end of this leaf subroutine. |
| skip      | ( -- )       | Skip (do not execute) the current instruction. |
| step      | ( -- )       | Single-step one instruction. |
| steps     | ( n -- )     | Execute step n times. |
| till      | ( addr -- )  | Execute until the given address is encountered. Equivalent to +bp go. |
# Forth Source-level Debugger Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>“Continue”. Switch from stepping to tracing, thus tracing the remainder of the execution of the word being debugged.</td>
</tr>
<tr>
<td>d</td>
<td>“Down a level”. Mark for debugging the word whose name was just displayed, then execute it.</td>
</tr>
<tr>
<td>u</td>
<td>“Up a level”. Un-mark the word being debugged, mark its caller for debugging, and finish executing the word that was previously being debugged.</td>
</tr>
<tr>
<td>f</td>
<td>Start a subordinate Forth interpreter. When that interpreter exits (with <code>resume</code>), control returns to the debugger at the place where the <code>f</code> command was executed.</td>
</tr>
<tr>
<td>g</td>
<td>“Go.” Turn off the debugger and continue execution.</td>
</tr>
<tr>
<td>q</td>
<td>“Quit”. Abort the execution of the word being debugged and all its callers and return to the command interpreter.</td>
</tr>
<tr>
<td>s</td>
<td>“see”. Decompile the word being debugged.</td>
</tr>
<tr>
<td>$</td>
<td>Display the address,len on top of the stack as a text string.</td>
</tr>
<tr>
<td>h</td>
<td>“Help”. Display symbolic debugger documentation.</td>
</tr>
<tr>
<td>?</td>
<td>“Short Help”. Display brief symbolic debugger documentation.</td>
</tr>
<tr>
<td>debug <code>name</code></td>
<td>Mark the specified Forth word for debugging. Enter the Forth Source-level Debugger on all subsequent attempts to execute name. After executing <code>debug</code>, the execution speed of the system may decrease until debugging is turned off with <code>debug-off</code>. (Do not debug basic Forth words such as “dup”.)</td>
</tr>
<tr>
<td>(debug</td>
<td>Like <code>debug</code> except that <code>(debug</code> takes an execution token from the stack instead of a name from the input stream.</td>
</tr>
<tr>
<td>debug-off</td>
<td>Turn off the Forth Source-level Debugger so that no word is being debugged.</td>
</tr>
<tr>
<td>resume</td>
<td>Exit from a subordinate interpreter, and go back to the stepper (See the <code>f</code> command in this table.)</td>
</tr>
<tr>
<td>stepping</td>
<td>Set step mode for the Forth Source-level Debugger, allowing the interactive, step-by-step execution of the word being debugged. Step mode is the default.</td>
</tr>
<tr>
<td>tracing</td>
<td>Set trace mode for the Forth Source-level Debugger. Tracing enables the execution of the word being debugged, while showing the name and stack contents for each word called by that word.</td>
</tr>
<tr>
<td><code>&lt;space-bar&gt;</code></td>
<td>Execute the word just displayed and proceed to the next word.</td>
</tr>
</tbody>
</table>
Time Utilities

TABLE I-44  Time Utilities

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>get-msecs</td>
<td>( -- ms )</td>
<td>Return the approximate current time in milliseconds.</td>
</tr>
<tr>
<td>ms</td>
<td>( n -- )</td>
<td>Delay for ( n ) milliseconds. Resolution is 1 millisecond.</td>
</tr>
</tbody>
</table>

Miscellaneous Operations

TABLE I-45  Miscellaneous Operations

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>callback</td>
<td>( value -- )</td>
<td>Call Solaris with the given value and string.</td>
</tr>
<tr>
<td>catch</td>
<td>( ... xt -- ??? error-code</td>
<td>Execute ( xt ); return ( \text{throw} ) error code or 0 if ( \text{throw} ) is not called.</td>
</tr>
<tr>
<td>eject-floppy</td>
<td>( -- )</td>
<td>Eject the diskette from the floppy drive.</td>
</tr>
<tr>
<td>firmware-version</td>
<td>( -- n )</td>
<td>Return major/minor CPU firmware version (that is, 0x00030001 = firmware version 3.1).</td>
</tr>
<tr>
<td>forth</td>
<td>( -- )</td>
<td>Restore main Forth vocabulary to top of search order.</td>
</tr>
<tr>
<td>ftrace</td>
<td>( -- )</td>
<td>Show calling sequence when exception occurred.</td>
</tr>
<tr>
<td>noop</td>
<td>( -- )</td>
<td>Do nothing.</td>
</tr>
<tr>
<td>reset-all</td>
<td>( -- )</td>
<td>Reset the entire system (similar to a power-cycle).</td>
</tr>
<tr>
<td>sync</td>
<td>( -- )</td>
<td>Call the operating system to write any pending information to the hard disk. Also boot after sync-ing file systems.</td>
</tr>
<tr>
<td>throw</td>
<td>( error-code -- )</td>
<td>Return given error code to ( \text{catch} ).</td>
</tr>
</tbody>
</table>
Multiprocessor Commands

TABLE I-46   Multiprocessor Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>switch-cpu</td>
<td>( cpu# -- )</td>
<td>Switch to indicated CPU.</td>
</tr>
</tbody>
</table>

Memory Mapping Commands

TABLE I-47   Memory Mapping Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>map?</td>
<td>( virt -- )</td>
<td>Display memory map information for the virtual address.</td>
</tr>
<tr>
<td>memmap</td>
<td>( phys space size -- virt )</td>
<td>Map a region of physical addresses; return the allocated virtual address. Unmap with free-virtual.</td>
</tr>
<tr>
<td>obio</td>
<td>( -- space )</td>
<td>Specify the device address space for mapping.</td>
</tr>
<tr>
<td>obmem</td>
<td>( -- space )</td>
<td>Specify the onboard memory address space for mapping.</td>
</tr>
<tr>
<td>sbus</td>
<td>( -- space )</td>
<td>Specify the SBus address space for mapping.</td>
</tr>
</tbody>
</table>

Memory Mapping Primitives

TABLE I-48   Memory Mapping Primitives

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>iomap?</td>
<td>( virt -- )</td>
<td>Display IOMMU page map entry for the virtual address.</td>
</tr>
<tr>
<td>iomap-page</td>
<td>( phys space virt -- )</td>
<td>Map physical page given by phys and space to the virtual address.</td>
</tr>
<tr>
<td>iomap-pages</td>
<td>( phys space virt size -- )</td>
<td>Perform consecutive iomap-pages to map a region of memory given by size.</td>
</tr>
<tr>
<td>iopgmap@</td>
<td>( virt -- pte</td>
<td>0 )</td>
</tr>
<tr>
<td>Command</td>
<td>Stack Diagram</td>
<td>Description</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>iopgmap!</td>
<td>( pte virt -- )</td>
<td>Store a new page map entry for the virtual address.</td>
</tr>
<tr>
<td>map-page</td>
<td>( phys space virt -- )</td>
<td>Map one page of memory starting at address phys on to virtual address virt in the specified address space. All addresses are truncated to lie on a page boundary.</td>
</tr>
<tr>
<td>map-pages</td>
<td>( phys space virt size -- )</td>
<td>Perform consecutive map-pages to map a region of memory to the specified size.</td>
</tr>
<tr>
<td>map-region</td>
<td>( region# virt -- )</td>
<td>Map a region.</td>
</tr>
<tr>
<td>map-segments</td>
<td>( smentry virt len -- )</td>
<td>Perform consecutive smap! operations to map a region of memory.</td>
</tr>
<tr>
<td>pgmap!</td>
<td>( pmentry virt -- )</td>
<td>Store a new page map entry for the virtual address.</td>
</tr>
<tr>
<td>pgmap?</td>
<td>( virt -- )</td>
<td>Display the page map entry (decoded and in English) corresponding to the virtual address.</td>
</tr>
<tr>
<td>pgmap@</td>
<td>( virt -- pmentry )</td>
<td>Return the page map entry for the virtual address.</td>
</tr>
<tr>
<td>pagesize</td>
<td>( -- size )</td>
<td>Return the size of a page.</td>
</tr>
<tr>
<td>rmap!</td>
<td>( rmentry virt -- )</td>
<td>Store a new region map entry for the virtual address.</td>
</tr>
<tr>
<td>rmap@</td>
<td>( virt -- rmentry )</td>
<td>Return the region map entry for the virtual address.</td>
</tr>
<tr>
<td>segmentsize</td>
<td>( -- size )</td>
<td>Return the size of a segment.</td>
</tr>
<tr>
<td>smap!</td>
<td>( smentry virt -- )</td>
<td>Store a new segment map entry for the virtual address.</td>
</tr>
<tr>
<td>smap?</td>
<td>( virt -- )</td>
<td>Formatted display of the segment map entry for the virtual address.</td>
</tr>
<tr>
<td>smap@</td>
<td>( virt -- smentry )</td>
<td>Return the segment map entry for the virtual address.</td>
</tr>
</tbody>
</table>
Cache Manipulation Commands

TABLE I-49  Cache Manipulation Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear-cache</td>
<td>( -- )</td>
<td>Invalidate all cache entries.</td>
</tr>
<tr>
<td>cache-off</td>
<td>( -- )</td>
<td>Disable the cache.</td>
</tr>
<tr>
<td>cache-on</td>
<td>( -- )</td>
<td>Enable the cache.</td>
</tr>
<tr>
<td>ecdata!</td>
<td>( data offset -- )</td>
<td>Store the data at the cache offset.</td>
</tr>
<tr>
<td>ecdata@</td>
<td>( offset -- data )</td>
<td>Fetch (return) data from the cache offset.</td>
</tr>
<tr>
<td>ectag!</td>
<td>( value offset -- )</td>
<td>Store the tag value at the cache offset.</td>
</tr>
<tr>
<td>ectag@</td>
<td>( offset -- value )</td>
<td>Return the tag value at the cache offset.</td>
</tr>
<tr>
<td>flush-cache</td>
<td>( -- )</td>
<td>Write back any pending data from the cache.</td>
</tr>
</tbody>
</table>

Reading/Writing Machine Registers in Sun-4u Machines

TABLE I-50  Reading/Writing Machine Registers in Sun-4u Machines

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>aux!</td>
<td>( data -- )</td>
<td>Write auxiliary register.</td>
</tr>
<tr>
<td>aux@</td>
<td>( -- data )</td>
<td>Read auxiliary register.</td>
</tr>
</tbody>
</table>
# Commands

## Alternate Address Space Access Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>spacec!</code></td>
<td><code>( byte addr asi -- )</code></td>
<td>Store the byte in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacec?</code></td>
<td><code>( addr asi -- )</code></td>
<td>Display the byte in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacec@</code></td>
<td><code>( addr asi -- byte )</code></td>
<td>Fetch the byte from <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spaced!</code></td>
<td><code>( quad1 quad2 addr asi -- )</code></td>
<td>Store the two quadlets in <code>asi</code> at <code>addr</code>. Order is implementation-dependent.</td>
</tr>
<tr>
<td><code>spaced?</code></td>
<td><code>( addr asi -- )</code></td>
<td>Display the two quadlets in <code>asi</code> at <code>addr</code>. Order is implementation-dependent.</td>
</tr>
<tr>
<td><code>spaced@</code></td>
<td><code>( addr asi -- quad1 quad2 )</code></td>
<td>Fetch the two quadlets from <code>asi</code> at <code>addr</code>. Order is implementation-dependent.</td>
</tr>
<tr>
<td><code>spacel!</code></td>
<td><code>( quad addr asi -- )</code></td>
<td>Store the quadlet in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacel?</code></td>
<td><code>( addr asi -- )</code></td>
<td>Display the quadlet in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacel@</code></td>
<td><code>( addr asi -- quad )</code></td>
<td>Fetch the quadlet from <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacew!</code></td>
<td><code>( w addr asi -- )</code></td>
<td>Store the doublet in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacew?</code></td>
<td><code>( addr asi -- )</code></td>
<td>Display the doublet in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacew@</code></td>
<td><code>( addr asi -- w )</code></td>
<td>Fetch the doublet from <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacex!</code></td>
<td><code>( x addr asi -- )</code></td>
<td>Store the number in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacex?</code></td>
<td><code>( addr asi -- )</code></td>
<td>Display the word in <code>asi</code> at <code>addr</code>.</td>
</tr>
<tr>
<td><code>spacex@</code></td>
<td><code>( addr asi -- x )</code></td>
<td>Fetch the word from <code>asi</code> at <code>addr</code>.</td>
</tr>
</tbody>
</table>

## SPARC Register Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>%g0</code> through <code>%g7</code></td>
<td><code>( -- value )</code></td>
<td>Return the value in the specified global register.</td>
</tr>
<tr>
<td><code>%i0</code> through <code>%i7</code></td>
<td><code>( -- value )</code></td>
<td>Return the value in the specified input register.</td>
</tr>
<tr>
<td><code>%l0</code> through <code>%l7</code></td>
<td><code>( -- value )</code></td>
<td>Return the value in the specified local register.</td>
</tr>
<tr>
<td><code>%o0</code> through <code>%o7</code></td>
<td><code>( -- value )</code></td>
<td>Return the value in the specified output register.</td>
</tr>
</tbody>
</table>
### TABLE I-52  SPARC Register Commands (Continued)

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>%pc %npc %y</td>
<td>( -- value )</td>
<td>Return the value in the specified register.</td>
</tr>
<tr>
<td>%f0 through %f31</td>
<td>( -- value )</td>
<td>Return the value in the specified floating point register.</td>
</tr>
<tr>
<td>.registers</td>
<td>( -- )</td>
<td>Display the values in %f0 through %f31.</td>
</tr>
<tr>
<td>.locals</td>
<td>( -- )</td>
<td>Display the values in the i, l and o registers.</td>
</tr>
<tr>
<td>.registers</td>
<td>( -- )</td>
<td>Display values in processor registers.</td>
</tr>
<tr>
<td>.window</td>
<td>( window# -- )</td>
<td>Same as w .locals; display the desired window.</td>
</tr>
<tr>
<td>ctrace</td>
<td>( -- )</td>
<td>Display the return stack showing C subroutines.</td>
</tr>
<tr>
<td>set-pc</td>
<td>( new-value --)</td>
<td>Set %pc to new-value, and set %npc to (new-value+4).</td>
</tr>
<tr>
<td>to regname</td>
<td>( new-value --)</td>
<td>Change the value stored in any of the above registers.</td>
</tr>
<tr>
<td>w</td>
<td>( window# -- )</td>
<td>Set the current window for displaying %ix, %lx, or %ox.</td>
</tr>
</tbody>
</table>
SPARC V9 Register Commands

**TABLE I-53**  SPARC V9 Register Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Stack Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>%fprs</td>
<td>( -- value )</td>
<td>Return the value in the specified register.</td>
</tr>
<tr>
<td>%asi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%pstate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%tl-c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%pil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%tstate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%tt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%tba</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%cwp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%cansave</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%canrestore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%otherwin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%wstate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%cleanwin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.pstate</td>
<td>( -- )</td>
<td>Formatted display of the processor state register.</td>
</tr>
<tr>
<td>.ver</td>
<td>( -- )</td>
<td>Formatted display of the version register.</td>
</tr>
<tr>
<td>.ccr</td>
<td>( -- )</td>
<td>Formatted display of the ccr register.</td>
</tr>
<tr>
<td>.trap-registers</td>
<td>( -- )</td>
<td>Display trap-related registers.</td>
</tr>
</tbody>
</table>

Emergency Keyboard Commands

**TABLE I-54**  Emergency Keyboard Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>Bypass POST. This command does not depend on security-mode. (Note: some systems bypass POST as a default; in such cases, use Stop-D to start POST.)</td>
</tr>
<tr>
<td>Stop-A</td>
<td>Abort.</td>
</tr>
</tbody>
</table>
**TABLE I-54  Emergency Keyboard Commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop-D</td>
<td>Enter diagnostic mode (set diag-switch? to true).</td>
</tr>
<tr>
<td>Stop-F</td>
<td>Enter Forth on TTYA instead of probing. Use fexit to continue with the initialization sequence. Useful if hardware is broken.</td>
</tr>
<tr>
<td>Stop-N</td>
<td>Reset NVRAM contents to default values.</td>
</tr>
</tbody>
</table>
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