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Chapter 1
Introduction

1.1 Overview

The DSP561CCC GNU based C cross-compiler is the latest high-level language development system for the Motorola DSP56100 family of digital signal processors (DSPs). It includes:

- an integrated control program — **g561c**
- an ANSI compliant C language preprocessor — **mcpp**
- an ANSI optimizing C compiler — **g561-cc1**
- a DSP56100 common object file format (COFF) assembler — **asm56100**
- a COFF linker — **dsplnk**
- a COFF librarian — **dsplib**
- a source level debugger for C — **gdb561**
- a simulator based execution program — **run561**
- various object file manipulation tools — **srec, cldlod, cofdmp**

This integrated software system runs on a variety of machines and operating systems, including the IBM PC™ (80386 family and above — 386sx, 486, etc.), and Sun SPARC™ workstations.

The compiler implements the full C language as defined in American National Standard for Information Systems - Programming Language - C, ANSI X3.159-1989. It accepts one or more C language source files as input and generates a corresponding number of assembly language source files which are suitable as input to the DSP56100 assembler. The compiler automatically implements numerous optimizations, which aid in implementing fast and efficient DSP algorithms.

The C language preprocessor is an implementation of the ANSI standard which includes support for arbitrary text file inclusion, macro definition and expansion, and conditional compilation. The preprocessor exists as a separate program and may be used as a general-purpose macro preprocessor.

The compiler control program, **g561c**, is the standard compiler interface used to control

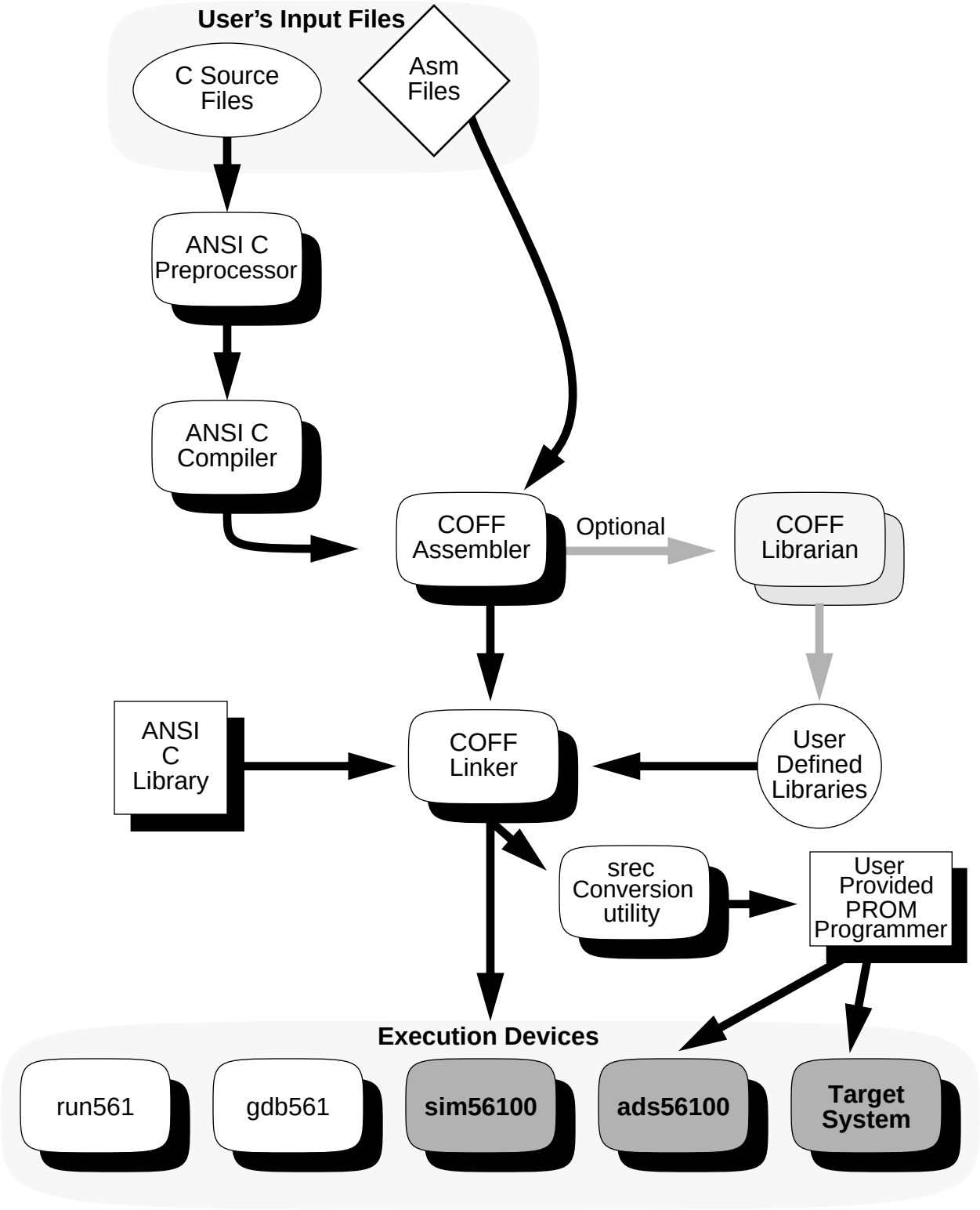


Figure 1-1. Motorola Software Development System

the sequence of operations required to compile a program. This control program allows the user to select a wide variety of control options which affect the four compilation phases — preprocessing, compiling, assembling, and linking. The control program parses the command line options, and invokes the required sub-programs on the specified files.

Note: Object files are stored using the COFF format. COFF stands for Common Object File Format. Utilities such as **cldinfo** and **cldlod** may be used to gain visibility into object files.

1. Given a list of C source files from the user (see Figure 1-1) and options to apply to those files, the control program runs each file through the C preprocessor and the C compiler. The compiler creates individual assembly language source files for each C source file provided on the command line.
2. The control program then sends the compiler output from these files to the assembler, in addition to any assembly language files specified by the user on the **g561c** command line.
3. The assembler output is routed to the linker for final processing. The linker tries to resolve all unresolved link-time symbols with the standard (and any explicitly requested) C libraries. The COFF linker object file output may then be directed to any of several execution devices. Notice that the assembler can also be used to create library files which can be included in a user defined library.
4. The execution devices shown in Figure 1-1 are:
    a. **run561** which allows the DSP56100 code (in COFF format) to be executed on the host computer's CPU,
    b. **gdb561** which is a debugging tool for trouble-shooting the compiled application,
    c. **sim56100** which is a complete DSP56100 simulator that can be used to execute the compiled application (in either COFF format or .lod file format) and allow examination of registers and memory,
    d. **ads56100** is the development system hardware that can then be used to load and execute the compiled application (in either COFF format or .lod file format) on the ADS development system, and
    e. the target system shown is the user's custom DSP system.

Note: The three execution devices in the shaded boxes are not part of the C compiler software. The COFF linker output can be used by these execution devices directly. The conversion utility **srec** (see Figure 1-1) can be used to convert the executable file from the COFF Linker to a suitable format for PROM burning. These PROMs can then be used on the ADS development system or the user's target system. The PROM programmer, ADS development system and user's target system are not part of the DSP561CCC compiler system.

The DSP56100 family represents a departure from more conventional architectures on which many other implementations of the C language are based. Also, the nature of DSP applications dictates that a great measure of control be provided to the programmer in specifying the constraints of the run-time environment. For these reasons, the components of the development system include options for handling stack initialization, chip operating modes and other issues.

The purpose of this manual is to:

1. provide detailed installation procedures for both UNIX based systems and MS-DOS based systems. This manual explains how to install and operate the DSP561CCC compiler development system.
2. provide an overview of the compiler operation. It also includes information on combining C modules with assembly language programs and advanced topics pertaining to compiler run-time characteristics.
3. provide reference information on compiler options, ANSI library routines, and utilities.

This manual assumes a familiarity with the C programming language, and with the host machine and operating environment. It also assumes that the programmer understands how to create and edit C language source files on the host system. For more information on the C language and other DSP56100 development tools, see the references listed in Appendix D.

1.2 Error Codes

The error messages generated by the compiler are intended to be complete without additional explanation. Since the compiler produces a detailed description of the problem rather than an error code, these error messages have not been reproduced in this manual.

1.3 Notation

The following notation will be used in this text.

1. A prompt is indicated in this manual by:
   ```
   C:\>
   ```
2. An example of an MS-DOS directory name is:
   ```
   \USR\DIRECTORY
   ```
3. The contents of an MS-DOS directory are examined by entering:
   ```
   C:\> DIR
   ```
4. The contents of an MS-DOS file are displayed by entering:
   ```
   C:\> TYPE FILE
   ```
5. The program “HELLO.EXE” would be executed by the command line:
   ```
   C:\> HELLO
   ```

1.4 Manual Organization

Installation details are provided in Chapter 2, the compiler operation is described in Chapters 3-6 and reference information is in Chapter 3 and Appendices A-E. The contents of each chapter and each appendix are described below.

Chapter 1, Introduction, describes the overall organization of the DSP561CCC compiler system. It also details the structure of this document, and conventions followed herein.

Chapter 2, Installation Guide, describes the installation and organization of DSP561CCC. It details how to set up an operating environment on the host system by defining global environment variables and includes a step-by-step installation procedure.

Chapter 3, Compiler Operation, discusses the four passes of the compilation process with particular attention to the functions of the compiler control program **g561c**. This chapter includes a list of the compiler invocation options along with example command lines for different memory and program configurations.

Chapter 4, About g561c, provides information on the compiler run-time environment, including explanations of compiler register and memory usage, stack frame architecture, stack overflow checking, and defining/referencing of absolute memory locations. Additionally, this chapter covers implementation issues such as data type sizes.

Chapter 5, Mixing C and Assembly Language, discusses the methods for using assembly language in conjunction with C language programs. It covers the inclusion of assembly language within a C source file and also describes linking assembly language modules with C modules and linking C modules with assembly language modules.

Chapter 6, Software-Hardware Integration, describes how to modify a program's run-time environment, how to write software to handle interrupts, and the **setjmp**/**longjmp** ANSI library routines.

Appendix A, Programming Support, provides a complete description and brief example for every ANSI library subroutine distributed with the C compiler.

Appendix B, DSP56100 Instruction Set and Assembler Directive Summary, provides a brief overview of the assembly language instructions and assembler directives.

Appendix C, Utilities, provides documentation for each of the support utilities provided with the compiler.

Appendix D, Additional Support, provides a description of software, hardware, support telephone numbers, and suggested reading for the C language and various DSP topics.

Appendix E, Debugger, provides a reproduction of the GNU debugger manual.

Chapter 2
Installation Guide

2.1 Introduction

This chapter describes installation on MS-DOS and Sun computers. Two installation procedures are detailed for the Sun. The first procedure uses the default location for the files. The second procedure allows the user to select the directory where the compiler's files will be located. Only one procedure is needed for MS-DOS machines.

The various parts of the compiler reside in a directory tree named **dsp**. The default location for the **dsp** directory tree is **/usr/local** on UNIX systems. If this default location is acceptable, then perform the standard installation; if it is not acceptable, then perform the alternate installation. The alternate installation procedure allows the user to install the **dsp** directory tree anywhere.

2.2 Installation On An MS-DOS Machine (80386 or 80486)

1. Insert the supplied floppy labeled **Disk 1** into floppy drive **A:**.
2. Change to floppy drive **A**, with the command **A:**.
3. Run the install program, **install.exe**. This installation program will ask questions about the computer being used and about where the compiler's directory tree, **dsp**, is to reside.
4. Add all new lines of code specified by **install** into the **autoexec.bat** file. The only difference between the standard and alternate installation procedure on the PC is whether or not the default output drive or default location is selected. If the defaults are not selected, an environment variable named **DSPLOC** must be set in the **autoexec.bat** file. The **install** program will provide directions. The lines to be added to the **autoexec.bat** file follow:

a. **TERMCAP** must be set to the current location of **<compiler's dsp directory tree>\dsp\etc\termcap**:

```
SET TERMCAP=<DSP location>\DSP\ETC\TERMCAP
```

for example, if the directory <compiler's dsp directory tree> is **d:\usr\mydir**, then the line to be added is

```
SET TERMCAP=D:\USR\MYDIR\DSP\ETC\TERMCAP
```

b. **TERM** must be set to indicate the type of display to be used (probably **nansi-mono**):

```
SET TERM=NANSI-MONO
```

c. **DSPLOC** need only be set if the default output drive or the default location is not chosen. If **DSPLOC** is set, it must be set to the location of the dsp directory tree. For example, if the user installed the compiler's directory tree **dsp** in the directory **d:\usr\mydir**, then **DSPLOC** would need to be set as **d:\usr\mydir:**

```
SET DSPLOC=<compiler's dsp directory tree>
```

if the directory <compiler's dsp directory tree> is d:\usr\mydir, then

```
SET DSPLOC=D:\USR\MYDIR
```

5. Make sure that **<compiler's dsp directory tree>\dsp\bin** is included in the **path** instruction. This is needed by **command.com** if it is to find **g561cg56k**. If the default drive and path were chosen, then the path **c:\dsp\bin** would need to be added as follows:

```
PATH ...;C:\DSP\BIN;...
```

If, for example the compiler's dsp directory tree was installed in **c:\usr\mydir**, then **c:\usr\mydir\dsp\bin** would need to be added as follows:

```
PATH ...;C:\USR\MYDIR\DSP\BIN;...
```

6. Make sure that other DOS memory managers do not interfere with the DOS extended memory manager for **g561cg56k**. The compiler uses its own DOS extended memory manager called **dos4gw.exe**, and this memory manager may not work if a different memory manager is already installed. Although this DOS extender is **DPMI 0.9** compliant, It is recommended that initially all other DOS extended memory managers be removed, in order to test the installation. The DOS extended memory manager dos4gw.exe is called during the compiler's execution, and re-

quires at least 2M bytes of RAM. This memory manager uses hard drives for the swap space for the memory management. By default, the swap space location is the C drive and the size of the swap space is 16 Mbytes.

7. The DOS environment DOS4GVM controls the configuration of the DOS extended memory management, and the environment DOS4GVM has the following format.

   [option[#value]] [option[#value]]

   The possible parameters for the option are:

MINMEM	The minimum amount of RAM managed by the memory manager. Default value is 512KB.
MAXMEM	The maximum amount of RAM managed by the memory manager. Default value is 4MB.
SWAPNAME	The swap file name for the memory manager uses for the swap space. Default is DOS4GVM.SWP on the current drive.
DELETESWAP	Specifies that the swap file should be deleted after memory management.
VIRTUALSIZE	The size of the virtual memory space. Default is 16MB.

   The value should be entered as numeric value of Kbyte.

   As an example, the following line in the autoexec.bat file will enable an 8MB swap file with automatic deletion of the swap file:

   ```
   SET DOS4GVM=DELETESWAP VIRTUALSIZE#8192
   ```

   The following line will use F drive for the swap space instead of the current drive.

   ```
   SET DOS4GVM=DELETESWAP SWAPNAME#F:\BIG.SWP
   ```

8. There is a READ.ME file included in the package and it should be read for any recent changes in the installation on compiler itself.

2.3 Standard Installation On A SUN

1. Insert the supplied first floppy diskette into the tape drive.
2. Login as **root**.

3. Enter the command: **cd /usr/local**.

4. Enter the command: **bar xZvf /dev/rfd0**. If the floppy drive must be accessed via a different device file than **rfd0**, then use the appropriate device for your system.

5. Logout.

6. Make sure that all users add **/usr/local/dsp/bin** to their path. This enables the shell to find the control program **g561cg56k** and other programs in the DSP561CCCDSP56KCC distribution package.

2.4 Alternate Installation On A SUN

1. Insert the supplied first floppy diskette into the floppy drive.

2. Login as **root**, or as yourself, if access permissions allow.

3. Inside the shell, use the command **cd** to go to the directory where the compiler's **dsp** directory tree is to reside. For this example, assume that the compiler is to be installed in **/usr/mydir** (referred to by **<compiler's dsp directory tree>** here).

4. Make sure that you have write permission in the directory.

5. Enter the command: **bar xZvf /dev/rfd0**. If the floppy drive must be accessed via a different device file than **rfd0**, then use the appropriate device for your system.

6. Make sure that every user adds **<compiler's dsp directory tree>/dsp/bin** to their path. In this example, the path **/usr/mydir/dsp/bin** would be added to everyone's path.

7. Make sure that every user sets the environment variable **DSPLOC** to the path leading to the **dsp** directory tree which is the directory **<compiler's dsp directory tree>**. In this example, **DSPLOC** would be set to **/usr/mydir**. Note that **DSPLOC** would not be set to **/usr/mydir/dsp.**

2.5 Test Program

The following test program is intended to be a very simple check to see if the installation has been completed correctly. The program should be put in a file named “hello.c”. The control program, **g561cg56k**, compiles the program in the file “hello.c” and generates the output file “a.cld”. Do not enter the C:> as it is simply a prompt indicating that this line should be entered from the keyboard. The command **run561run56** executes the program in the file “a.cld” and the result is to print “hello world.” on the computer screen.

Example Program

```
#include <stdio.h>
main ( )
{
printf ( “hello world.\n” );
}
```

Commands to Compile and Execute the Example Program

```
C:\> g561cg56k hello.c
C:\> run561run56 a.cld
```

Result Printed on the Computer Screen

```
hello                                                    world.
```

Example 2-1. Test Program

Chapter 3
Control Program Options

3.1 Overview

Program **g561cg56k** is the control program for Motorola's optimizing C compiler for the DSP56100 family of digital signal processors. The program **g561cg56k** automates control of the four C compiler phases – preprocessing, compiling, assembling, and linking. The program **g561cg56k** utilizes a command syntax similar to those adopted by typical UNIX utilities. The **g561cg56k** syntax is:

```
g561cg56k [options] files
```

where:

1. [options] is one or more of the options found in this chapter. One difference between **g561cg56k** and UNIX-style utilities is that the combination of multiple single character options is not allowed. For example, "**-O -g**" instructs the compiler to generate an optimized executable with source level debug information, whereas "**-Og**", which is acceptable to UNIX-style compilers is not acceptable to **g561cg56k**.

2. "files …" are the files to be processed. Program **g561cg56k** accepts input filenames suffixed with "**.c**" (ANSI C source files), "**.i**" (preprocessed C source files), "**.asm**" (DSP56100DSP56000/1 assembly code), and "**.cln**" (COFF link files). The control program processes each file according to this suffix. The **g561cg56k** output is controlled by the specific set of command line options provided. For instance, if no command line arguments are provided, the compiler will attempt to generate a COFF load file "**a.cld**". If the **-c** option is invoked, the compiler will generate a COFF link file suffixed with "**.cln**". A complete description of the command line options, with examples, is provided in Section 3.2.

Note: It is strongly recommended that g561cg56k always be used to invoke the C compiler utilities rather than individually executing them.

A standard directory search list is consulted by **g561cg56k** for:

1. Each of the four executables,
   a. **mcpp** – the C preprocessor,
   b. **g561g56-cc1**– the C compiler/optimizer,
   c. **alo561alo56** – the assembly language optimizer,
   d. **asm56100asm56000** – the DSP56100DSP56000/1 assembler,
   e. **dsplnk** – the DSP56100DSP56000/1 linker.
2. Start-up file, **crt056*.cln**. Where ***** is a single character (**x**, **y** or **l**; i.e., x data memory, y data memory or long data memory) to denote the memory model.
3. Start-up file, **crt0561.cln**.
4. ANSI C library, **lib56c*.clb**. Where ***** is a single character (**x**, **y** or **l**) to denote the memory model.
5. ANSI C library, **lib561c.clb**.

This standard directory search list for **UNIX** systems is:

1. /usr/local/dsp/bin/
2. /usr/local/dsp/lib/
3. /lib/
4. /usr/lib/
5. **./**

The standard **MS-DOS** directory search list for the path set up in Section 2.2 is:

1. c:\dsp\bin
2. c:\dsp\lib
3. c:
4. c:\dos
5. other directories in the **path** name

Note that if the environment variable **DSPLOC** is set, the value of **DSPLOC** will be substituted for 1 and 2 above.

Table 3-1 lists all the user selectable options used by **g561cg56k**. They are grouped to show what program uses each option. All of these options are described in detail later in this chapter; however, these lists provide an overview of what options are available. Notice that there is a **-v** option listed under both **g561cg56k** Command Options and under Preprocessor Phase Options. This is actually the same option but it is used by these two programs in different ways (see Section 3.2 and Section 3.2.1).

Under compile phase options, there is a group of **-f** options; these are the machine inde-

Table 3-1 - Options

g561cg56k Command Line Options

-Bdirectory
-**b**PREFIX
-o FILE
-v

Preprocessor Phase Options

-C
-DMACRO
-DMACRO=DEFN
-E
-IDIR
-I-
-i FILE
-M
-MM
-nostdinc
-pedantic
-v
-UMACRO
-Wcomment
-Wtrigraphs

Assemble Phase Options

-asm string
-c

Link Phase Options

-crt file
-j string
-lLIBRARY
-r MAPFILE

Compile Phase Options

-alo
-fno-opt
-fno-peephole
-fno-strength-reduce
-fno-defer-pop
-fforce-addr
-finline-functions
-fcaller-saves
-fkeep-inline-functions
-fwritable-strings
-fcond-mismatch
-fvolatile
-ffixed-REG
-g
-O
-m56002
-mno-dsp
-mno-do-loop-generation
-mno-linv-plus-biv-promotion
-mp-mem-switchtable
-mx-memory
-my-memory
-ml-memory
-mstack-check
-pedantic
-Q
-S
-w
-W
-Wimplicit
-Wreturn-type
-Wunused
-Wswitch
-Wall
-Wshadow
-Wid-clash-LEN
-Wpointer-arith
-Wcast-qual
-Wwrite-strings

pendent optimization options whereas the **-m** options below are the optimization options specific to the DSP56100DSP56000/1. Although these various methods of optimization are all effective, they may have side effects which are undesirable in specific cases, e.g. an optimization option may increase code speed at the cost of increased memory usage. It is often preferable to trade memory space for speed, but in cases where the extra memory space is not available, a particular optimization might be unwise.

The various compiler phases will report errors; however, the user has the option to turn off all compiler warnings using **-w** and can enable additional warnings individually or as a group using **-Wall**. The warnings which are not enabled by **-Wall** are those listed below **-Wall** in Table 3-1.

3.2 g561cg56k Command Line Options

The default options are:

1. use strict ANSI syntax,
2. perform all machine dependent and independent optimizations, and
3. use trigraphs.
4. locate data in the Y data memory space.

-Bdirectory

Add directory to the standard search list and have it searched first. This can also be accomplished by defining the environment variable **G561G56_EXEC_PREFIX.** Note that only **one** additional directory can be specified and that the **-B** option will override the environment variable.

Example 3-1. To test a new version of the ANSI C library, lib561c.clblib56cy.clb, which is installed as **\dsp\new**\lib561c.clblib56cy.clb use:

```
C:\> g561cg56k -B\dsp\new\ file.c -o file.cld
```

Example 3-2. Using the G561G56_EXEC_PREFIX environment variable to have the same effect as Example 3.1, include in the autoexec.bat file:

```
set G561G56_EXEC_PREFIX=C:\DSP\NEW\
```

and then execute:

```
C:\> g561cg56k file.c -o file.cld
```

Example 3-3. To test a new version of the DSP56100DSP56000/1 C preprocessor before permanent installation, install a new **mcpp** program as **c:\tmp\new\mcpp** and then execute:

```
C:\> g561cg56k -Bc:\tmp\new\ testfile.c
```

-**b**PREFIX

Direct **g561cg56k** to search for compilation phases, start-up files and libraries whose names are prefixed with the word PREFIX. Note that only **one** additional prefix can be specified. This is very similar to the **-B** option.

Example 3-4. Test a new version of the ANSI C library, lib56cy.clb, installed as c:\dsp\lib**\new-lib561c.clblib56cy.clb.**

```
C:\> g561cg56k -bnew- file.c -o file.cld
```

Example 3-5. Test a new version of the DSP561CCCDSP56KCC preprocessor before permanent installation.

install the new **mcpp** program as **c:\dsp\bin\new-mcpp** and

```
C:\> g561cg56k -bnew- testfile.c
```

-o FILE

Select FILE as the output file. This applies to all phases of the compiler. When the **-o** flag is not in use, the following file names are used by the compiler as the default output file names depending upon the compile options as follows:

-E (preprocess only)	stdout
-S (compile only)	foo.asm
-c (no linkage)	foo.cln
complete process	a.cld

where stdout is “standard output” and prints to the console.

Example 3-6. Only generate a preprocessed file (do not invoke the compiler, assembler or linker) and put the results in file.i.

```
C:\> g561cg56k -E file.c -o file.i
```

Example 3-7. Compile **file.c** and generate the executable output file, **fft.cld**. If an output name is not given, the default file name is **a.cld.**

```
C:\> g561cg56k file.c -o fft.cld
```

-v

Verbose mode. The compiler control program announces to **stderr** all commands that it attempts to execute for each phase of the compilation process. This command is also used by the preprocessor to print the software version information. If the **-E** option is selected, **-v** will only enable the verbose mode, otherwise it will enable the verbose mode and print the version information.

3.2.1 Preprocessor Phase Options

The options listed below control the C preprocessor, which is run on each C source file before actual compilation. Some options described only make sense when used in combination with the **-E** option (preprocess only), as the requested preprocessor output may be unsuitable for actual compilation. The default option is to use ANSI C syntax. For example, if the **-IDIR** option is not specified then ANSI specifies that the current working directory will be searched first for user defined **include** files.

-C

Tell the preprocessor **not** to discard comments. This option is only valid when used in conjunction with the **-E** option.

Example 3-8. This example preprocesses a simple program, foo.c, without discarding comments.

```
C:\> type foo.c
/*
 * This COMMENT won't be deleted.
 */
main()
{
   printf("Hello, DSP56156DSP56000\n");
}

C:\> g561cg56k -E -C foo.c
# 1 "foo.c"
/*
 * This COMMENT won't be deleted.
 */
main()
{
   printf("Hello, DSP56156DSP56000\n");
}
```

-DMACRO

Define the preprocessor macro MACRO with a constant value of **1**. This is equivalent to making MACRO a constant set to one.

Example 3-9. Compile and run a simple program, dsp.c, and enable or disable a printed message depending on the macro definition given at the command line.

```
C:\> type dsp.c
   #include <stdio.h>
   main()
   {
   #ifdef DSP56156DSP56000
     printf("message: DSP56156DSP56000.\n");
   #else
     printf("message: DSP56166DSP56001.\n");
   #endif
   }

C:\> g561cg56k -DDSP56156DSP56000 dsp.c
C:\> dir
   a.cld  dsp.c

C:\> run561run56 a.cld
   message: DSP56156DSP56000.

C:\> g561cg56k dsp.c
C:\> ls
   a.cld  dsp.c
C:\> run561run56 a.cld
   message: DSP56166DSP56001.
```

-DMACRO=DEFN

Define preprocessor macro MACRO as DEFN.

Example 3-10. The program dsp.c uses the macro FROM_COMMAND_LINE which prints a message to the standard output using a message code given on the command line.

```
C:\> type dsp.c
#include <stdio.h>
main()
{
  printf("message code: %d.\n", FROM_COMMAND_LINE);
}

C:\> g561cg56k -DFROM_COMMAND_LINE=15656000
dsp.c
C:\> dir
a.cld  dsp.c

C:\> run561run56 a.cld
message code: 15656000.
```

-E

The input source file will only be preprocessed through **mcpp** and the output results will be sent to the standard output. See the **-o** option to save the output into a named file.

Example 3-11. This example shows how to preprocess the C source program foo.c and send the results to the standard output.

```
C:\> type foo.c
#define DELAY 1000
main()
{
  int cnt = DELAY;
  while(cnt--);
}
C:\> g561cg56k -E foo.c
# 1 "foo.c"

main()
{
  int cnt = 1000 ;
  while(cnt--);
}
```

Example 3-12. The mcpp output can be saved into file "foo.i" by using the **-o** option.

```
C:\> type foo.c
   #define DELAY 1000
   main()
   {
     int cnt = DELAY;
     while(cnt--);
   }

C:\> g561cg56k -E foo.c -o foo.i
C:\> dir
   foo.c  foo.i

C:\> type foo.i
   # 1 "foo.c"

   main()
   {
     int cnt = 1000 ;
     while(cnt--);
   }
```

-IDIR

The control line of the C source program of the form

#include <filename>

will cause the replacement of that line by the entire contents of the file filename. This is normally referred to as **file inclusion**. The named file is searched for in a sequence of implementation-dependent directories. The standard include directory for this compiler is /usr/local/dsp/include on UNIX systems, and c:\dsp\include on MS-DOS systems. Similarly, a control line of the form

#include “filename”

searches first in the current working directory, and if that fails, then searches as if the control line were #include <filename>.

The option **-I**DIR directs the C compiler to include the directory DIR in addition to the standard include directory. For the file inclusion <filename>, the compiler searches first in the DIR directory and if that fails, then searches /usr/local/dsp/include or c:\dsp\include. For the file inclusion “filename”, the compiler searches first in the DIR directory and if that fails, then searches the current working directory, and if that fails also, then searches /usr/local/dsp/include or c:\dsp\include.

Example 3-13. A delay program foo.c uses delay constant DELAY which is defined in the include file, myinclude.h. The program uses the control line #include “myinclude.h” to include the definition of the constant DELAY. Without any option, the include file should be located in the current working directory since it is not in the standard include directory. Assuming that the include file “myinclude.h” is desired to be in the directory .\inc, the following sequence of the commands explains how the -I option is used to include the file myinclude.h in the ./inc directory with the control line #include “myinclude.h” in the foo.c program.

```
C:\> dir
   foo.c  inc/

C:\> dir inc
   myinclude.h

C:\> type foo.c
```

```
#include "myinc.h" /* this is the control line to include it */
main()
{
  int cnt;
  cnt = DELAY;
  while(cnt--);
}
```

```
C:\> type inc\myinc.h
#define DELAY   100

C:\> g561cg56k -I.\inc foo.c
C:\> dir
a.cld  foo.c  inc/
```

-I-

This option is always used in conjunction with the **-I**DIR option and limits the file search to look for file inclusions #**include "filename"**, whereas -IDIR alone directs C compiler to search the directory DIR for both file inclusion <filename> and "filename". Any directories specified with **-I** options before the **-I-** option are searched only for the case of #**include "filename"**; they are not searched for **#include <filename>**.

If additional directories are specified with **-I** options after the **-I-** option, these directories are searched for both #**include "filename"** and **#include <filename>** directives.

As an example, the sequence of the options

-IDIRA -I- -IDIRB

directs C compiler to use both the directories DIRA and DIRB for the file inclusion "filename" and DIRB only for file inclusion <filename>.

NOTE

The **-I-** option inhibits the use of the current directory as the first search directory for **#include "filename"**. There is no way to override this effect of **-I-**. However, the directory which is current when the compiler is invoked can be searched by using **-I**. This is different from the preprocessor's default search list, but it is often satisfactory. **-I-** does not inhibit the use of the standard system directories for header files. Thus, **-I-** and **-nostdinc** are independent.

Example 3-14. A test program file.c is used to test a file operation fopen() which is, in this example, desired to be developed for a DSP56100DSP56000/1 system. The file include <stdio.h> is used as if it is in the standard include directory. The file is desired to be developed or debugged, and it is located in the user working directory .\mysys. This example shows how to use -IDIR and -I- combination to test file inclusion <filename>. Notice that the **-I./inc -I- -I./mysys** option specifies the inc directory only for the file inclusion “cnt.h” and mysys directory for the file inclusion <stdio.h>.

```
C:\> dir
    file.c      inc/        mysys/

C:\> dir inc
    cnt.h

C:\> dir mysys
    stdio.h

C:\> type file.c
    #include <stdio.h>
    #include “cnt.h”
    main()
    {
        int delay = COUNT;
        FILE *fp;
        fp = fopen(“myfile”, “w”);
        while(--delay);
    }
C:\> type inc\cnt.h
    #define COUNT  25

C:\> type mysys\stdio.h
typedef    struct       FILE { /* FILE data structure to develop */
    char       name[10];
    char       buffer[1024];
 }  FILE;
 FILE *fopen(char *, char *); /* new function to develop */

C:\> g561cg56k -I.\inc -I- -I.\mysys -E file.c
#   1   ”file.c”
#   1   ”.\mysys\stdio.h”      1
typedef    struct       FILE {
    char       name[10];
    char       buffer[1024];
```

```
}   FILE;
FILE*fopen(char*,char*);
#   1   ”file.c”    2
#   1   ”.\inc\cnt.h”       1
#   2   ”file.c”    2

main()
{
    int delay = 25;
    FILE *fp;
    fp = fopen (“myfile”, ”w”);
    while (--delay);
}
```

Notice that the file inclusion “cnt.h” is from the directory ./inc as shown in the line # 1 “.\inc\cnt.h” 1 and the file inclusion <stdio.h> is from the directory .\myinc as shown in the line # 1 “.\myinc\stdio.h” 1.

-i FILE

Process FILE as an input, discarding the resulting output, before processing the regular input file. Because the output generated from FILE is discarded, the only effect of **-i** FILE is to make the macros defined in FILE available for use in the main input.

Example 3-15. The program greeting.c prints a simple message using the macro MESSAGE. The file macros.c contains the macro definition, i.e. the actual message. The only role of the file macros.c is to provide the macro definitions and will not affect any other code or data segments.

```
C:\> dir
    macros.c   greeting.c

C:\> type macros.c
    #define  MESSAGE   "Hello, world."

C:\> type greeting.c
    #include <stdio.h>
    main()
    {
      printf("Greeting: %s\n", MESSAGE);
    }

C:\> g561cg56k -i macros.c greeting.c
C:\> run561run56 a.cld
```

Greeting: Hello, world.

-M

Cause the preprocessor to output the makefile rules to describe the dependencies of each source file. For each source file, the preprocessor outputs one make-rule whose target is the object file name for that source file and whose dependencies are all the files needed to generate the object target file. This rule may be a single line or may be continued with '\'-newline if it is long. **-M** implies **-E** with makefile rules.

Example 3-16. The program big.c, which prints the larger of two integers, uses the macro greater(x,y) which is defined in the file greater.h. A command line output using the **-M** option can be used for makefile utilities. For more information on how to use this dependency check the make utility information in any UNIX utility manual.

```
C:\> dir
    big.c      greater.h

C:\> type big.c
    #include <stdio.h>
    #include "greater.h"
    main()
    {
      printf("big:%d\n", greater(10,20));
    }

C:\> type greater.h
    #define   greater(x,y)   ((x)>(y)?(x):(y))
C:\> g561cg56k -M big.c
    big.o : big.c \dsp\include\stdio.h     \dsp\include\ioprim.h  \dsp\in-
clude\stdarg.h greater.h
```

-MM

Like **-M** but the output mentions only the header files described in the **#include "FILE"** directive. System header files included with **#include <FILE>** are omitted. **-MM** implies **-E** with makefile rules.

Example 3-17. The program big.c, which prints the larger of two integers, uses the macro greater(x,y) defined in the file greater.h. The **-MM** option is used to generate a makefile rule. Notice that the rule that generates an output file appended by ".o" can be modified to generate ".cld" which is required for the Motorola Cross C Compiler.

```
C:\> dir
   big.c     greater.h

C:\> type big.c
   #include <stdio.h>
   #include "greater.h"
   main()
   {
     printf("big:%d\n", greater(10,20));
   }

C:\> type greater.h
   #define   greater(x,y)   ((x)>(y)?(x):(y))

C:\> g561cg56k -MM big.c
   big.o : big.c greater.h

C:\> dir
   big.c     greater.h  makefile   text

C:\> type makefile
   a.cld : big.o
         g561cg56k big.o
   big.o : big.c greater.h
         g561cg56k -c -o big.o big.c
C:\> make
   g561cg56k -c -o big.o big.c
   g561cg56k big.o

C:\> run561run56 a.cld
   big:20
```

-nostdinc

Do not search the standard system directories for file inclusions. Only the directories specified with **-I** options (and the current directory, if appropriate) are searched.

Using both **-nostdinc** and **-I-** options, all directories from the search path except those specified can be eliminated.

Example 3-18. A test program, test.c, is used to test a new version of the function printf() which is declared in a new header file inc\stdio.h. The directive #include <stdio.h> causes the program to use stdio.h; however, it would normally find it in the standard search directory, c:\ds\include or /usr/local/dsp/include. Using the -nostdinc option prevents the standard search directory from being searched and allows the **-I** option to point to the correct directory.

```
C:\> dir
   inc/    test.c

C:\> dir inc
   stdio.h

C:\> type test.c
   #include <stdio.h>
   main()
   {
     printf("Hello, there.\n");
   }

C:\> type inc\stdio.h
   void printf(char *);

C:\> g561cg56k -nostdinc -I.\inc -E test.c
   # 1 "test.c"
   # 1 ".\inc\stdio.h" 1
   void printf(char *);
   # 1 "test.c" 2

   main()
   {
     printf("Hello, there.\n");
   }
```

-pedantic

The **-pedantic** option is used by both the preprocessor and the compiler (see **-pedantic** in the Compile Phase Options section for an explanation of this option).

-v

Output preprocessor version information. The primary purpose of this command is to display the software version. This information is needed when calling the Motorola DSP helpline for assistance (see Appendix D — Additional Support for the helpline phone number). Although information pertaining to the internal flags and switch settings is included in this information, it is not intended for use by the pro-

grammer and may be misleading. This command is also used by the command program to initiate the verbose mode of operation.

Example 3-19. The -v option is selected using the control program **g561cg56k.** The version numbers for **g561cg56k**, **mcpp** and **g561g56-cc1** are printed. This information is showing the commands that the control program invokes along with the selected options. In this case it is showing the default options plus the **-v** option. However, **the user should not** invoke these programs independently but should **always use the control program** to invoke them.

```
C:\> dir
    foo.c

C:\> g561cg56k -v foo.c
    g561cg56k version Motorola Version: g1.11 -- GNU 1.37.1
     c:\dsp\bin\mcpp -v -undef -D__Y_MEMORY -trigraphs -$ -
        D__STRICT_ANSI__ -D__DSP561C__D__DSP56K__ -D__OPTIMIZE__
        foo.c cca00527.cpp

    GNU CPP version 1.37.1
      c:\dsp\bin\g561-cc1g56-cc1 cca00527.cpp -ansi -fstrength-reduce -quiet
        -dumpbase foo.c -O -version -o cca00527.asm

    GNU C version 1.37.1 Motorola DSP56100DSP56000/1 Motorola Version:
        g1.11 compiled by GNU C version 1.37.1.

    default target switches: -mdsp -mlinv-plus-biv-promotion -mdo-loop-genera
        tion -my-memory -mcall-overhead-reduction -mrep -mreload-cleanup
        -mnormalization-reduction

     c:\dsp\bin\asm56100asm56000 -c -B foo.cln -- cca00527.asm

    c:\dsp\bin\dsplnk -c -B a.cld --c:\dsp\lib\crt0561.clncrt056y.cln foo.cln -L
        c:\dsp\lib\lib561c.clblib56cy.clb

C:\> dir
    a.cld  foo.c
```

-UMACRO

Undefine macro MACRO.

Example 3-20. An application program, test.c, is being tested and some portions of the code need to be debugged. The flag DEBUG may be turned on or off through the command line with the **-D** and **-U** options respectively. This flag can then be used inside the program to enable/disable debugging features within the program.

```
C:\> dir
    debug.c

C:\> type debug.c
    #include <stdio.h>
    main()
    {
    #ifdef DEBUG
      printf("debug: a message.\n");
    #endif
      printf("normal operation.\n");
    }

C:\> g561cg56k -UDEBUG debug.c
C:\> run561run56 a.cld
    normal operation.
```

-Wcomment

Warn the user whenever the comment start sequence **/*** appears within a comment.

Example 3-21. A comment is enclosed with /* and */ and therefore is ignored by the preprocessor. Any number of leading /*'s are permitted within the comment and will not be reported; however, a warning message can be enabled by using the -Wcomment option.

```
C:\> dir
    foo.c

C:\> type foo.c
    /* foo.c */
    main() { /* begin */
      int d = 1000;  /* /* delay */
      while(d--);   /* /* main /* loop */
    }  /* end */

C:\> g561cg56k -Wcomment foo.c
    foo.c:3: warning: '/*' within comment
    foo.c:4: warning: '/*' within comment
```

```
foo.c:4: warning: '/*' within comment
C:\> g561cg56k foo.c
```

-Wtrigraphs

Warn if any trigraphs are encountered (Trigraphs are sequences of three characters which are replaced by a single character. These trigraph sequences enable the input of characters that are not defined in the Invariant Code Set as described in ISO 646:1983, which is a subset of the seven-bit ASCII code set.).

3.2.2 Compile Phase Options

The default options are:

1. perform all machine dependent and independent optimizations,
2. do not run the assembly language optimizer (**alo561alo56**), and
3. do not generate debugging information.

-alo

Run the assembly language optimizer on the assembly language output of **g561-cc1g56-cc1**. This improves the utilization of parallel moves.

-fno-opt

Disable all optimizations.

-fno-peephole

Disable the peephole portion of optimization.

-fno-strength-reduce

Disable the optimizations of loop strength reduction and elimination of iteration variables as well as DSP56100DSP56000/1 specific looping optimizations (**DO** instruction usage, etc.).

-fno-defer-pop

By default, the compiler will try to defer (delay) restoring the stack pointer upon the return of a function call. The purpose of deferring restoration of the stack pointer is to reduce code size and decrease execution time; however, the stack penetration may increase (see the DSP56100DSP56000 Family Manual for information on stack overflow).

Examples of function calls that will **not** incur deferred pops whether or not the **-f**no-defer-pop option is specified are:

- calls as function arguments
- calls in conditional expressions

- calls inside a statement expression

-fforce-addr

Force memory address constants to be copied into registers before doing arithmetic on them. The code generated with this option may be better or it may be worse depending on the source code**.** This option forces memory addresses into registers which, in turn, may be handled as common sub-expressions.

-finline-functions

Attempt to insert all simple functions in-line into their callers. The compiler heuristically decides which functions are simple enough to merit this form of integration.

If all calls to a given function are inserted, and the function is declared **static**, then the function is no longer needed as a separate function and normally is not output as a separate function in assembly code.

-fcaller-saves

Enable values to be allocated in registers that will be overwritten by function calls by emitting extra instructions to save and restore the registers around such calls. Such allocation is done only when it seems to result in better code than would otherwise be produced.

-fkeep-inline-functions

Output a separate run-time callable version of the function even if all calls to a given function are integrated and the function is declared **static**.

-fwritable-strings

Store string constants in the writable data segment without making them unique. This is for compatibility with old programs which assume they can write into string constants. Writing into string constants is poor technique; constants should be constant.

-fcond-mismatch

Allow conditional expressions with mismatched types in the second and third arguments. The value of such an expression is void.

-fvolatile

Consider all memory references through pointers to be volatile.

-ffixed-REG

Treat the register named REG as a fixed register; generated code should never refer to it (except perhaps as a stack or frame pointer). Legal values for REG are:

r0, r1, **r3r1**, **r2**, **r3**, **r4**, **r5**, **r7**

This flag should be used sparingly as it can have devastating results on the code generated.

Example 3-22. Reserve **r0r4** for later special purpose.

```
C:\> g561cg56k -O -ffixed-r0r4 file.c -o file.cld
```

Caution

C code that utilizes library code can produces non-deterministic results, as the libraries have been written to utilize the complete set of registers.

-g

Produce COFF debugging information for **gdb561gdb56**, the GDB cross debugger for the DSP56100DSP56000/1.

A key feature afforded by the use of the GNU C compiler (**g561cg56k**) teamed with the GNU source level debugger (**gdb561gdb56**) is that the programmer is allowed to generate optimized code with debug information (**select options -g -O**) making it possible for the programmer to debug optimized code directly. Due to the optimizations performed, it is possible that variables will not be defined (unused variable elimination), statements may not be executed (dead code elimination), and code may be executed early (code motion). This is a partial list of the oddities that may be encountered when debugging optimized code. However, the improved code performance due to optimization normally out weighs the problems encountered.

Example 3-23. The program foo.c has a bug. In this application the line i *= 2 should be i += 2. In order to use the symbolic debugger, **gdb561gdb56**, to locate this problem, the -g option is used when foo.c is compiled. This causes the compiler to generate additional information used by the debugger.

```
C:\> ls
   foo.c

C:\> type foo.c
   main()
   {
     int i = 100;
     i *= 2;
   }

C:\> g561cg56k -g foo.c
C:\> dir
   a.cld  foo.c
C:\> gdb561gdb56 a.cld
```

-O

Perform machine dependent and independent optimizations. This is the **default** mode of the compiler.

Invoking the compiler with the optimizer may cause compile times to increase and require more system memory.

Invoking the compiler without the optimizer should be done only when the programmer requires additional flexibility while debugging code. An example of such flexibility includes the ability to assign new values to declared c variables. Additionally, non-optimized code takes register usage clues from the storage class specifier **register**, something not done with the optimizer invoked.

Disabling the optimizer is done via **-f** options listed above.

-m56002

Enables the generation of DSP56002 instructions.

-mno-dsp-optimization

Disables all Motorola optimizer enhancements.

-mno-do-loop-generation

Disable **DO** instruction usage by optimizer.

-mno-biv-plus-linv-promotion

Disable the promotion of address expressions to address registers within loops. This optimization transforms array base address plus induction variable expressions into auto-increment/decrement style memory references.

-mp-mem-switchtable

Forces the compiler to locate all switch tables in P memory.

-mstack-check

Generate extra run-time code to check for run-time stack collision with the heap. This option causes run-time execution times to increase dramatically.

Example 3-24. An application is programmed to utilize only the DSP56001 X data memory space and therefore must be compiled using the -mx-memory option.

```
C:\> ls
   x.c
```

```
C:\> type x.c
   void function(int a, int b);
   int X;
   main()
   {
     int arg1,arg2;
     function(arg1, arg2);
   }
   void function(int a, int b)
   {
     X = a + b;
   }

C:\> g56k -S -mx-memory x.c
C:\> dir
   x.asm x.c
```

-my-memory

Direct the compiler to locate data in the Y data memory space. This is the **default** memory mode. Memory modes cannot be mixed, i.e. **only one** of **-m**x-memory, **-m**y-memory or **-m**l-memory **may be selected**.

-ml-memory

Direct the compiler to locate data in the L data memory space. This has 2 side effects.

1. A performance increase for 48-bit data code (**long, float, and double**).
2. This requires that the X and Y memory spaces be evenly populated.

Memory modes cannot be mixed, i.e. **only one** of **-m**x-memory, **-m**y-memory or **-m**l-memory **may be selected**.

-mx-memory

Direct the compiler to locate data in the X data memory space. Memory modes cannot be mixed, i.e. only one of **-m**x-memory, **-m**y-memory or **-m**l-memory may be selected.

-pedantic

Issue all the warnings demanded by strict ANSI standard C; **reject** all programs that use forbidden extensions.

Without this option, certain GNU extensions and traditional C features are supported. **With** this option, they are rejected. **Valid ANSI standard C programs** will compile properly **with or without** this option.

-pedantic does not cause warning messages for use of the alternate keywords whose names begin and end with "_ _".

-Q

Direct the compiler to execute in verbose mode.

-S

Compile to DSP56100DSP56000/1 assembly code with the original C source lines as comments but do not assemble. The assembly language output is placed into a file suffixed **.asm**.

Example 3-25. Generate an optimized assembly language file (test.asm) of the C source program (test.c).

```
C:\> dir
   test.c

C:\> type test.c
   #include <stdio.h>
   main()
   {
     int i = 100;
     printf("value:%d\n", i++);
   }

C:\> g561cg56k -S test.c
C:\> dir
   test.asm  test.c
```

Example 3-26. Generate an optimized assembly language file test.asm.

```
C:\> g561cg56k -O -S test.c
```

-w

Inhibit all warning messages.

-W

Print **extra** warning messages for the following events:

- An automatic variable is used without first being initialized.

  This warning is possible only when the **optimizer** is invoked during compilation (default). The optimizer generates the data flow information required for reporting.

This warning **will only occur** for variables that are candidates for register promotion. Therefore, they **do not occur** for a variable that is declared **volatile**, whose address is taken, or whose size is other than 1 or 2 words (integral and float data types). Warnings **will not** occur for structures, unions or arrays, even when they are in registers.

There may be no warning about a variable that is used only to compute a value that is never used because such computations may be deleted by data flow analysis before the warnings are printed.

Spurious warnings may be avoided by declaring functions that do not return as **volatile**.

- A nonvolatile automatic variable may be changed by a call to **longjmp**.

  This warning also requires that the optimizer be invoked.

  The compiler sees only the calls to **setjmp**. It cannot know where **longjmp** will be called; in fact, a signal handler could call it at any point in the code. As a result, a warning may be issued even when there is no problem because **longjmp** cannot be called at the place which would cause a problem.

  A function can return either with or without a value. (Falling off the end of the function body is considered returning without a value.) For example, this function would evoke such a warning:

```
foo (a)
{
    if (a > 0)
        return a;
}
```

  Spurious warnings can occur because GNU CC does not realize that certain functions (including ‘abort’ and ‘longjmp’) will never return.

- An expression-statement contains no side effects.

Example 3-27. Extra warning messages are wanted to help find potential problems in a test function, foo(), which is programmed to return a value only if a > 0.

```
C:\> dir
    foo.c

C:\> type foo.c
    int foo(int);
    main()
    {
```

```
    int i;
    foo(i);
}
int foo(a)
{
    if(a > 0)
        return a;
}
```

```
C:\> g561cg56k -W foo.c
```
foo.c: In function main:
foo.c:4: warning: ‘i’ may be used uninitialized in this function
foo.c: In function foo:
foo.c:11: warning: this function may return with or without a value

-Wimplicit

Warn whenever a function is implicitly declared.

Example 3-28. The function foo() is declared implicitly in the program foo.c, the -Wimplicit option will generate a warning message for this situation.

```
C:\> dir
```
foo.c

```
C:\> type foo.c
```
```
main()
{
    foo();
}
int foo(){}
```
```
C:\> g561cg56k -Wimplicit foo.c
```
foo.c: In function main:
foo.c:3: warning: implicit declaration of function ‘foo’
```
C:\> dir
```
a.cld foo.c

-Wreturn-type

Warn whenever a function is defined with a return-type that defaults to **int**. Also warn about any **return** statement with no return-value in a function whose return-type is not **void**.

Example 3-29. The function foo() is declared as a function that should return an integer but in this case does not return an integer. The -Wreturn-type option generates a warning message in this situation.

```
C:\> dir
    foo.c

C:\> type foo.c
    int foo(), main();
    int main()
    {
      return foo();
    }
    int foo(){}

C:\> g561cg56k -Wreturn-type foo.c
    foo.c: In function foo:
    foo.c:6: warning: control reaches end of non-void function

C:\> dir
    a.cld  foo.c
```

-Wunused

Warn whenever a local variable is unused aside from its declaration, whenever a function is declared static but never defined and whenever a statement computes a result that is explicitly not used.

Example 3-30. The file foo.c contains an undefined static function, unused local variable, and a dead statement. The -Wunused option will issue warnings to indicate these situations.

```
C:\> dir
    foo.c

C:\> type foo.c
    static int foo();
    main()
    {
      int x;
      2+3;
    }
C:\> g561cg56k -Wunused foo.c
    foo.c: In function main:
    foo.c:5: warning: statement with no effect
    foo.c:4: warning: unused variable ‘x’
    foo.c: At top level:
```

foo.c:1: warning: ‘foo’ declared but never defined

```
C:\> dir
```
a.cld foo.c

-Wswitch

Warn whenever a **switch** statement has an enumeration type of index and lacks a **case** for one or more of the named codes of that enumeration. (The presence of a **default** label prevents this warning.) **case** labels outside the enumeration range also provoke warnings when this option is used.

-Wall

All of the above **-W** options combined. The remaining **-W** options described below are **not** implied by **-Wall** because certain kinds of useful macros are almost impossible to write without causing those warnings.

-Wshadow

Warn whenever a local variable shadows another local variable.

-Wid-clash-LEN

Warn whenever two distinct identifiers match in the first **LEN** characters. This may help prepare a program that will compile with certain obsolete compilers.

-Wpointer-arith

Warn about anything that depends on the **sizeof** a function type or of **void**. GNU C assigns these types a size of 1, for convenience in calculations with **void *** pointers and pointers to functions.

-Wcast-qual

Warn whenever a pointer is cast so as to remove a type qualifier from the target type. For example, warn if a **const char *** is cast to an ordinary **char ***.

-Wwrite-strings

Give string constants the type **const char[**LENGTH**]** so that copying the address of one into a non-**const char *** pointer will generate a warning. These warnings help at compile time to find code that can try to write into a string constant, but only if **const** in declarations and prototypes have been used carefully.

3.2.3 Assemble Phase Options

This group of assemble phase options is the sub-set of the available assembler options that are compiler oriented (see the Motorola DSP56100DSP56000 Macro Assembler

Reference Manual for a complete option list). The **default option** is to add to the standard search list the directory that the C compiler writes its output into and then search that directory first.

-asm string

Pass the argument string directly to **asm56100asm56000**, the DSP56100DSP56000/1 assembler.

Example 3-31. Pass a single command line option to the assembler.

```
C:\> g561cg56k -asm -v file.c
```

Example 3-32. Pass multiple options to the assembler.

```
C:\> g561cg56k -asm “-v -OS,CRE” file.c
```

-c

Compile and/or assemble the source files, suppressing the link phase. This option generates corresponding output files suffixed **“.cln”**. Affected input files are suffixed with **“.c”** and **“.asm”**.

3.2.4 Link Phase Options

The options listed below control the link phase of the compilation process. This group of link phase options is the sub-set of the available linker options that are compiler oriented (see the Motorola DSP56100DSP56000 Linker/Librarian Reference Manual for a complete option list). The **-crt** and **-l** options locate the file provided as an argument by searching a standard list of directories. See Section 3.1 for this directory list. The default option is to add the C compiler output directory into the standard search list and search that directory first.

-crt file

Replace the default start-up file (**crt0561.clncrt056y.cln**) with file. **g561cg56k** searches the standard list of directories to find the start-up file. In addition, any directory defined using the **-B** option or the **G561G56_EXEC_PREFIX** environment variable will be searched. For additional information, see Chapter 6.

Example 3-33. Compile the C program foo.c with the crt0 file crt.asm. Notice that the crt0 file crt.asm should be assembled before use since the option -crt takes .cln file not .asm file.

```
C:\> dir
  crt.asm    foo.c
```

```
C:\> g561cg56k -c crt.asm
C:\> dir
  crt.cln     crt.asm     foo.c
C:\> g561cg56k -crt crt.cln foo.c
```

-j string

Pass the argument string directly to **dsplnk**, the DSP56100DSP56000/1 linker.

Example 3-34. Pass a single option to the linker.

```
C:\> g561cg56k -j -v file.c
```

Example 3-35. Pass multiple options to the linker.

```
C:\> g561cg56k -j “-v -i” file.c
```

-lLIBRARY

Search the standard list of directories for a library file named **libLIBRARY.clb**. The linker automatically expands LIBRARY from the option command into **libLIBRARY.clb** and uses this file as if it had been specified precisely by name.

Example 3-36. Compile the source code using the special dsp application library. Searching the standard list of directories for a library named **libdspaps.clb.**

```
C:\> g561cg56k -O file.c -ldspaps
```

-r CTLFILE

Search the standard list of directories for the memory control file CTLFILE to be passed as an argument to the DSP56100DSP56000/1 relocatable linker. This control file will be used as a table to locate object files sections to be linked. For more detailed information, see the **-R** options and the section on “Memory Control File” in the Motorola Linker/Librarian Reference Manual.

Example 3-37. Compile the source code main.c and data.c with the memory configuration described in the control file map.ctl. Notice that the section main_c of the program main.c is located at the memory address p:$3000 and the section of data_c of the data data.c is located at the memory address x:$5000. See chapter 5 for detailed information on the in-line assembly code (_ _ asm(...)).

```
C:\> type map.ctl
 section        main_c      p:$3000
```

```
section     data_c     xy:$5000
```

```
C:\> type data.c
int data = 0x1; /* test value */
```

```
C:\> type main.c
extern int data;
main()
{
    int i;
    for(i = 0; i < 10; i++)
        _ _asm("rol %0" : "=D" (data) : "0" (data));
}
```

```
C:\> g561cg56k -j "-mmap.map" -r map.ctl main.c data.c
```

```
C:\> type map.map
...
XY Memory
Start       End       Length       Section
5000        5000      1            data_c
...
P Memory
Start       End       Length       Section
3000        3008      9            main_c
...
```

Chapter 4
About g561c

4.1 Introduction

The DSP56100 digital signal processors are designed to execute DSP oriented calculations as fast as possible. As a by-product, they have an architecture that is somewhat unconventional for C programming. Because of this architecture, there are characteristics of the compiler, and the code generated by the compiler, that the programmer must understand in order to take full advantage of the DSP561CCC programming environment. All programmers, whether they are familiar with DSP or not, should understand the DSP56100 architecture before attempting to program it in C. The following sections provide important information on data types, storage classes, memory and register usage, and other topics which will be useful to the DSP56100 application developer programming in C.

4.2 Identifiers

An identifier is defined as a sequence of letters, digits and underscore characters ('_'). The first character must be a letter or underscore. DSP561CCC identifier length limits are listed in Table 4-1.

Table 4-1 Identifier Length Limits

Identifier Storage Class	Length
Global/Static (External Linkage)	255
Auto	unlimited

4.3 Predefined Preprocessor Macro Names

DSP561CCC supports and expands all ANSI defined macros and three additional non-ANSI predefined macro names. Table 4-2 lists the macros and their explanation.

4.4 Data Types and Sizes

Due to the word orientation of the DSP56100 family (16-bit words), all data types are

aligned on word boundaries. This has several side effects, one of which is that **sizeof(char)** is equal to **sizeof(int)**.

Table 4-2 Predefined Macro List and Explanation

MACRO	ANSI Required?	Explanation
_ _LINE_ _	YES	The line number of the current source line (a decimal constant).
_ _FILE_ _	YES	The name of the source file (a character string).
_ _DATE_ _	YES	The compilation date (a character string of the form “Mmm dd yyyy” e.g., Jul 22 1991).
_ _TIME_ _	YES	The compilation time (a character string of the form “hh:mm:ss”).
_ _STDC_ _	YES	Decimal constant 1, indicates ANSI conformation.
_ _DSP561C_ _	NO	Decimal constant 1, indicates that code is being generated for the DSP56100 Digital Signal Processor family.
_ _VERSION_ _	NO	The GNU version number of the compiler (a character string of the form “d.dd.d”).
_ _INCLUDE_LEVEL_ _	NO	Decimal constant, indicates the current depth of file inclusion.

4.4.1 Integral Data Types

The type **char**, **short int**, **int**, **long int** and the enumerated types comprise the integral data types. All but the enumerated types are available as unsigned types as well as signed by default. The type sizes and ranges are defined in Table 4-3. Note that **long int**s are stored in memory with the least significant word occupying the memory location with the smaller address.

Table 4-3 Integral Data Type Sizes and Ranges

Data Type	Size (words)	Min value	Max value
char	1	-32768	32767
unsigned char	1	0	0xFFFF
short	1	-32768	32767
unsigned short	1	0	0xFFFF
int	1	-32768	32767
unsigned int	1	0	0xFFFF
long	2	-2147483648	2147483647
unsigned long	2	0	0xFFFFFFFF

4.4.2 Floating-point Types

In DSP561CCC, the C data types **float** and **double** are both implemented as single precision floating point numbers (see Table 4-4). DSP561CCC does partially implement the IEEE STD 754-1985 standard format for binary floating-point arithmetic, except that denormalized numbers and affine numbers are not supported. Exception handling and rounding modes are also unsupported; only the format of exponent, sign, and mantissa are IEEE. A description of the format follows. Note that both **float** and **double** are stored in memory with the most significant word (which contains the sign, exponent, and most significant mantissa bits) occupying the memory location with the greater address.

Table 4-4 Floating-point Data Type Sizes and Ranges

Data Type	Size (words)	Min value	Max value
float	2	1.175494351e-38	3.402823466e+38
double	2	1.175494351e-38	3.402823466e+38

4.4.2.1 Comparison with IEEE STD 754-1985 Standard

The DSP561CCC floating-point format differs from the IEEE standard primarily in its handling of floating-point exceptions, rounding, and support for affine numbers. If complete conformance to the IEEE standard is desired, the assembly language source of the floating-point code is provided.

The DSP561CCC format does not provide the arithmetic safety offered by the IEEE standard. It avoids extensive error checking and exception handling in favor of execution speed and space efficiency.

The bit format is as follows: a sign bit, followed by eight exponent bits, followed by twenty-three mantissa bits.

Table 4-5 Characteristics of DSP561CCC floating-point.

CHARACTERISTIC	DSP561CCC IMPLEMENTATION
Mantissa Precision	24 bits
Hidden Leading One	Yes
Mantissa Format	23-bit Unsigned Magnitude Fraction
Exponent Width	8 bits
Maximum Exponent	+127
Minimum Exponent	-127
Exponent Bias	+127
Format Width	32 bits
Rounding	Not Specified
Infinity Arithmetic Denormalized Numbers	Not Implemented Not Implemented
Exceptions	Divide by Zero

4.4.3 Pointer Types

With DSP561CC, all pointers are **16-bits** in size (see Table 4-6). When computing addresses with long arithmetic, only the **least significant 16-bits** are relevant.

Table 4-6 Pointer Size and Range

Data Type	Size (words)	Min value	Max value
pointers	1	0	0xFFFF

4.5 Register Usage

The DSP56100 digital signal processor register set is shown in Table 4-7. DSP561CCC uses all of the registers listed in Table 4-7 with the **exception** of the M_n address modifier registers.

Table 4-7 DSP56100 Family Processor Registers

Data ALU		
x_n	-	Input Registers x1, x0 (16-bits)
y_n	-	Input Registers y1, y0 (16-bits)
a_n	-	Accumulator Registers a2 (8-bits), a1, a0 (16-bits)
b_n	-	Accumulator Registers b2 (8-bits), b1, b0 (16-bits)
x	-	Input Register x (x1**:**x0, 32-bits)
y	-	Input Register y (y1**:**y0, 32-bits)
a10	-	Input Register a10 (a1**:**a0, 32-bits)
b10	-	Input Register b10 (b1**:**b0, 32-bits)
a	-	Accumulator a (a2**:**a1**:**a0, 40-bits)
b	-	Accumulator b (b2**:**b1**:**b0, 40-bits)
Address ALU		
r_n	-	Address Registers r0-r3 (16-bits)
n_n	-	Address Offset Registers n0-n3 (16-bits)
m_n	-	Address Modifier Registers m0-m3 (16-bits)

Caution

The **m_n address modifier registers** are not used directly by DSP561CCC. Some of these registers are implied whenever any address registers (r0 - r3) are referenced either in C library or in C. While assembly code can access and use these registers, the programmer **must** restore them to their previous state ($FFFF) before returning control to DSP561CCC. Failing to do so will cause **unpredictable errors** when DSP561CCC accesses these registers. Again, the C compiler assumes that the modifier registers have been initialized for linear addressing.

The programmer is required to preserve any registers that are directly used in in-line and in out-of-line assembly language code (see Chapter 5, Mixing C and Assembly Language). Table 4-8 outlines the compiler's usage of each register.

Table 4-8 DSP561CCC registers and Usage

Register	Usage
r2	Stack Pointer
r0 - r1, r3	Register promotion by the optimizer
n0 - n3	Code generator temporary
m0 - m3	Used by compiler; keep this at $FFFF
a	32-bit function return value. float, double, or long
a1	16-bit return value. Integer or pointer
a2,b2	Sign extension for all types.
b, x, y	32-bit register promotion by optimizer
x1, x0, y1, y0, b1	16-bit register promotion by optimizer

4.6 Memory Usage

The DSP56100 memory can be partitioned in several ways to provide high-speed operation and additional off-chip memory expansion. Program and data memory are separate.

By default, the compiler expects that both memory spaces are fully populated and that several global C variables are defined in the **crt0** file (see Chapter 6 —

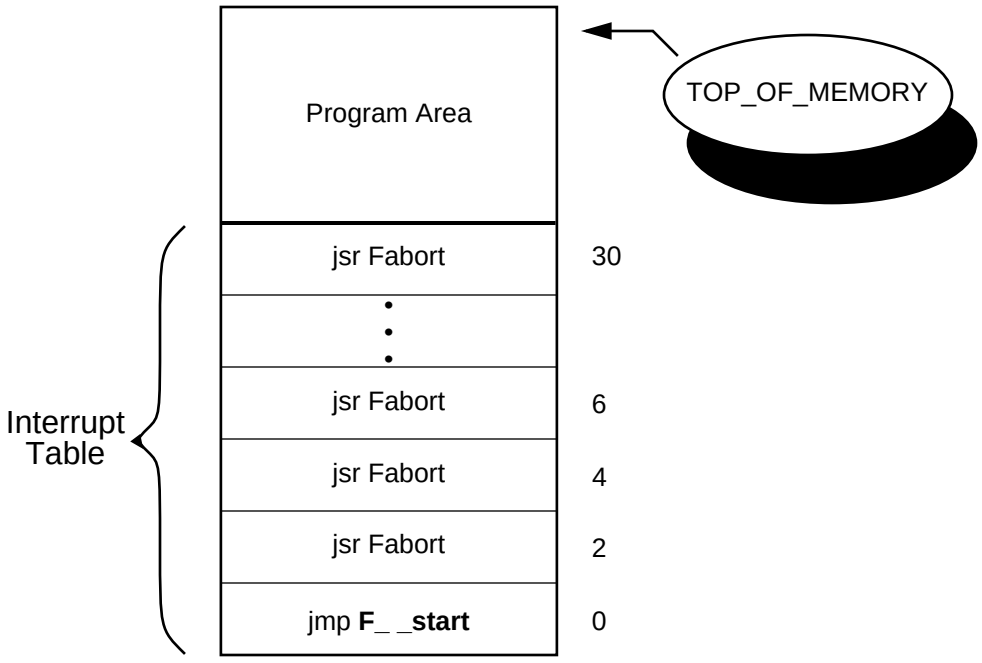


Figure 4-2 Default Program Memory Configuration

Software-Hardware Integration for information about customizing the memory

configuration). Figure 4-2 and Figure 4-4 illustrate the default program and data memory configuration.

4.6.1 Activation Record

An activation record is where a C subroutine stores its local data, saved registers and return address, etc. A typical DSP561CCC activation record consists of the following elements and is illustrated in Figure 4-3:

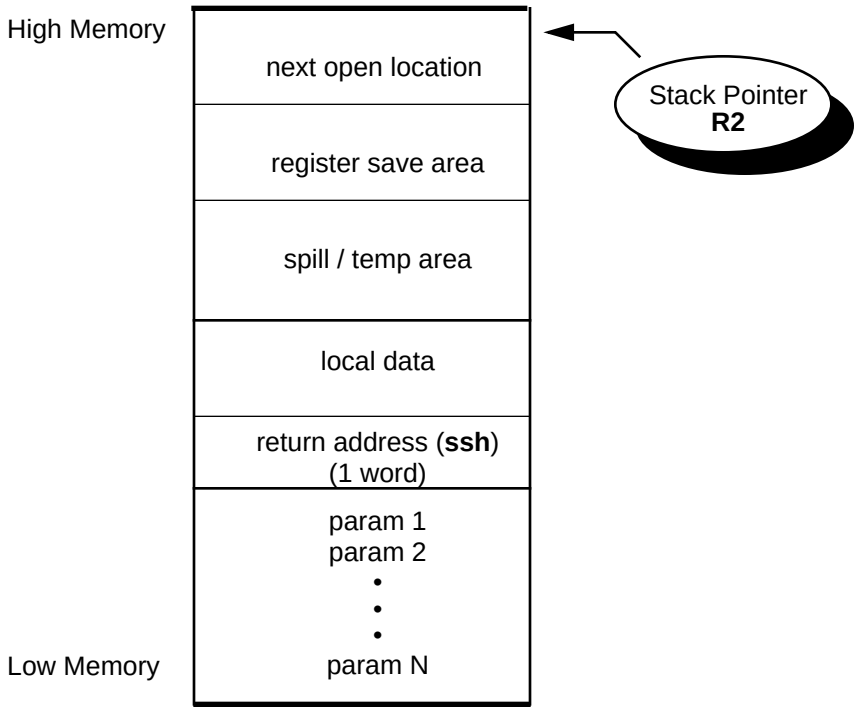


Figure 4-3 Activation Record

1. Parameter data space. Information passed to C subroutines is stored in a parameter data space which is similar to the local data space (see Figure 4-3). However, the data is in reverse order and each parameter is referenced via a negative offset from the frame pointer. Actual parameters are pushed onto the activation record in reverse order by the calling subroutine.
2. Return address — which is pushed on the DSP's system stack high (**ssh**) register. This is the return address to the calling subroutine. The return address is not saved for subroutines that have been determined to be a leaf. A leaf subroutine is one that makes no subroutine calls.
3. Local data space. The location of C variables that have a lifetime that extends only as long as the subroutine is active and that could not be explicitly promoted to **register** storage class by the optimizer.

4. Register spill and compiler temporary space. This area is utilized by the compiler to store intermediate results and preserve registers.

   Note: The Stack Pointer (**r2**) points to the next available data memory location.

Each subroutine called generates a new subroutine activation record on the run-time stack. When it returns, the subroutine removes the activation record. The run-time stack is described in Figure 4-4, Default Data Memory Configuration. The variables in the

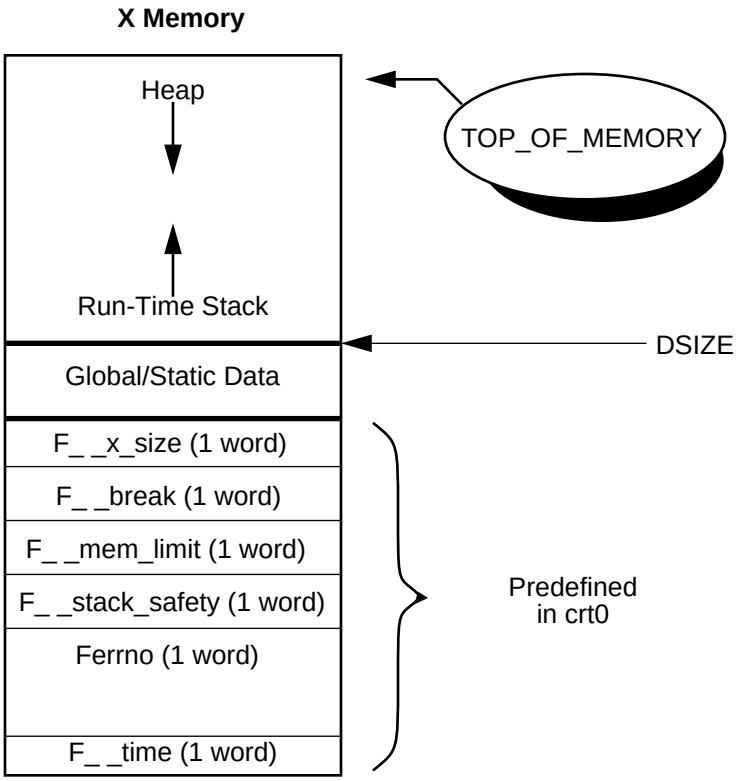
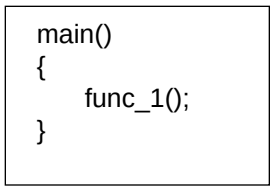


Figure 4-4 Default Data Memory Configuration

“Predefined in crt0” file may be changed or relocated by the user. These variables are needed for the C run-time environment. In general, the linker expects that they will exist somewhere in memory, but it doesn’t really care where. **DSIZE** is set by the linker and points to the top address of the global and static data. **DSIZE** is used in the **crt0** file as the default initial stack pointer.

Dynamic run-time stack growth is illustrated in Figure 4-5. In this example, there is one activation record as execution of the sample C code begins. This activation record is pushed onto the stack and a new activation record is built. When the function returns, the callee and caller work together to clear the callee’s activation record from the stack. The register **r2** is used both as a stack pointer and as a frame pointer; references to local data are made with offsets of **r2**, and **r2** marks the next free location on the run-time stack. This means that a caller’s activation record may be restored by simply restoring



Sample C code

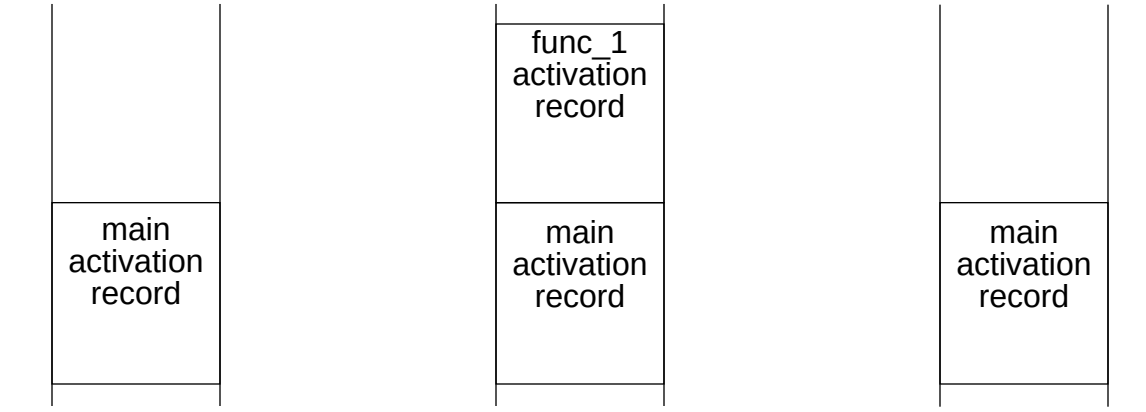


Figure 4-5 Run-time Stack Growth

the value of **r2**.

4.6.2 Global/Static Data

By default, global and static data elements are located **below** the run-time stack and each element is referenced by a unique label that is known at compile-time (see Chapter 6, Software-Hardware Integration for additional information).

4.7 Compiler Naming Conventions

The compiler uses five different internal label formats and a special section naming format. These six separate formats simplify the procedures to combine hand written assembly language and C language statements. Use of these formats also makes compiler generated assembly language listings easier to read. It is **strongly recommended** that the programmer avoid using labels with these formats.

L#	Local labels. Generally the targets of conditional and unconditional jumps. Where # is a decimal digit.
LC#	String Constant labels. The data memory location for C string constants, such as **“**hello world\n**”**.
F<identifier>	Global C variables, global subroutines, static C variables and

	static subroutines. A static C variable or subroutine is one which is not visible to any C code outside the file in which it has been declared, thus making it possible to reuse variable names across file boundaries. Where identifier is the variable or subroutine name.
F_ _<identifier>#	Variables static to a function.
ASM_APP_#	In-line assembly code delimiters. Required to allow the programmer to define and use local labels (labels beginning with an underscore character '_').
<filename_c>	Section names. The contents of each assembly language file generated by the compiler are contained in a unique **section**. Where filename is the file name minus any '**.**' extensions.

4.8 Subroutine Call Sequence

Each time a C language subroutine is called, a strict calling convention is followed. The subroutine calling sequence is broken down into three sub-sequences that are strictly defined. The three sub-sequences are **caller**, **callee** and **return sequence**.

Note: This calling convention must be followed when writing in-line or out-of-line assembly language subroutines that call subroutines written in C.

4.8.1 Caller Sequence

The caller portion of the subroutine calling sequence is responsible for:

1. pushing arguments onto the activation record (in reverse order),
2. actual subroutine call (**jsr**),
3. stack pointer adjustment.

Additional caller sequence when the subroutine called will return a **struct**:

4. allocate space in the caller's activation record to store the return **struct**,
5. pass the return value address in accumulator **a**.

4.8.2 Callee Sequence

During the initial portion of the subroutine calling sequence, the callee is responsible for:

1. saving return address (ssh).
2. updating frame / stack pointer,

Table 4-9 Floating-point Arithmetic

Routine	Source Module
fadd_[xyab][ab]	fadd561.asm
fsub_[xyab][ab]	fsub561.asm
fmpy_[xyab][ab]	fmpy561.asm
fdiv_[xyab][ab]	fdiv561.asm
fcmp_[xyab][ab]	fcmp561.asm

3. saving the following registers, as required, **b1**, **b0**, **x1**, **x0**, **y1**, **y0**, **r0** - **r1** and **r3**.

4.8.3 Return Sequence

During the final portion of the subroutine calling sequence, the callee is responsible for:

1. placing the return value in accumulator **a**.
2. testing the return value. This optimizes the case where function calls are arguments to conditional operators. The return value need not be tested if the function is returning void, or a struct.

Additional callee sequence when the subroutine called will return a **struct**:

3. the return value is not passed in accumulator **a**. A copy of the return **struct** is placed into the space allocated in the caller's activation record and pointed to by accumulator **a**.

4.9 Software Support for Arithmetic Routines

The DSP56100 family provides full hardware support for all 16-bit integer arithmetic operations, and partial support for 32-bit integer operations. Support for all float/double and a portion of the 32-bit long is provided via special software library routines. These special library routines do not pass arguments to the routines according to the normal subroutine calling convention for performance reasons. See Table 4-9 and Table 4-10 for a list of the routines supported in software. All of these routines restore all registers used except for the register that contains the result.

4.10 Run-time Safety

DSP561CCC provides two methods for providing run-time memory utilization checks. The first method, heap memory allocation checking, is automatic. The second method, run-time stack probing, is provided by selecting the command-line argument **-mstack-check**.

Table 4-10 32-bit Long Integer Arithmetic

Routine	Source Module
udiv_[ab][ab]	udm561.asm
umod_[ab][ab]	udm561.asm
ldiv_[xy][ab]	l_div561.asm
lmod_[xy]ab]	l_mod561.asm
uldiv_[xy][ab]	l_div561.asm
ulmod_[xy][ab]	l_mod561.asm

4.10.1 Memory Allocation Checks

Heap memory allocation checks are provided during every call to the run-time library routines **malloc**, **calloc** and **realloc**. These automatic run-time checks determine when the heap is about to collide with the run-time stack. When this occurs, the library routine returns a **NULL** pointer and sets the global variable **errno** to **ENOMEM**.

4.10.2 Run-time Stack Checks

By selecting the **-mstack-check** option on the command-line, the compiler is instructed to generate extra code to watch the stack and heap and detect when the run-time stack is about to collide with the heap. This may be important when writing code for embedded applications.

Note: All run-time libraries provided have been compiled/assembled without the stack checking option. Thus it is possible to have a run-time stack/ heap collision during execution of library routines. The user is free to rebuild the library routines with **-mstack-check** as needed.

4.11 Optimization Techniques Implemented

This section provides a brief overview of the optimization techniques currently included in DSP561CCC. Many machine-independent optimization techniques are used by DSP561CCC, along with some machine-specific optimizations as well. By default, the control program **g561c** enables all levels of optimization (see chapter 3, Compiler Operation, for command-line options to disable all or part of the optimizer) except post-pass instruction scheduling.

4.11.1 Register Promotion and Lifetime Analysis

The compiler automatically identifies all variables that are candidates for promotion to the **register** storage class. Using standard data flow techniques, lifetime analysis is performed to determine the best variables for promotion. When variable lifetimes do not

overlap, more than one variable may be promoted to a single register.

4.11.2 Common Sub-expression Elimination

A **C**ommon **S**ub-**E**xpression, or CSE, is created when two or more statements compute the same value. When CSEs are detected during data flow analysis, the compiler eliminates all but one of the computations and propagates the result. A classic example of a CSE is the array element assignment from another array,

```
array_1[index + 1] = array_2[index + 1];
```

where the expression **index + 1** is the CSE.

This optimization is especially effective when CSEs become candidates for register promotion.

4.11.3 Constant Propagation

Propagation of constants is detected during data flow analysis and is simply the replacement of variable references with constant references when possible. For example,

```
a = 3;
/* block of C code with no references to a */
func_call ( a + 709 );
```

becomes:

```
/* block of C code */
func_call ( 3 + 709 );
```

Constant folding is the replacement of run-time computations with compile-time computations.

4.11.4 Dead Code Elimination

During data flow analysis, the compiler detects when the results of C expressions are never used. When this is detected, the useless C statements are eliminated. This includes both the initialization of variables that are never referenced in the subroutine and back to back assignments.

To guarantee code generation for statements that have hidden effects, a **volatile** type specifier can be used when declaring variables and functions.

```
main()
{
        int volatile i = 0, j = 1;
}
```

The example above generates code to initialize variables i and j even though they are not used anywhere else. Without the key word **volatile**, the optimizing C compiler will eliminate the two local variables because they are not referenced anywhere in the function main.

4.11.5 Tail Merging

When two or more conditional blocks of code have similar ending sequences, the sections of code are rewritten to generate similar code only once.

This is a space saving optimization technique. For example:

```
if ( a > b )
{
      b = a;
      func( a );
}
else
      func( a );
```

may become:

```
if ( a > b )
{
      b = a;
}

func( a );
```

4.11.6 Strength Reduction

Strength reduction replaces expensive operators with less expensive operators. This optimization method can be very machine specific. For instance, a popular strength reduction for many compilers is to replace a multiplication by a constant with a series of shifts, additions and subtractions. The exact opposite is the case on the DSP56100, however since a series of left shifts may be replaced with a single multiply by a constant power of 2.

4.11.7 Loop Invariant Code Motion

Loop Invariant Code Motion is a method in which all C expressions that yield the same result in each iteration of the loop are moved outside of the loop and are executed once prior to entering the loop.

4.11.8 Hardware DO Loop Instruction

The DSP56100 provides a method in hardware to perform zero overhead looping via the **do** instruction. DSP561CCC may exchange the standard increment/compare/conditional jump sequence with a single **do** instruction (this is called do loop promotion) when the

following conditions are met:

1. The body of the loop contains no subroutine calls,
2. The loop is entered from the top, i.e., no **goto label** entries.
3. No conditional exits from the loop are allowed.
4. The loop's induction variable is only altered in the body of the loop once per iteration. Please note that this includes any modifications to the induction variable within the actual **for** or **while** statement.

4.11.9 Loop Rotation

Loop rotation is the elimination of the code generated to check the loop's entry conditions. When a loop fails to qualify for do loop promotion i.e., it does not meet the four conditions listed above, it will qualify for loop rotation if the length of the loop is known at compile-time, for example:

for (**i = 0** ; **i < 10** ; **i ++**)

The loop created with this for statement will always be executed at least one time. Therefore, the "is i < 10?" test does not have to be run the first time through the loop and as a result, can be eliminated during the first pass through the loop only. If the result of the first test cannot be predetermined then it cannot be eliminated. In the example below, the number of loops is a variable (and therefore cannot be predetermined) that may equal zero.

for (**i = 0** ; **i < j** ; **i ++**)

4.11.10 Jump Optimizations

All cases of jumps (conditional and unconditional) to unconditional jumps are eliminated to create a single jump and target label.

4.11.11 Instruction Combination

Instruction combination replaces several operators with a single, less expensive operator. This optimization method is very machine specific.

Sequences that are commonly combined by the optimizer include:

1. integer add/multiply becomes a **mac** instruction,
2. integer subtract/multiply becomes a **mac** instruction,
3. a memory reference combined with a pointer adjustment becomes an **autoincrement** or **autodectrement** addressing mode. This is very powerful when combined with register promotion and do loop promotion. For example,

```
for ( i = 0 ; i < 10 ; i ++ )
{
    array_1[ i ] = array_2[ i ];
}
```

the **for** loop becomes a **do** instruction, the array references are promoted to address registers and the induction variable is eliminated with array pointer advancement done via the autoincrement addressing mode.

4.11.12 Leaf Routine Detection

A leaf routine is a subroutine that makes no further subroutine calls. When the compiler identifies such routines, the prologue and epilogue code are optimized (no save and restore of the **ssh**).

4.11.13 Function In-lining

When explicitly requested via the command-line option **-finline-function**, the compiler will replace calls to subroutines with an in-line copy of the subroutine if the subroutine meets these requirements:

1. the subroutine must be a non-volatile leaf function
2. the subroutine must be in the same module
3. the definition must precede use of the subroutine.

Function in-lining eliminates the overhead associated with subroutine calls and provides additional opportunities for the optimizer and register allocator to further increase code quality. Function in-lining can also be performed explicitly by the programmer by utilizing the additional non-ANSI function type specifier _ _**inline.** By default, many run-time libraries are in-lined by the compiler.

Note: The function in-lining method can cause program memory requirements to grow significantly. See Appendix A, Programming Support, for instructions on disabling library routine in-lining.

4.11.14 Instruction Scheduling / Microcode Compaction

The command line switch **-alo** causes an assembly language optimizer (**alo561**) to be run, using the assembly code emitted by the compiler as input. This optimizer attempts to compact multiple operations into a single instruction word, while simultaneously avoiding the pipeline hazards exposed by the address generation unit. Because this optimizer mixes together instructions from different C language statements, debugging code compiled with **-alo** may be more difficult.

Chapter 5
Mixing C and Assembly Language

5.1 Overview

In cases where the DSP56100 programmer requires direct access to the hardware or greater performance in the inner-loop of an algorithm, C can be mixed with assembly in the same program. This chapter describes two methods for combining C and assembly language source code. The first is the **in-line** method which is a convenient way to put assembly code into the compiler output via the non-ANSI C directive _ _**asm().** The second is the **out-of-line** method, a generic method of combining C and assembly language generated object **files**.

Caution

Before mixing C and assembly, read and understand Chapter 4, **About g561c**, and the **DSP56100 Family Manual**. Attempting to write programs for this DSP without knowledge of the chip and how the compiler utilizes registers, memory, defines labels, etc. may generate unsatisfactory results. However, with an understanding of the DSP architecture and how this implementation of C uses it, programming should be straightforward.

Note: Labels which begin with a double underline (e.g., _ _asm ()) in this manual have a space between the double underlines to visually separate them. Do not separate the leading double underlines with a space when coding them (i.e., code _ _asm () as __asm ()).

5.2 In-line Assembly Code

In-line assembly code is assembly code that is inserted inside a C statement in a C source file. Since assembly code is generated from this C statement directly, the C statement looks like assembly code in the C source and is referred to as in-line assembly code. All of the assembly code to be generated is visible at the C source-level and it is often convenient to intermix assembly code with a C source program in this fashion.

Typically, in-line assembly code is used when:

1. inserting a small amount of assembly code directly into the compiler output i.e., inner loop kernels.

2. writing fast, small assembly language routines to be called by C subroutines. This eliminates the need to manage data referencing, register saving and allocation, and function call/return code.

The keyword _ _**asm** is introduced as an extension to the ANSI C language standard. This keyword is used in a fashion similar to a function call in order to specify in-line assembly code generation.

The in-line assembly statement syntax is:

_ _**asm** (instruction_template: output_operands: input _operands**:** reg_save)**;**

where:

1. **instruction_template** is a string used to describe a sequence of assembly code instructions that are to be inserted into the compiler output stream. It may specify arguments, which are listed in output_operands and input_operands. It does this via a substring called an operand expansion string (OES). An OES starts with a '%'. OES and instruction_template interpretation is described in Section 5.2.1.

2. **output_operands** are optional operands used to provide specific output information to the compiler. Each output_operand string is separated by a comma and should begin with the character '='. As an example, the output_operand **"=A" (cptr)** means "the C variable **cptr** will get its value from this output operand, which will be in an address register". See Section 5.2.2 for more details.

3. **input_operands** are optional operands to provide specific input information to the compiler. Each input_operand is separated by a comma and may include a C variable. As an example, the input_operand **"A" (cptr)** means "the value of this input operand will be taken from the C variable **cptr**, and placed in an address register". Again, full descriptions of the input and output operands can be found in Section 5.2.2.

4. **reg_save** specifies registers that are to be explicitly reserved for the _ _asm () statement. The registers to be saved must be named as strings such as **"a"** and **"b"**. Each register is separated by a comma (see Section 5.2.3 for additional information) The compiler assumes that all data residing in the reg_save registers will be invalidated by the _ _ asm () statement.

5.2.1 Instruction Template

The first argument of the _ _**asm()** extension is the instruction template or assembler instruction template. This instruction template is mandatory, and describes the line or lines of assembly language to be placed into the compiler's assembly language output (see Example 5-2 in Section 5.2.4). This template is not parsed for assembly language syntax violations and is simply written to the compiler output. As a result, the compiler will not detect assembly-time errors. These errors will be caught by the assembler.

More than one assembly instruction can be put into a single instruction template by using the line separator '\n'. The line separator, or newline, can be utilized as in a normal C statement. The line continuation sequence, a '\' followed by an immediate newline, is particularly useful when an instruction template contains an assembly instruction that is too long to fit in one source line (see Example 5-17 and Example 5-18 in Section 5.2.4). Other C language character constants such as '\t', '\f', etc. can also be used in the instruction template.

In many situations, it is desirable to use the values of C variables and/or expressions directly in the instruction template. Since all memory and register accesses are accomplished through variables, manipulating memory and registers directly using assembly code requires knowledge of their locations. Without optimizations, the current value of a variable will be maintained in memory at a specific address. However, an optimizing C compiler such as DSP561CCC may retain a variable in a register and perform operations on that variable without updating the memory location corresponding to the variable between operations. This enhances the performance of the compiled code but makes accessing variables in memory risky. In order to guarantee that the correct value of a variable is returned when it is referenced, a mechanism called operand expansion string (OES) is provided.

The OES allows a variable to be securely accessed even though its current location is unknown. The operand expansion string is a substring of the instruction template and begins with the character '%'. This string is usually two or three characters long and provides the compiler with special information about an operand, and how its reference should be printed. An OES must reference only one C variable or expression, which in turn must be listed in either one or both operand lists (see Section 5.2.2). The OES is parsed by the compiler and gives sufficient information to allow the variable to be correctly referenced by the assembly language instruction in the instruction template. Most examples in Section 5.2.4 include an OES.

The OES syntax is:

% [modifier] operand_id_number

where:

1. **modifier** is a single optional character which specifies a particular class of operand. The available modifiers are '**j**', '**e**', '**h**', '**k**', '**g**', '**i**', '**f**', '**d**', '**m**', '**o**', and '**c**'.

   j — an offset register (**nx**) associated with the corresponding address registers (**rx**). Since the offset register is paired with the address register, the allocated offset register has the same index as the address register (see Example 5-4 in Section 5.2.4).

   e — **a1** or **b1**, upper word of the destination registers **a** or **b** (see Example 5-5 in Section 5.2.4).

   h — **a0** or **b0**, lower word of the destination registers **a** or **b** (see Example 5-6 in Section 5.2.4).

   k — **a2** or **b2**, extension register of the destination register, **a** or **b** (see Example 5-7 in Section 5.2.4).

   g — Select the 16-bit portion of the 32-bit ALU register (**x** or **y**) that is not occupied by data pointed to by the operand id — e.g., if the operand id points to **x0** then **x1** is selected and similarly **x1**→**x0**, **y0**→**y1**, **y1**→**y0** (see Example 5-8 and Example 5-9 in Section 5.2.4).

   i — strip the **0** or **1** from the allocated register name i.e., **a1**→**a**, **a0**→**a**, **b1**→**b**, **b0**→**b** (see Example 5-10 in Section 5.2.4).

   f — insert the memory space identifier (**x**) for the memory location (see Example 5-11 in Section 5.2.4).

   d — print the accumulator name, but do not print a trailing '**0**' under any circumstance.

   m — print the source register name ('**x**' or '**y**'), but don't print a trailing '**1**' or '**0**'.

   o — print the accumulator name with a trailing '**10**'.

2. **operand_id_number** specifies the operand location in the operand descriptor list (see Example 5-3 in Section 5.2.4). The operand descriptor list is a concatenation of the output operands and input operands (see Section 5.2.2). The first operand is labeled zero and there can be up to 31 more operands in the list. More than one instruction template can be used if more than 32 operands are needed.

In-line assembly code can also be used to insert a label directly into the compiler output. A label without any white spaces in the in-line assembly code instruction template will

guarantee that the same template label will be in the compiler output (see Example 5-21). Care should be taken not to use labels that the C compiler generates. Using the same labels as the C compiler will cause a duplicate label error (see Section 4.7, Compiler Naming Conventions).

5.2.2 Output/Input Operands

The operand list is a concatenation of **output** and **input operands** which the OES can access via the operand_id_number (see Section 5.2.1). Output or input operands consist of operands separated by a comma (‘,’). Each operand should be associated with a C expression and its operand constraint described below.

A colon**, ‘:**’, is used to separate the assembler instruction template from the first output operand. A second colon separates the final output operand from the first input operand. A third colon can be used to separate the input operands from the optional field **reg_save**. Two consecutive colons are required when only input operands are needed in the operand list, leaving us with the empty list of output operands.

The operand syntax is:

“[=]operand_constraint” (C_expression)

where:

1. **=** differentiates input and output operands. All output operands must use this character first.

2. **operand constraint** is a single character that describes the type of resource (memory or register) that an operand is to be loaded into or read from. Each operand constraint has an optional set of modifiers that may be applied in the instruction template.

3. **C_expression** is any valid C expression defined by the ANSI C standard. The C expression can be either l-value or r-value. Any output operand should use the l-value to specify the memory location to store the data.

The available **operand constraints** are “**A**”, “**D**”, “**Q**”, “**r**”, “**x**”, “**y**”, “**i**” and “**m**”. All of these constraints originate from the DSP56100 architecture: a full understanding of these constraints requires that the programmer understand said architecture. The constraints are:

A — One of the **Address Registers** (**rx**, where **x** = **0** through **3**; see the DSP56100 Family Manual) will be allocated, (see Example 5-4) and the C expression will be promoted to this register. Typically the C expression should be a pointer to be assigned to an address register. The OES modifier, **j**, can only be associ-

ated with operand constraint **A** (see Section 5.2.1).

D — One of the 40-bit accumulators (**a** or **b** which are referred to as **Destination Registers**; see Section 4 of the DSP56100 Family Manual) will be allocated (see Example 5-5 through Example 5-7), and the C expression will be promoted to this register. The OES modifiers '**e**', '**h**' and '**k**' can be associated with operand constraint **D** (see Section 5.2.1).

Q — One of the Input Registers (X0, X1, Y0 or Y1 which are also called **Source Registers;** see Section 4 of the DSP56100 User's Manual) will be allocated to the C expression (see Example 5-12 through Example 5-16). The C expression will be promoted to this register. The OES modifiers '**g**' and '**i**' can only be associated with operand constraint **Q** (see Section 5.2.1).

r — One of the General Registers (**a**, **b**, **x0**, **x1**, **y0**, **y1**, **r0**, **r1**, **r2**, **r3**). This operand constraint is useful when one wants a scratch register that won't be used in an instruction other than a **move**.

x — The double Input Register **x** will be allocated (see Example 5-12 through Example 5-16). The C expression will be promoted to this register. The OES modifiers '**m**' can only be associated with operand constraint **x** (see Section 5.2.1).

y — The double Input Register **y** will be allocated (see Example 5-12 through Example 5-16). The C expression will be promoted to this register. The OES modifiers '**m**' can only be associated with operand constraint **y** (see Section 5.2.1).

i — An immediate constant; a constant is generated in the form of #constant if no modifier is specified.

m — The C expression will be referenced in memory (see Example 5-11). The DSP56100 has two memory spaces: **x:** and **p:**, but the C compiler will only use the x memory space for this expression. The OES modifier '**f**' can only be associated with operand constraint **m** (see Section 5.2.1).

number — Inherit all memory or register characteristics of the operand indicated by the operand id number (see Example 5-3). This constraint is usually used for read/write operands which are declared by using the same C variable as both the input and output operand.

The operand is sometimes referred to as a read-only operand if it is used only as an input (see Example 5-13). It is called a write-only operand if it is used only as an output (see Example 5-14). In most cases, the operand is used as both an input and an output operand (see Example 5-15 and Example 5-16). In these cases the operand must be de-

scribed as both. Since output operands should be listed first, the operand id number is determined when the output operand is declared. The id number will be used as the operand constraint of the associated input operand.

Table 5-1 lists the operand constraints and their related modifiers.

Table 5-1 Operand Constraints/Modifiers Associations

Operand Constraint		Modifier	
A	- Address Register (**rx**)	**%j**	- **rx**'s paired offset register
D	- Destination Register (**a**, **b**)	**%e**	- Upper word (**a1**, **b1**)
		%h	- Lower word (**a0**, **b0**)
		%k	- Extension (**a2**, **b2**)
Q	- Source Register (**x0**,**x1**,**y0**,**y1**)	**%g**	- Select other register portion
		%i	- Strip **0**/**1** from register name
x	- Double Input Register (**x**)	**%m**	- Print name correctly.
y	- Double Input Register (**y**)	**%m**	- Print name correctly.
r	- Any register (**A**, **D**, or **Q**)	None.	
i	- Constant (#number)	**%c**	- 16 bit immediate value
m	- Memory Location	**%f**	- Memory space identifier

5.2.3 Explicit Register Saving

It is possible to manually perform register allocation. This may simplify the process of converting an existing body of DSP56100 assembly language subroutines to in-line assembly code. The programmer need only identify each register explicitly referenced in the assembly code and list them in the reg_save argument region (see Section 5.2). This guarantees that the compiler won't expect values to be preserved in these registers across _ _asm() calls. Modification of the register **r2** is prohibited in the assembly code because it is reserved for the C compiler during run-time as the stack pointer. **n** registers are used by the compiler as temporary registers and **m** registers are assumed to be set for linear addressing. As a result, these registers do not need to be saved unless the programmer uses them in assembly code. If they are used in assembly code, they should only be used as local variables. If an **m** register is to be modified, then its original value must be restored by the programmer.

Explicit register saving is done by specifying the registers to be saved. A string is used to specify each register. The valid register names are listed in Table 5-2.

Table 5-2 reg_save Names

Register Type	Valid Names
Accumulator	"**a**", "**b**"
Source	"**x0**", "**x1**", "**y0**", "**y1**"
Address	"**r0**" - "**r3**"

An example for reg_save is a function performing a FIR filter operation. Data is passed through the C variables **flen**, **delay**, and **coeff**, the latter being pointers to single word fractional data.

Example 5-1 FIR function:

```
int fir ( int flen, int *delay, int *coeff )
{
        _ _asm volatile ( “\
        move %2,r3                          \n\
        move (%0)-                          \n\
        move x:(%1)+,y0 x:(r3)+,x0          \n\
        do %0,_loop                         \n\
        mac y0,x0,a x:(%1)+,y0 x:(r3)+,x0   \n\
_loop                                       \n\
        macr y0,x0,a”
        : : “A” ( flen ), “A” ( delay ), “r” ( coeff ) : “r3”, “x0”, “x1”, “a” );
}
```

5.2.4 In-line Assembly Code Examples

The examples in this section illustrate the practical application of the _ _asm() extension. The main purpose of this section is to show how to write in-line assembly code. Since these examples are intended to illustrate the information presented earlier in this chapter, references to the appropriate subjects have been included.

Example 5-2 illustrates the use of the in-line assembly code instruction_template. Since this in-line assembly code directly clears register a, the programmer should check to be sure that the contents of A are not needed The correct way of doing this would be to include “**a**” in the reg_save section of the _ _ **asm ()** statement.

Example 5-2 **Instruction_template:** The following are a few examples of how to utilize the instruction template in in-line assembly code. This feature allows the generation of any valid assembly instruction and it is probably the most frequently used feature in in-line assembly coding.

```
_ _asm("clr    a"); /* clears the register A */
_ _asm("move   #$10, a2"); /* load the register A2 with the hex value 10 */
_ _asm("HCR     equ  $ffc4"); /* equate the symbol HCR to $ffc4   */
```

A pseudo operand will be used to illustrate use of the OES operand id number. The pseudo operand functions as an input or output operand. Example 5-3 uses five pseudo operands: V, W, X, Y and Z each of which is referenced by operand ids **0**, **1**, **2**, **3** and **4**, respectively. The pseudo operands are used as in the OES "**%0**", "%**1**", "**%2**", "**%3**" and "**%4**". Table 5-3 shows which operands in Example 5-3 are input or output operands.

Example 5-3 **Instruction template with operand_id:** In order to illustrate how to use output or input operands, pseudo operands V, W, X, Y, and Z are used. The operand_id listed in this example can be used as part of an instruction_template.

```
_ _asm("instruction_template" : V, W, X : Y, Z );
```

Examples 5-3 through 5-11 illustrate the use of OES modifier (see Section 5.2.1).

Table 5-3 Output and Input Operands for Example 5-3

operand id	pseudo operand	operand type	OES
0	V	output	%0
1	W	output	%1
2	X	output	%2
3	Y	input	%3
4	Z	input	%4

Example 5-4 **OES modifier j:** The following in-line assembly code is used to generate executable assembly code. Notice that the actual register selection is totally dependent on the C compiler but the register selected (**r3** in this example) is guaranteed to be related to the C expression used (in this case cptr, see Section 5.2).

In-line Assembly code:

```
char *cptr;
_ _asm("move (%0)+%j0"::"A"(cptr));
```

Assembly Code Generated:

```
move (r3)+n3
```

Example 5-5 **OES modifier e:** The modifier **e** can be used to generate the assembly code below because A1 is the upper part of register **a**.

In-line Assembly code:

```
int foo;
_ _asm("move #$ffff,%e0":"=D"(foo));
```

Assembly Code Generated:

```
move #$ffffff,a1
```

Example 5-6 **OES modifier h:** The **h** modifier can be used to generate the following assembly code because **a0** is the lower part of register **a**.

In-line Assembly code:

```
int foo;
_ _asm("move #$ffff,%h0":"=D"(foo))
```

Assembly Code Generated:

```
 move #$ffff,a0
```

Example 5-7 **OES modifier k:** The **k** modifier can be used to generate the following assembly code because **a2** is the extension portion of register **a**.

In-line Assembly code:

```
int foo;
_ _asm("move #$ff,%k0":"=D" (foo));
```

Assembly Code Generated:

```
move #$ff,a2
```

Example 5-8 **OES modifier g:** Swap the most significant 16-bit portion and the least significant 16-bit portion of 32-bit registers **x** and **y** to allow the **OR** instruction to operate on an entire 32-bit register.

```
/*
 *  The following assembly code could be generated (note that the
 *  optimizer may vary the code actually generated).
                move x1,a1
                move x0,x1
                move a1,x0
 *
 *  The variable foo can be allocated to either x0, x1, y0, or y1
 *  by using the operand constraint Q. The swap operation can
 *  be applied to the register allocated to the variable foo by
 *  using the following in-line assembly code.
 *
 */
main()
{
  int foo;
  _ _asm volatile ("move %g0,a1" : : "Q" (foo));
  _ _asm volatile ("move %0,%g0" : "=Q" (foo) : "0" (foo));
  _ _asm volatile ("move a1,%0"  : "=Q" (foo));
}
```

Example 5-9 **OES modifier g:** A bit checker program looks to see if any bit in the 32-bit registers **x** or **y** is set. The example code looks to see whether the variable foo, which is placed in either the **x** or **y** register, is zero or contains a set bit. The result is stored in the register **a1**. If register **a1** is not 0x0000, then foo has one or more set bits.

```
/*
 * The variable foo can be allocated to either the x or Y register by using
 *  the operand constraint Q. The or instruction only operates on 16-bit
 * registers so that to OR the x register with another register, x1 must
 *  be ored separately from x0. The same applies for the y register.
 */
main()
{
  long volatile foo;

  _ _asm volatile (“clr A”);
  _ _asm volatile (“or %0,A” :: “Q” (foo));
  _ _asm volatile (“or %g0,A” :: “Q” (foo));
}
```

Example 5-10 **OES modifier i:** The modifier can be used to generate the following assembly code because **x** is a register without a **0** or **1** portion.

In-line Assembly code:

```
int foo;
_ _asm("move x:<$0,%i0" : "=Q"(foo));
```

Assembly Code Generated:

```
move x:<$0, x
```

Example 5-11 **OES modifier f:** The f modifier can be used to generate the following assembly code. Assuming that the memory location of the variable "foo" is 233, then the memory space indicator "**x:**" will be automatically generated by the f modifier.

In-line Assembly code:

```
int foo;
_ _asm("move #$ffff,%f0": "=m" (foo));
```

Assembly Code Generated:

```
move #$ffff,x:233
```

Example 5-12 **Input Expression / Output Expression:** This in-line assembly code uses the pseudo assembly mnemonic “asm_instruction” and refers to two C expressions: output_expression and input_expression. This example illustrates how to interpret the **operand constraint** (see Section 5.2.2) and operand id (see Section 5.2.1 and Example 5-3). The example implies that the C expression output_expression is expanded with constraint D and is an output of the assembly code instruction asm_instruction. Similarly, the C expression input_expression is expanded with constraint Q and used as an input to the assembly code instruction asm_instruction.

```
_ _asm(“asm_instruction %1,%0” : “=D” (output_expression) : “Q” (input_expression));
```

Example 5-13 **Read-Only Operand:** This in-line assembly code uses the pseudo assembly mnemonic “asm_instruction” and uses input_expression as a read-only operand.

```
_ _asm(“asm_instruction %0” :: “Q” (input_expression));
```

Example 5-14 **Write-Only Operand:** This in-line assembly code uses the pseudo assembly mnemonic “asm_instruction” and uses output_expression as a write-only operand.

```
_ _asm(“asm_instruction %0” :“=D”(output_expression));
```

Example 5-15 **Read-Write Operand:** An addition is programmed using in-line assembly code and the C expression result is used as a read-write operand. The variable, foo, is used as a read only operand. Notice that operand constraint ‘**0**’ was used to reference the **add** instructions second source operand which is also the destination operand (see the DSP56100 Family Manual — Appendix A for the syntax of the **add** instruction).

```
int foo, result;
_ _asm(“add %1,%0” : “=D” (result) : “Q” (foo), “0” (result));
```

Example 5-16 **Read-Write Operand:** The same result will be obtained as in Example 5-15. Notice how the operand id is changed according to the placement of the C variables.

```
int foo, result;
_ _asm(“add %2,%0” : “=D” (result) : “0” (result), “Q” (foo));
```

Example 5-17 **Multiple Instruction — Single-Line:** An in-line assembly program which places a value (e.g. $709) in register **a** and negates the result is written in one line. This one line will generate two lines of assembly code in the C compiler output.

```
_ _asm(“move #$709,A\n neg a” : : “a” );
```

Example 5-18 **Multiple Instruction — Multiple-Line:** The two lines of in-line assembly code in this example have the same effect as the one line in Example 5-17. Notice that using two lines increases the in-line assembly code readability. The line continuation character '\' used at the end of the in-line assembly codes first line makes this possible.

```
_ _asm("move #$709,a\n\
        neg a" : : "a" );
```

Example 5-19 **Multiple use of _ _asm().** This trivial example and Example 5-20 are done in-line with the compiler performing all register allocation and all operands are referenced via C expressions. The method used to write this in-line assembly program is to use an _ _asm() statement for each assembly language instruction.

```
int read_n_add ( int data, int* ptr_a, int* ptr_b )
{
        int tmp_a, tmp_b;
        _ _asm ( "move x:(%1),%0" : "=Q" (tmp_a) : "A" (ptr_a) );
        _ _asm ( "move x:(%1),%0" : "=Q" (tmp_b) : "A" (ptr_b) );
        _ _asm ( "add  %1,%0" : "=D" (data) : "Q" (tmp_a), "0" (data) );
        _ _asm ( "add  %1,%0" : "=D" (data) : "Q" (tmp_b), "0" (data) );

        return data;
}
```

Example 5-20 **Line Separation.** This in-line program is functionally identical to Example 5-19 except that line separation is used to insert the entire assembly language program. Notice how much easier it is to read the program.

```
int read_n_add ( int data, int* ptr_a, int* ptr_b )
{
        int tmp_a, tmp_b;
        _ _asm ( "\
        move x:(%3),%1          \n\
        move x:(%4),%2          \n\
        add  %1,%0              \n\
        add  %2,%0" : "=D" (data), "=Q", "=Q" : "A" (ptr_a), "A" (ptr_b));

        return data;
}
```

Example 5-21 **Instruction Template Label:** The following in-line assembly code which generates the label "foo" uses a return character "\n" to insure that there is no white space in front of the label.

_ _asm(“\nfoo”);

5.2.5 Controlling Labels Generated by the Compiler

Using the _ _asm() keyword, it is possible for the programmer to override the compilers label generation conventions for subroutines and global variables. In general, this practice is discouraged. This may be useful for:

1. calling assembly language subroutines,
2. calling C subroutines from assembly code,
3. referencing assembly language global variables from C,
4. referencing global C variables from assembly code.

5.2.5.1 Calling Assembly Subroutines

Calling a subroutine or function requires using a label that points to the subroutine or function. The C compiler uses a predetermined labeling convention (see Section 4.7). In order to call assembly subroutines labeled in an arbitrary fashion, _ _asm() can be used to overwrite the C convention label with an arbitrary label.

To illustrate how to use the _ _asm directive for this purpose, Example 5-22 reads the data at x memory location $100 and X memory location “X+2”. For test purposes, the x memory space is filled with the integer sequence 0 through 9. The printf() statement prints the data returned from the function calls ValOfX(100) and ValOfX(X+2). This function was written in assembly code and resides in another file. The assembly subroutine ReadX was written using the out-of-line assembly technique described in Section 5.4. The listing for ReadX is shown in Example 5-36 in Section 5.4.5.

By using the statement

extern int ValOfX() _ _asm(“ReadX”);

all C compiler generated function labels for ValOfX() are replaced by the label ReadX.

Example 5-22 **Calling assembly from C.** This C program (called test.c) can be used to examine the data in x memory by calling the assembly routines “ReadX”. Notice that the assembly code for ReadX is listed in Example 5-36 of Section 5.4.5.

C:\> type test.c

```
#include <stdio.h>
extern int ValOfX() _ _asm("ReadX");
unsigned X[] = {0x1,0x2,0x3,0x4,0x5,0x6,0x7,0x8,0x9};
main()
{
  printf("<%x><%x>\n", ValOfX(100), ValOfX(X+2));
}
```

The following two command lines test Example 5-22.

```
C:\> g561c test.c memread.asm
C:\> run561 a.cld
```

5.2.5.2 Calling C Subroutines from Assembly Code

Any C function can be called from an assembly program to test the assembly program data or utilize built-in standard C libraries such as floating-point operations. Calling a C subroutine from assembly code requires using the C subroutine calling convention (see Section 4.8 and Section 5.4.4) and matching the C function labels. The in-line-assembly directive, _ _**asm()**, can be used as shown in Example 5-23 to change the C program labels.

Example 5-23 **Calling C from assembly.** This C subroutine (called C_print.c) uses the standard C library routine, **printf()**, to print the input argument as a string.

C:\> type c_print.c

```
#include <stdio.h>
int C_printf() _ _asm("print");
C_printf(char *msg)
{
printf("%s\n", msg);
 }
```

Example 5-24 **Calling C from assembly.** This assembly program (called greeting.asm) prints the message "greeting: hello, there" on the screen. It uses the C subroutine **printf ()**, to print this message. Notice that the assembly program name is **Fmain** because the control program, **g561c**, uses the default start-up file **crt0561.cln**. **crt0561.cln** uses **Fmain** to start up the main program

```
C:\> type greeting.asm

        section     greeting
        org         x:
LC0     dc          “greeting: hello,there.”,$00
        org         p:
        global      Fmain
Fmain   move        ssh,x:(r2)+
        move        r1,x:(r2)+
        move        #LC0,r1
        move        r1,x:(r2)+
        jsr         print
        move        (r2)-
        move        (r2)-
        move        x:(r2)-,r1
        move        x:(r2),ssh
        rts
        endsec
```

The following two MS-DOS command lines can be used to test the program:.

```
C:\> g561c greeting.asm c_print.c
C:\> run561 a.cld
```

5.2.5.3 Referencing Assembly Global Variables from C

The data in assembly language programs must be accessible to C programs to take full advantage of the DSP56100 family architecture since the C language cannot access all of the DSP56100 features directly. One way to access this data is through global data which can be defined in assembly language and accessed in the C program environment. This feature is particularly useful to allocate modulo buffers. Detailed information on modulo buffers can be found in the DSP56100 Family Manual

Example 5-25 **Generate data with assembly language.** The data file, sqtbl.asm, is generated in assembly language and consists of a series of squares.

```
C:\> type sqtbl.asm
```

```
            section  data
            global   table
            org      x:
table       dc 0,1,4,9,16,25,36,49,64
            endsec
```

Example 5-26 **Access data with C.** This test program (called test.c) prints the value of 5^2 on the screen.

C:\> type test.c

```
#include <stdio.h>
extern int SQUARE[] _ _asm("table");
main()
{
   printf("square of %d is %d\n", 5, SQUARE[5]);
 }
```

The following two command lines for Example 5-26 test the two programs sqtbl.asm and test.c.

```
C:\> g561c test.c sqtbl.asm
C:\> run561 a.cld
```

5.2.5.4 Referencing Global C Variables from Assembly Language

One DSP561CCC feature is that global data in a C program is available to assembly language programs. This feature is particularly useful when the data to be processed by an assembly language program is generated by the C program. Example 5-27 provides coefficients that are used in Example 5-28.

Example 5-27 **Generate data with C.** data.c contains the coefficients of an average filter which takes the average of the last four input data.

C:\> type data.c

```
int Cwaddr[]   _ _asm("waddr");
int Ccaddr[]   _ _asm("caddr");
int NTAP       _ _asm("N_1");

int Cwaddr[4];
int Ccaddr[]  = { 0x2000, 0x2000, 0x2000, 0x2000 };
int NTAP = 4;
```

Example 5-28 **4-tap FIR filter — Access data with assembly language:** This FIR filter reads an input sample from memory location **x:input** and writes the filtered output to memory location **x:output**. The input data array is stored in x memory starting at **waddr** and the

FIR coefficients are stored in x memory starting at **caddr**. Notice that the memory space for **waddr** and **caddr** is allocated in the C routine described in Example 5-27.

C:\> type fir.asm

```
org             p:
move            #waddr,r0
move            #caddr,r3
move            y:N_1,m0
move            m0,m3

movep           x:input,x:(r0)

clr             a
move            x:(r0)+,y0      x:(r3)+,x0
rep     #n-1
mac             x0,y0,a         x:(r0)+,y0      x:(r3)+,x0
macr            x0,x0,a         (r0)-

movep           a,x:output
move            #-1,m0
move            m0,m3

end
```

C:\> g561c -S data.c
C:\> g561c -c fir.asm
C:\> g561c -c data.asm
C:\> g561c fir.cln data.cln

5.2.6 Specifying Registers for Variables

DSP561CCC allows the programmer to identify a specific register for local and global variables, but due to the limited number of registers available, this may not have a positive effect on run-time performance. With this in mind, this feature should be used sparingly.

Both global and local variables are candidates for promotion to specific registers and syntactically they look the same:

```
register int *ptr __asm("r3");
```

By specifying a specific register for a local or global variable, the programmer is reserving the register for the variable's entire scope (global for the entire program, local for the

function in which they are declared). This means that the compiler will not use the register for any other purpose and the register **will not be saved and restored** by the C function call.

5.2.7 Optimizer Effects on Code

All in-line assembly code is visible to the optimizer and as such it is possible that the optimizer will convert it into a new form or eliminate it entirely if it is determined to be unreachable or dead. In order to guarantee that code is **not removed** by the optimizer, the ANSI keyword **volatile** must be used.

__asm **volatile** (…);

5.3 #pragma Directive

The purpose of this section is to explain the proper techniques for manipulating the assembler's run-time and load-time counters while programming in the C language.

Currently the Motorola DSP assemblers allow the programmer to specify both a run-time location and a load-time location for any object; however, there is no corresponding concept within C. The generic **#pragma** facility is used to add this capability rather than extending the C language. Users now have complete freedom in specifying both the run-time and load-time counters for any static or global object. These directives may be used with either code or data.

This flexibility is achieved by allowing the user to modify any of four counter strings maintained by the compiler — two for each memory space: x and p. When an object is or defined, the current values of those counter strings are bound to that object.

Syntax for the pragma directive is

#pragma counter_string argument

C function or data storage definition

#pragma counter_string

where

1. the two #pragma statements must encase the entire definition.
2. counter_string in the first **#pragma** specifies which phase (run or load time) and memory space is to be affected. It can be **x_run**, **p_run**, **x_load**, or **p_load**.
3. the argument in the first **#pragma** is the string that will be passed as either the runtime or load-time argument to the org assembler directive. This address, which is optional, is of the form x:address_value where x is the counter

associated with x memory, and address_value is the value to be initially assigned to that counter. As an example, **p:$300** might be used for the counter string **p_load**.

4. the C function or data storage definition is a declaration that reserves storage.
5. The second counter_string should be the same as the first counter_string and will return the memory specification to the default setting.

If and only if the memory space of the counter string in the #pragma directive matches the memory model of the C compiler, then the compiler will insert an assembly org statement of the form:

(1) org a:runtime_address,b:loadtime_address

or

(2) org a:runtime_address

where "a" is the run time counter and runtime_address is the optional initial value for that counter, as specified in the "argument" to **#pragma**.

"b" is the load time counter and loadtime_address is the optional initial value for that counter, as specified in the "argument" to **#pragma**.

The following two examples illustrate that the load time counter is optional. See the section on the ORG statement in the Motorola DSP56100 Assembler Manual for a complete description and list of options.

Notice that the pragma directive run-time counter string will only affect the run-time address and the pragma directive load-time counter string will only affect the load-time address.

As a simple example, the following C segment:

```
#pragma x_load p:$100
int coeff[5] = {0x19999a, 0x200000, 0x266666, 0x2ccccd, 0x333333};
#pragma x_load
```

produces the following assembly language code:

```
        global  Fcoeff
        org     x:,p:$100
Fcoeff
        dc 1677722
        dc 2097152
        dc 2516582
        dc 2936013
        dc 3355443
```

Notice that the second **#pragma** directive will remove the effect of the first memory specification, i.e., **#pragma x_load p:$100**; any following data definitions would have x memory load time locations, as is the default.

The above example code will be loaded at p memory location $100, and it should be copied to the x memory space upon system start-up. When burning a PROM, often only one memory space is desired to be used, as an example, p memory space, so that only one PROM is enough for both data and program. In such case, both the data and the program will be burned in the PROM and the data should be moved to the data memory space upon system start-up.

Let's assume that the coefficients of the above example are desired to be in the program space when burning the PROM. Then the following C segment

```
#pragma x_load p:$100
int coeff[5] = {0x19999a, 0x200000, 0x266666, 0x2ccccd, 0x333333};
#pragma x_load
```

produces the following assembly language code:

```
        global  Fcoeff
        org     x:,p:$100
Fcoeff
        dc 1677722
        dc 2097152
        dc 2516582
        dc 2936013
        dc 3355443
```

The above assembly code will be loaded into the p memory space at **p:$100** for the

PROM burning, and it should be copied to the x memory space before the actual program is executed. Manipulating the assembler's run-time and load-time counters requires a thorough understanding of the underlying assumptions about memory layout, which are made by the compiler (see Chapter 6). Incorrect use of this feature may cause compile-time, link-time and even run-time errors**.**

5.4 Out-of-line Assembly Code

Out-of-line assembly code is assembly code written in a separate source file that is called from a C program. Separating the assembly code and C code in this way provides a powerful and flexible interface to the DSP56100 family architecture. This out-of-line method may be used to convert existing assembly subroutines, or new subroutines completely in assembly language may be written. The key advantage of out-of-line assembly code is that it provides a complete assembly programming environment for the DSP56100 family whereas the in-line assembly code must follow the C programming environment rules.

Writing out-of-line assembly code requires a complete understanding of the C Cross Compiler and the DSP56100 family architecture. For out-of-line assembly code to be callable from a C program, the following five basic elements should be included in the assembly source file in sequence.

1. C subroutine entry code (prologue code)
2. Save all registers to be used
3. Function core
4. Restore all registers used
5. C subroutine exit code (epilogue code)

In order to illustrate the steps listed above, the out-of-line assembly code template is described first and each element of the template is then explained in detail. After reviewing the five elements, some optimization techniques are discussed.

5.4.1 General Template

The following template is a generic form used to make the C function "foo". The actual code for the prologue and epilogue is shown but the "Save all registers to be used", "Main

Program", and "Restore all registers used" are listed as comments because the actual code depends on the function.

```
        global      Ffoo        ; prologue:
Ffoo                            ; sets up entry point (C function address).

        move        #k,n2       ; k is the amount of local space needed.
        move        ssh,x:(r2)+ ; save the return address.
        move        (r2)+n2     ; allocate local stack space of size k.
; Save all registers to be used
; Function body.
; Restore all registers used
        move        #-k-1,n2
        tst         a       (r2)+n2; deallocate local stack space, set ccr flags.
        move        x:(r2),ssh  ; get the return address.
        rts
```

5.4.1.1 Prologue

The first two lines of the prologue make the assembly program visible to the C program so that the subroutine or function is callable from the C program. In this case, any one of the following C statements can be used to access out-of-line assembly code.

```
foo();

x = foo();

x = foo(arg1, arg2, arg3);
```

The first function call assumes that the C function does not use any arguments and does not return any values. The second only returns a value which is the same data type as the variable **x**. The last call assumes that the C function uses the three arguments: **arg1**, **arg2** and **arg3** and then returns the value **x**.

The rest of the prologue saves the return address and allocates any needed stack space for the function. Increasing the stack pointer value will protect local data from corruption by interrupt routines. The return address is saved when the **jsr** instruction pushes the program counter onto the high 16 bits of the system stack (**ssh**).

5.4.1.2 Save all registers

All registers used in the function should be saved before the function alters them. This step is the second element of the template — "Save all registers to be used".

In order to save the registers, **r2** is used as a stack pointer. The stack grows upward and the current stack pointer (**r2**) points to the next element above the top of stack. The following statement saves one register to the top of stack and sets the stack pointer to the next available stack location.

```
move    x0,x:(r2)+
```

Two registers, y1 and x1, can be saved with the following statements:

```
move    y1,x:(r2)+
move    x1,x:(r2)+
```

Since saving and restoring the registers are the subroutine's responsibility, the order of saving the registers should be in accordance with their restoration. The restore process should be exactly the reverse order of the register saving sequence.

5.4.1.3 Main Program

A typical C function accesses the parameters passed, executes the operations on the parameters and returns a value. Passing parameters is done by pushing them onto the stack. When a function is called, the first parameter is directly underneath the stack pointer (see Section 4.6.1). The parameters are pushed by the caller in reverse order. For example, the following statement should be used to move the first single word parameter to register **r3**.

```
move    x:(r2-z-2),r3                   ; z is local stack area size.
```

Assuming the first three parameters are one word long, the following statements move the second and third parameters to registers **r0** and **r1**, respectively.

```
move    x:(r2-z-3),r0
move    x:(r2-z-4),r1
```

5.4.1.4 Restore all registers

The stack pointer, **r2**, is needed to restore the registers. The following code will restore one register. At this point in the function's execution, the stack pointer points to the location above the last saved register, hence the pre-decrement.

```
move    x:-(r2),x0                      ; restore
```

The restoring procedure can be simplified if more than one register is to be restored. Restoring registers **x0**, **x1**, **y0** and **y1** can be done by the statements below.

```
move    (r2)-
move    x:(r2)-,x0
move    x:(r2)-,x1
move    x:(r2)-,y0
move    x:(r2),y1
```

After the function has finished, a return value can be passed to the caller. Any 32-bit or 16-bit value must be returned through register **a**. If the return value is larger than 32 bits, then the compiler allocates the proper amount of buffer space and register **a1** becomes the pointer to this buffer space upon callee execution. It is the callee's responsibility to copy any return values from the buffer whose address resides in register **a1**. This is the method used for returning **struct**s.

5.4.1.5 Epilogue

The out-of-line template epilogue is the reverse of the prologue. The epilogue restores the stack pointer and the return address. In addition, register **a** is tested to update the **ccr** flags. This testing is a part of the C compiler code generation feature and should be included in functions that return values in the **a** register (see Section 5.4.5 for optimization).

5.4.1.6 Out-of-line Assembly Code Example

The following example illustrates using the general template as well as the fact that the DSP56100 performs fractional arithmetic. Assume that section mod1 contains two C callable subroutines, **mac01()** and **mac02()** and section **mod2** contains a single C callable subroutine, **mactwo()**. The two functions **mac01()** and **mac02()** take one argument each and **mactwo()** takes two arguments. These functions perform multiplication according to the following formulas and return their results:

```
mac01(arg)          calculates      arg * 0.01
mac02(arg)          calculates      arg * 0.02
mactwo(arg1, arg2)  calculates      arg1 * arg2
```

Note that multiplication on the DSP56100 treats data as fractions; however, the C programming language does not yet support a fractional data type. Therefore data will be passed as integers from the C programming environment and will be treated as fractional data in the DSP56100. This can be an advantage if fractional arithmetic is desired since this is normally difficult to accomplish in C. Note that the calling routine must ensure that **arg** is in range to prevent overflow.

The following function declarations can be used to declare functions which are known to perform fractional arithmetic. Internally, the size of integers is the same as the size of fractions.

```
int mac01(int);
int mac02(int);
int mactwo(int, int);
```

These three functions can be called as follows:

```
int fractvalue;
fractvalue = mac01(0x1234);   /* the value 0x1234 is 0.14221 in fractional */
fractvalue = mactwo(0x1234, 0x0147); /* 0x0147 is 0.00998 */
```

The conversion between fractional data and integer data (in hex form) can be performed using the **evaluate** command in the DSP56100 simulator.

Example 5-29 **General Template for Out-of-line Assembly Code:** The two sections of this out-of-line assembly code are **mod1** and **mod2**. The first section implements:

1. **mac01(arg)** which takes a fractional argument and returns 0.01 times the argument and
2. **mac02(arg)** which takes a fractional argument and returns 0.02 times the argument.

The second section implements **mactwo(arg)** which takes two fractional arguments and returns **arg1*****arg2**.

```
; section mod1:
;    int mac01(int arg);
;         takes a fractional argument and returns 0.01 * argument.
;    int mac02(int arg);
;         takes a fractional argument and returns 0.02 * argument.
```

```
        section     mod1
        global      Fmac01
Fmac01
        move        ssh,x:(r2)+   ; save the return address.

        move        x1,x:(r2)+    ; save register X1
        move        y0,x:(r2)+    ; save register Y0

        move        x:(r2-4),x1   ; argument
        move        #0.01,y0      ; operand 0.01
        clr         a
        macr        x1,y0,a       ; main program: calculates multiplication of
                                  ; x1 and y0

        tst         a       (r2)-
        move        x:(r2)-,y0    ; restore register Y0
        move        x:(r2)-,x1    ; restore register X1

        move        x:(r2),ssh    ; restore the return address.
        rts

        global      Fmac02
Fmac02
        move        ssh,y:(r2)+   ; save the return address.

        move        x1,x:(r2)+    ; save register X1
        move        y0,x:(r2)+    ; save register Y0

        move        x:(r2-4),x1   ; argument
        move        #0.02,y0      ; operand 0.02
        clr         a
        macr        x1,y0,a       ; calculates multiplication of  x1 and y0

        tst         a       (r2)-
        move        x:(r2)-,y0    ; restore register Y0
        move        x:(r2)-,x1    ; restore register X1

        move        x:(r2),ssh    ; restore the return address.
        rts
        endsec
```

```
; section mod2
;    int mactwo( int arg1, int arg2);
;         takes two fractional arguments and returns arg1 * arg2.

         section     mod2
         global      Fmactwo
Fmactwo
         move        ssh,y:(r2)+    ; save the return address.

         move        x1,x:(r2)+     ; save register X1
         move        y0,x:(r2)+     ; save register Y0

         move        x:(r2-4),x1    ; the first argument
         move        x:(r2-5),y0    ; the second argument
         clr         a
         macr        x1,y0,a        ; main program:
                                    ; calculates multiplication of x1 and y0

         tst         a       (r2)-
         move        x:(r2)-,y0     ; restore register Y0
         move        x:(r2)-,x1     ; restore register X1

         move        x:(r2),ssh     ; restore the return address.
         rts
         endsec
```

The DSP561CCC control program, **g561c**, should be used to assemble the out-of-line assembly code. The two sections of this code, **mod1** and **mod2**, can be put in the same file or in separate files. The following command lines and source files provide a test for the case where each program is in a separate file.

C:\> type main.c

```
#include <stdio.h>
int mac01(int), mac02(int), mactwo(int,int);
main()
{
  printf("%x, %x\n", mac01(0x123456), mactwo(0x123456, 0x0147ae));
  printf("%x, %x\n", mac02(0x123456), mactwo(0x123456, 0x28f5c));
}
```

```
C:\> g561c main.c mod1.asm mod2.asm
C:\> run561 a.cld

2e9a, 2e9a
5d35, 5d35
```

5.4.2 Global C and Static Variables in C

The global C variables are accessed using labels generated by the C compiler. Any variables that are static to an assembly language subroutine will be accessed the same way. These variables are placed into memory at compile-time and are referenced symbolically according to the labels automatically generated by the compiler. However, it is possible to override the default labels by using the _ _**asm()** keyword as explained in Section 5.2.5 Controlling Labels Generated by Compiler.

For example, using the default labeling convention, the global integer, **Ginteger** which can be declared within the C statement **extern int Ginteger**; is loaded into the input register **x0** in assembly code as follows:

```
        move    x:FGinteger,x0
```

When declaring C global variables in an assembly language file, the programmer must be careful to follow the label generating convention or use the _ _asm() keyword to report to the compiler that the labeling convention has been changed. In both cases, the assembler directive **global** is used to export the labels to the C files. **DO NOT** use the **XDEF**/**XREF** pair of directives. **NOTE** that it is the programmer's responsibility to allocate space for the global variables declared in this manner. In the example below, this is done with the assembler directive **dc**. Also, ANSI C requires that all global variables be initialized to zero if they are not explicitly initialized.

Example 5-30 **Global Label in Assembly Language.** This example shows assembly code that defines a global integer (named FGinteger) which is normally accessed as **Ginteger** in the C environment and **FGinteger** in the assembly programming environment.

```
            org     x:
            global  FGinteger
FGinteger
            dc      $0
```

Example 5-31 **Global Variable Declaration.** This is the C code equivalent to Example 5-30 which defines the global integer **Ginteger.**

```
int         Ginteger;
```

Example 5-32 **Changing a Global Label.** This example shows C code that generates a global integer (**Ginteger**) which is accessed as **Ginteger** in both the C environment and the assembly programming environment.

```
int Ginteger _ _asm("Ginteger");
```

Which will appear in assembly language code as:

```
Ginteger    dc      $0
            global  Ginteger
```

5.4.3 Using Run-time Stack for Local Data

The run-time stack may be used when the programmer requires a temporary data space for automatic style variables — i.e., local variables in subroutines. Using the run-time stack requires additional steps in the prologue and epilogue sections. It is the subroutine's responsibility to automatically allocate and deallocate the stack at run-time.

In the prologue, an extra step is required to save the run-time stack space. Keeping in mind that the stack pointer should always point to the next available stack location, the stack space is allocated by advancing the stack pointer by the amount of space required. One way to allocate this space is shown in the Example 5-33.

Example 5-33 **Run-time stack allocation:** This code segment can be inserted in the general template prologue for out-of-line assembly code. Notice that "size" in the move statement below should be replaced with the appropriate constant.

```
move    #size,n2        ; the stack size needed
nop                     ; wait for pipeline delay.
move    (r2)+n2         ; allocate the run-time stack for locals
```

Referencing the data space can then be accomplished using negative offsets from the stack pointer or via initialized address registers. There are many alternatives to these methods but they are all similar.

In the epilogue, an extra step is required to restore the stack pointer — i.e., deallocate the run-time local stack. This is simply the reverse of the allocation process in the prologue.

Example 5-34 **Run-time stack deallocation:** This code segment can be inserted in the general template epilogue for out-of-line assembly code. Notice that “size” in the move statement below should be replaced with the appropriate constant.

```
move    #-size,n2     ; the stack size used before
nop                   ; wait until n2 is available.
move    (r2)-n2       ; deallocate the run-time stack
```

There are many ways to do this. One simple optimization would be to advance the **n2** load instruction in the program to eliminate the nop.

5.4.4 Calling C Routines

C routines are routines that are callable by a C program and may be written in either C or assembly language. When writing assembly language subroutines, it may be necessary to call library routines that have been provided or that have been written by the programmer — e.g., a call to **sin()** or **printf()**. In order to do this, the programmer must follow 3 steps:

1. Push arguments onto the run-time stack in reverse order.
2. Make the subroutine call.
3. Restore the stack pointer.

The following example assumes that the four parameters to be passed to the C function foo() are currently located in registers **a1**, **b1**, **x0** and **x1**, respectively. The first four lines of assembly code push the arguments onto the run-time stack in reverse order. The **jsr** statement makes the subroutine call and the last two statements restore the stack pointer.

Example 5-35 **Calling C Routines.** The C function, **foo()**, is called from the following assembly code. Function **foo()** is declared as **int foo (int, int, int, int);**

```
move    x1,x:(r2)+          ; pushing arguments onto
move    x0,x:(r2)+          ; run-time stack in reverse
move    b1,x:(r2)+          ; order
move    a1,x:(r2)+
jsr     Ffoo                ; subroutine call
move    #-4,n3              ; the stack size restored.
nop
move    (r2)+n2             ; restore the stack pointer.
```

5.4.5 Optimization Techniques

The general template for out-of-line assembly code provides a clean template to build C callable functions. However, the DSP56100 family microprocessor chips have powerful features such as multiple instruction execution (multiply and accumulate) and parallel data move operations that may allow additional optimization. After constructing the out-of-line assembly code from the general template, some hand-optimization can be performed by combining several assembly statements.

Information about these optimization techniques can be obtained from the DSP56100 Family Manual. Some optimization techniques which are related to the C compiler are discussed in this section but additional optimization can be achieved using the architectural features described in the user's manual.

The return address (**ssh**) was saved in the out-of-line assembly code prologue but it is only required when a function calls another function. A function is called a leaf function if it does not call any other C function. In leaf functions, the return address does not have to be saved because the hardware stack will not overflow on subsequent **jsr** instructions.

The test statement "**tst a**" in the epilogue can be eliminated if the function does not return any value. The test statement may be required due to the C compiler's optimization features since it provides condition flags for an **if** statement in a function call. For example, if the out-of-line assembly function **foo()** is used in the statement **if (foo()) { ... }**, then the C compiler will not generate code to test the return value when a **jne** instruction is issued. This is primarily because the C compiler uses the condition flags which were generated at the end of the epilogue of **foo()**.

A variety of optimizations can be achieved by combining the **move** instructions and function body code to utilize parallel moves (see Section 5.4.5 and Example 5-36 which point out possible optimizations in the comments). These and other DSP56100 specific optimizations can dramatically improve the quality of the application specific library routines. A careful review of the DSP56100 Family Manual will be worthwhile for efficient library development.

Example 5-36 **ReadX Routine.** This out-of-line assembly routine (called memread.asm) reads the contents of x memory and returns the data to the caller. The **ReadX** subroutine returns the x memory space contents pointed to by the input argument.

```
            section  memread
            org      p:
            global   ReadX
ReadX       move     r1,y:(r2)+          ; save register r1.
            move     x:(r2-2),r1         ; read the first parameter.
            nop                          ; wait for the pipeline delay.
            move     x:(r1),a            ; read x memory.

            move     x:-(r2),r1          ; restore register r1.
            tst      a                   ; set CCR flags.
            rts

            endsec
```

Chapter 6
Software-Hardware Integration

6.1 Overview

This chapter explains how the run-time environment may be changed and provides examples of some changes and their effects. The run-time environment provided with the compiler assumes, as a default, that the simulator is the target execution device. Several aspects of the default run-time environment must be altered in order to adapt the compiler to work with a custom hardware configuration.

The files which are alterable are discussed and classified according to effect. Aspects of the run-time environment such as: bootstrapping, interrupts and memory management are addressed individually.

6.2 Run-Time Environment Specification Files

The run-time environment is specified by three assembly language files: **crt0561.asm**, **signal561.asm** and **setjmp561.asm**. These files may need to be modified if the run-time environment is to be customized.

The **crt0** file contains the C bootstrap code, parameters that specify memory configuration, memory management, interrupt vectors, and other miscellaneous code. This file must be modified to match the software and hardware configuration, as both the memory configuration and interrupt vectors are determined by hardware. The information in this manual on the **crt0** file applies to DSP561CCC Version g1.11. The **crt0** file may be different for other versions of this compiler.

The signal file, which is equivalent to a hardware interrupt, is implemented in the C environment. The signal file contains the code and data structures used to implement the **signal()** and **raise()** library functions. Changing this file is not recommended unless necessary since any change to this file requires detailed knowledge of the DSP56100 family interrupt mechanism in addition to the semantics of the **signal** and **raise** functions. This file is closely tied to the **signal.h** file.

The **setjmp** file contains code which implements the functions **setjmp()** and **longjmp()**. This file will probably never need to be modified unless the signal file is changed; however, if either the **setjmp** file or **setjmp.h** are modified, the code in both files must be kept consistent. The source code for **setjmp()** and **longjmp()** is provided with DSP561CCC to allow modification, should the signal mechanism need to be changed.

The operation of **setjmp()** and **longjmp()** is described in Section 6.5 and detailed implementation information can be obtained from the files provided with DSP561CCC.

6.3 The crt0 File

The following subsections describe the various functions of the **crt0** file.

6.3.1 Bootstrapping the C program

The processor enters a C program through the C bootstrap code in the **crt0** file. The C bootstrap code in **crt0** provides the C environment required to execute a C program. This environment includes a global / static data area, stack area, heap area, etc. This environment must be established before C programs can execute correctly.

The following bootstrapping steps are normally taken before the processor starts to execute C code:

1. Jump from the chip reset vector to the C bootstrap code labeled at **F_ _start** in **ctr0**. Remember that the mode select pins on the chip control the chip operating mode when leaving reset which, in turn, controls the reset vector address (see the Motorola DSP56100 Family Manual for more details).
2. Configure all hardware registers needed (i.e,. **omr**, host port, etc.). This is also a proper place to initialize any non-C related data structures or peripheral hardware.
3. Load the Stack Pointer, **r2**, with a pointer to the base of the stack. Remember that the stack grows up (the value in the stack pointer gets greater as data is pushed). The value of **DSIZE** is generated by the linker and is the first address above the statically allocated data (C global and static variables). By default, this value is used as the initial stack pointer.
4. Call **main()** with instruction **jsr Fmain**. Notice that the label is **Fmain** and there are no parameters passed to the main function. The normal C compiler start-up passes two arguments but **g561c** does not pass any arguments because DSP561CCC does not support a particular hosted environment.

The bootstrap code is followed with the label **F_ _crt0_end**. This label is used by **gdb561** and **run561** to detect program termination.

Note: Labels which begin with a double underline (e.g., _ _crt0_end) in this manual have a space between the double underlines to visually separate them. **Do not separate the leading double underlines with a space when coding them** (i.e., code _ _crt0_end as __crt0_end).

Example 6-1 **DSP56100 Operation Mode Change:** Mode 2 has a reset vector of $E000 which must contain a **bra** to the C program bootstrap code. Adding the following code segment to the **crt0** file will change the bootstrap mode to Mode2.

```
section mode2_reset
org p:$e000
bra F_ _start              ; jump to the C start-up program.
endsec
```

Example 6-2 Hardware was designed to have a 256 byte ROM monitor located in the program memory space starting at $0000 and ending at $FF. Program RAM starts at location p:$100. The following changes to the **crt0** file will change the beginning location of the C bootstrap code to the first available RAM location (p:$100). The DS statement allocates program space starting at p:$0000 and lets the ROM be located at address p:$0000. The org statement places the C bootstrap code at memory location p:$100.

Change this portion of the **crt0** file:

```
            org     p:
    F_ _start
```

to:

```
            org p:$0
            ds $100                 ; reserve space
            org p:$100
    F_ _start
```

6.3.2 Memory Configuration and Management

The DSP56100 family supports two memory spaces: program memory (p memory) and x data memory. There are four data segments in the C programming environment. These are the program segment, global/static data segment, stack data segment and heap data

segment. The program segment is located in program memory. The three data segments are located in x memory.

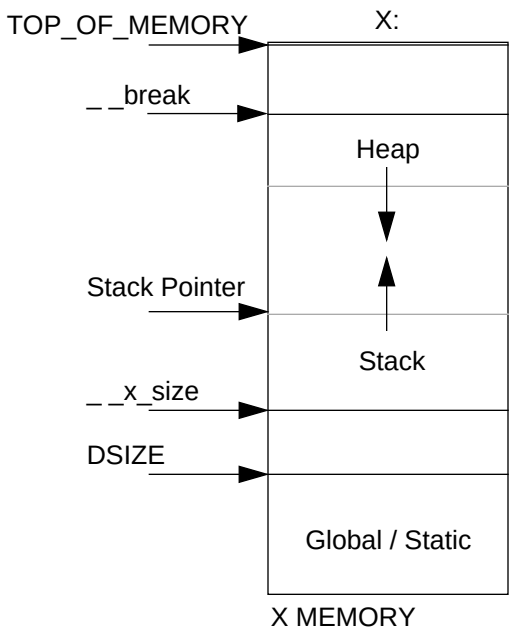


Figure 6-1 C Environment Memory Configuration

As indicated in Figure 6-1, global and static data reside at the bottom of the available data memory and the top address of the global and static data area, which is called **DSIZE**, is set by the linker. The constant **TOP_OF_MEMORY** is defined to indicate the top of the entire available memory.

The two data segments, heap and stack, are located as shown Figure 6-1. The stack is located so that it can grow up and the heap is located so that it can grow down. There are two locations used to indicate the initial values for the heap pointer and stack pointer. These locations are _ _**x_size** and _ _**break** and are initialized in the **crt0** file as **DSIZE** and **TOP_OF_MEMORY**, respectively.

In summary, two variables _ _**x_size** and _ _**break** and the constant **TOP_OF_MEMORY** are used to configure the data segments. The program segment is configured using the org statements in the **crt0** file. The variable, _ _**x_size**, should be initialized with the desired initial stack pointer and the variable, _ _**break**, should be initialized with the desired initial heap pointer.

Caution

The stack and heap regions must not contain on-chip peripheral memory or the static or global data regions. **Also**, no region may be reconfigured after the C main function is called. Variables _ _**x_size** and _ _**break** should not be altered by an arbitrary function since they are utilized by system level

libraries such as **malloc** and **free**.

Example 6-3 **Fast Stack:** In this example, it is desired that the stack reside in an 8k SRAM starting at x:$4000. The following program reserves the stack space using **org** and **ds** statements and sets the initial stack pointer to the SRAM stack area.

Add this section to the **crt0** file:

```
section fast_ram
org     x:$4000
ds      $2000
endsec
```

Change the following line of C bootstrap code in the **crt0** file:

```
move x:F_ _x_size,r2
```

to:

```
move #$4000,r2
```

Example 6-4 **Fast Heap:** It is desired that the heap reside in an 8k SRAM starting at x:$4000. The following program reserves the heap space using **org** and **ds** statements and sets the initial heap pointer to the SRAM heap area.

Add this section to the **crt0** file:

```
section fast_ram
org     x:$4000
ds      $2000
endsec
```

Change the following line in the **crt0** file:

```
TOP_OF_MEMORY       equ     $ffbe
```

to:

```
TOP_OF_MEMORY       equ     $5fff
```

Sometimes hardware configurations map more than one memory space into a single physical memory. Other implementations partially populate various address spaces leaving holes. Some may have different regions with fast memory and slow memory. All of these special cases can usually be handled by modifying the **crt0** file.

When both memory spaces are mapped into a single physical memory, the memory must be partitioned. A way to restrict the linker from overlapping these memory spaces is needed. For example, suppose that both the x and p spaces are mapped into the same 64k physical RAM and need to be partitioned with the low 48k for program memory and the high 16k for data memory.

The linker can be restricted from allocating across holes in physical memory by using the **org** and **ds** directives to confiscate those addresses. Note that the linker may not automatically take advantage of memory which is present between holes. It may be required to manually place data structures in order to utilize this memory.

6.3.3 Interrupt Vectors

The interrupt vector locations for the DSP56100 family (a.k.a. “interrupt source” in Section 8 of the DSP56100 Family Manual) contain one or two instructions each to be executed when the interrupt assigned to that location occurs. There are 32 interrupt vectors available, all of which should be initialized with some value to avoid undefined behavior resulting from an unexpected interrupt.

The **crt0** file contains code to initialize these interrupt vectors. By default, all but one of the vectors are initialized with the instruction **jsr Fabort**. The first element of the vector table, which is the hardware reset vector, is initialized with the instruction **jmp F_ _start.** The purpose of the C function **abort()**, which is labeled as **Fabort** in the assembly environment, is to stop program execution due to an error. The **F_ _start** labels the program address of the bootstrap code that calls **main()**.

Interrupt vectors that are to be used must be reprogrammed to point to the interrupt service routines instead of the **abort()** function. Initialization of the interrupt vectors in the **crt0** file reduces the size of the resulting application program and may increase its speed.

The following **crt0** code segment is the default interrupt vector table initialization.

```
section reset
org     p:$0
jmp     F_start
org     p:$2
dup     31
jsr     Fabort
endm
endsec
```

The interrupt vector table can be changed to point to user-provided interrupt service routines instead of the **abort()** routine in this portion of **crt0**. Example 6-5 illustrates how to initialize pointers to these user-provided interrupt service routines.

Example 6-5 **User-defined Interrupt Vector Table:** Assume the hardware supports all interrupts and each interrupt service routine is located at the address labeled interruptXX (where XX is the value of the interrupt vector). The following code initializes the interrupt vector table. Each service routine starting at interruptXX can be programmed in assembly language as shown in Example 6-6.

```
section reset
org     p:$0
jmp     F_start
jsr     interrupt02
jsr     interrupt04
jsr     interrupt06
jsr     interrupt08
…
jsr     interrupt3e
endsec
```

Example 6-6 **Interrupt Service Routine:** This service routine updates the global variable **F_ _time** at each hypothetical timer interrupt.

```
        section interrupt
        org         p:
        global      interrupt1c
interrupt1c
        move        (r6)+           ; secure the stack pointer
                                    ; (refer to section 5.4.1.4)
        move        r1,y:(r2)       ; save the r1 register
        move        x:F_ _time,r1   ; retrieve the variable _ _time
        move        (r1)+           ; increment the variable
        move        r1,x:F_ _time   ; save the result
        move        x:(r2)-,r1      ; restore the r2 register
        rti                         ; return from interrupt service
        endsec
```

Notice that fast interrupts can also be programmed by modifying the **crt0** file in the same way as for the long interrupts (see the DSP56100 Family Manual for more information on fast and long interrupts).

6.3.4 Miscellaneous Code

There are other data structures and code related to the run-time environment in the **crt0** file. They are:

1. The error code variable, **errno**, is a global integer used to record failure codes in C library calls. This error code variable is needed if standard ANSI C library calls are used. This variable can be utilized as a debugging aid in order to check which error code is returned from C function calls.

2. Heap-stack checking window variable, _ _**stack_safety**, is a global variable declared in the **crt0** file that is used by the heap allocation routines, **malloc()**, **calloc()** and **realloc()** to avoid heap-stack growth collisions. If the distance between the bottom of the heap and the top of the stack is less than the value contained in _ _**stack_safety**, then the heap allocation routine will return an error code indicating that no more memory is available. The value may be set as required by the application since the window _ _**stack_safety** is declared as a global variable.

3. Memory limit variable, _ _**mem_limit,** is a global variable declared in the **crt0** file and used by the library routine **brk()** to disallow any meaningless memory requests. This variable should have the same value as _ _**break** upon entry into **main().** For information on how to use the function **brk()**, refer to Appendix B in this manual.

4. Dynamic time variable, _ _**time,** is a global variable declared in the **crt0** file and used as a **volatile** timer counter by the simulator. This variable is updated by the DSP56100 simulator (**run561**) every clock cycle. Examining this variable allows the programmer to determine program execution time. This variable is only used by the simulator and can be omitted when the program is to be executed by hardware.

5. Host I/O stub functions, _ _**send()** and _ _ **receive(),** are defined in **crt0** and are called by the standard I/O library functions. The provided **crt0** file only has stub functions, as both **gdb561** and **run561** watch these addresses and perform all I/O directly.

All of these variables, constants, functions and pointers are related to the run-time environments that are used by C library functions and must be properly set.

6.4 Signal File

The hardware level interrupt mechanism (see section 8.3 of the DSP56100 Family Manual) is more efficient than the **signal()** function. However, in many cases interrupts can be handled in the C environment and it is often preferable to do so. There are two functions,

signal() and **raise()**, used to support programming interrupt service routines in C. These functions are not associated with the **crt0** file. Although they are more complicated than the simple hardware interrupt vector table discussed in Section 6.3.3 (see the DSP56100 Family Manual) they provide very handy tools for the C programmer. A thorough knowledge of the **signal()** function and the C environment is needed in order to modify the **signal()** function. This section describes how the **signal()** function is currently implemented.

6.4.1 Signal()

The **signal()** function is passed two arguments:

1. A **signal number** — On the DSP56100 family processor, the signal number corresponds directly to the interrupt vector address. Notice that the signal number is not an integer sequence but is an even number.
2. A **function pointer —** The function pointer passed is assumed to belong to a C function either generated by this compiler or by assembly code.

Signal() performs the following three steps when binding the specified signal number and function:

1. The instruction **jsr F_ _c_sig_goto_dispatch+<signal number>** is placed into the interrupt table location specified by the signal number.
2. The function pointer passed is entered into the table _ _**c_sig_handlers**, which is used to store pointers to C signal handlers, indexed by the signal number.
3. The old signal handler address is returned.

Once the signal number and specified function are bound, the instruction

```
jsr     F_ _c_sig_goto_dispatch+<signal number>
```

is executed upon receiving the interrupt, where the **F_ _c_sig_goto_dispatch** variable is the starting address of a table of

```
jsr     F_ _c_sig_dispatch
```

instructions and each **jsr** instruction points to an interrupt service routine. The pseudo-function _ _**c_sig_dispatch()** is used to calculate the actual C interrupt routine.

All registers are saved before the _ _**c_sig_dispatch()** function calls the C signal handler. Pseudo function _ _**c_sig_dispatch()** then calculates the signal number using the return address program counter of the ssh. Since the signal number is the same as the interrupt vector address, each entry of the _ _**c_sig_goto_dispatch** table corresponds to an interrupt vector. The pseudo function uses the signal number to fetch the actual C signal handler from the _ _**c_sig_handlers** table which is the C function pointer table.

Once the C signal handler is fetched from the _ _**c_sig_handler** table, its entry is replaced with the default signal handler **SIG_DFL**. This replacement is in compliance with the ANSI standard and forces the next signal service to abort. In most situations, this feature is not needed because any given interrupt will always invoke the same interrupt service routine. Resetting **signal()** after each C service routine or modifying this file so that it does not replace the table entry with **SIG_DFL** will change the interrupt service scheme. Modification of the signal file is only recommended when optimization of the service time is critical to the application.

Upon return from the C signal handler, all the registers are restored. Finally, the **rti** instruction is executed to return to the code that was executing when the interrupt occurred. Notice two factors in this scheme,

1. **all registers** are saved and restored before and after the C signal handler and
2. the **rti** instruction is executed by the _ _**c_sig_dispatch()** function.

Caution

The signal handler must not contain the **rti** instruction at the end of the program regardless which language is used to program the interrupt. The signal handler does not need to save or restore any context or registers. The function _ _**c_sig_dispatch()** will not act like a normal C function because it never returns to its caller. Instead, it will return to the code that was executing when the interrupt happened by executing the **rti** instruction.

Assembly language interrupt handlers can coexist with C signal handlers. The code in the signal file will not alter any interrupt vector except the one specified by the signal number passed to the **signal()** function (see the first of the three steps above). The C signal interface could be used with an assembly routine but would be unnecessarily slow. To use an assembly language interrupt handler, alter the vector (e.g., interrupt 08) with a **jsr** to it (e.g., **jsr interrupt 08**)or use a fast interrupt routine.

6.4.2 Raise()

The **raise()** function is used to simulate an interrupt. The code in **raise()** simply calls the entry in _ _**c_sig_goto_dispatch** that is matched to the interrupt vector specified by the signal number passed.

The ANSI standard signal handlers **SIG_DFL**, **SIG_ERR** and **SIG_IGN** are implemented by the hand-coded functions _ _**sig_dfl()**, _ _**sig_err()** and **_ _sig_ign()**, respectively.

1. **SIG_DFL** notes that the interrupt happened by incrementing _ _**sig_drop_count** and then returns.
2. **SIG_ERR** calls **abort()** and never returns.

3. **SIG_IGN** returns without any effect (i.e., ignore).

The mechanisms used to implement the C signal interface may be altered to fit a particular hardware application. Any series of alterations applied to the signal file must leave an implementation conforming to the ANSI standard X3.159 for C. Alteration of the signal file is done at one's own risk and is not generally advised. Again, the contents of the signal file must remain consistent with the include file **signal.h.**

6.5 Setjmp File

The functions **setjmp()** and **longjmp()** are implemented in the **setjmp** file. The **setjmp()** function stores the current process status (i.e., the current execution context) in a buffer that is passed. The **longjmp()** function is used to restore the process status to the execution context which was saved by **setjmp()**.

Saving the current execution context is done by saving the stack pointer, the return program counter value, the frame pointer and all of the callee-save registers into the buffer. The buffer that is passed to **setjmp()** should have enough space for the saving process. The structure **jmp_buf** defined in **setjmp.h** allocates the buffer space needed for the operation. The function **setjmp()** always returns a zero.

The function **longjmp()** takes two arguments, an environment buffer and a return value. It restores all registers from the buffer passed, including the frame pointer and stack pointer. It then places the return value passed into accumulator **a** and sets the **ccr** to reflect the return value just stored in accumulator **a**. The function **longjmp()** discards the return program counter on the hardware stack and jumps to the address pointed to by the program counter stored in the buffer.

This file must conform to the include files **setjmp.h** and **longjmp.h.** Since these two algorithms are very straightforward, modification of the file may be not needed. If modification is absolutely necessary, then the ANSI standard of the functions **setjmp()** and **longjmp()** should be followed.

6.6 Host-Supported I/O (printf (), et al)

The library provided with DSP561CCC includes a full implementation of the ANSI C standard input and output routines. These routines already work with **gdb561** and **run561**, and can easily be embedded in custom applications. Anywhere that formatted I/O is desired, these library routines can be included to simplify development. The entire suite of routines is based upon a simple communication protocol between the DSP and a host resident I/O driver, so porting the entire system to custom hardware is trivial.

6.6.1 DSP functions __send () and __receive ()

All standard I/O functions, no matter how complicated, are built upon two simple communication functions, **__send ()**, and **__receive ()**. **__send ()** sends a message to the I/O driver code residing on the host. **__receive ()** retrieves a message from that same driver. Implementing these two functions is all that need be done on the DSP in order to support standard I/O on custom hardware.

It is assumed that some sort of hardware communication channel exists between the host and the DSP. **__send ()** and **__receive ()** implement a simple message passing mechanism on top of such a channel. **__send ()** accepts two arguments: the address of the buffer to send, and the number of words to draw from that buffer. **__receive ()** accepts the address of a buffer in which to place the received message as its single argument. All of the interactions between the host and DSP are driven by the library code running on the DSP; because the DSP is in control, it knows the size of return messages from the host, rendering a count argument to the function **__receive ()** superfluous. **__send ()** and **__receive ()** are as simple as they seem; the complexity of the standard I/O package is embedded in the host-side driver and the **lib561c.clb** library routines.

6.6.2 The Host-Side I/O Driver

The application running on the host must have the provided I/O driver embedded in it. The driver is written in C, and uses typically available library routines such as **open (), close ()**, **read ()**, and **write ()** to perform the actions requested by the DSP. The I/O code is written as an event-driven state machine, so that the host side application can perform concurrently with the DSP when the DSP is not requesting I/O activity. In fact, the I/O driver on the host may be interrupt driven.

The host-side driver consists of the code in **dsp/etc/hostio.h** and **dsp/etc/hostio.c**. The meat of the package consists of two functions, **init_host_io_structures ()** and **process_pending_host_io ()**, and two buffers **hio_send** and **hio_receive**. The function **init_host_io_structures ()** is called to initialize host-side driver data structures before DSP execution is commenced. The buffer **hio_send** is used to send messages to the DSP, and **hio_receive** is used to receive messages from the DSP. The function **process_pending_host_io ()** considers the current state of the buffers and its own internal state, and then performs any required buffer modification or host I/O.

6.6.3 Communication between the Host and DSP

The messages passed between the DSP and the host's I/O driver are defined in the file **dsp/include/ioprim.h**. All sequences of communication are initiated by the DSP as a direct result of a call to a standard I/O function. Each standard I/O call may initiate a series of messages between the DSP and the host, with the host eventually returning a message containing the completion status of the original request. The file **dsp/include/ioprim.h** is

included by both the host-side I/O driver, and the standard I/O library code; it defines the constant definitions used in the aforementioned messages. A typical series of events and messages that comprise a standard I/O call might look like this:

1) The application running on the DSP makes a call to **fopen ()**.

2) The library code in **lib561c.clb** calls __**send ()**, with a buffer that contains the code **DSP_OPEN**, the flags, the mode, and the string length of the path.

3) The host receives the message into the buffer **hio_receive**, sets its valid flag, and calls **process_pending_host_io ()**. The state machine inside **process_pending_host_io ()** notes that it is now in the middle of an open file request, records the values from the first message, and then returns. At this point, code written by the application developer must check the valid flag of the buffer hio_send; in this case, the buffer **hio_send** has not been marked valid.

4) The library code in **lib561c.clb** calls __**send ()** again, this time sending the path.

5) Again, the host receives the message into the buffer **hio_receive**, and calls **process_pending_host_io ()** after setting the buffer's valid flag.

6) **process_pending_host_io ()** uses the information from the two messages to perform the file open. It then builds an operation status message, places it in the buffer **hio_send**, and sets that buffer's valid flag. **process_pending_host_io ()** resets its internal state and returns.

7) The host checks the buffer valid flag on **hio_send**, sees that it is true, and transmits the message to the DSP.

8) The library code running on the DSP finishes the **fopen ()** call and returns.

On the host side of the interface, the application writer must write the code that exchanges data with the DSP, the code that calls **process_pending_host_io ()**, and the code that checks buffer valid flags. On the DSP side of the interface, the application writer must write the routines __**send ()** and __**receive ()**. The communication between the DSP and the host is always initiated by the DSP and always follows a predetermined pattern, depending on the initial message. Because this communication is so simple, the code that calls **process_pending_host_io ()** can also be quite simple.

Example 6-7 is a hypothetical non-reentrant interrupt handler written in C. It uses two functions, **peek ()** and **poke ()**, to access some sort of hardware communication device connected to the DSP. The functions **peek ()** and **poke ()** aren't provided; they're simply an abstraction for host-side hardware access. This code assumes that the DSP sends the size of a message directly before sending a message. **CHECK_BUFFER_SIZE** is a macro defined in **dsp/etc/hostio.h**. It should always be used to ensure that the buffer

hio_receive is large enough to handle the incoming message. Finally, this example assumes that the function **signal ()** is available to register interrupt handlers.

This code doesn't have to be implemented in an interrupt driven manner; periodic polling could be used as well. The critical issues are that the communication must be reliable, and that the system must not deadlock; the latter is easy to ensure, given the simple nature of the communication protocol.

Example 6-7 Sample Host-Side Glue Code

```
void interrupt_driven_io ( )
{
        int i;

        /* get the size of the message from the DSP. */
        int size = peek ( IN_PORT );

        /* make sure that hio_receive is large enough. */
        CHECK_BUFFER_SIZE ( & hio_receive, size );

        /* read the message via hardware, into the buffer. */
        for ( i = 0; i < size; ++ i )
        {
                hio_receive.buffer[i] = peek ( IN_PORT );
        }

        /* mark the buffer as valid, perform any requested I/O. */
        hio_receive.valid_p = TRUE;
        process_pending_host_io ( );

        /* if the driver wants to send to the DSP, then do so now. */
        if ( hio_send.valid_p )
        {
                for ( i = 0; i < hio_send.length; ++ i )
                {
                        poke ( OUT_PORT, hio_send.buffer[i] );
                }
                hio_send.valid_p = FALSE;
        }

        /* re-register this handler for future DSP message interrupts. */
        signal ( SIG_IN_PORT, interrupt_driven_io );
}
```

Appendix A
Library Support

A.1 Standard ANSI Header Files

Each function provided in the ANSI C library **lib561c.clb** is declared with the appropriate prototype in a header file, whose contents may be included by using the **#include** preprocessing directive with angular brackets. In addition to function prototypes, the header also defines all type and MACRO definitions required for ANSI conformance.

The ANSI standard header files provided are:

assert.h	locale.h	stddef.h
ctype.h	math.h	stdio.h
errno.h	setjmp.h	stdlib.h
float.h	signal.h	string.h
limits.h	stdarg.h	time.h

In general, header files may be included in any order and as often as desired with no negative side effects. The one exception occurs when including **assert.h**. The definition of the assert macro depends on the definition of the macro **NDEBUG**.

The contents of the standard header files provided are exactly as described by the ANSI document X3.159-1989 dated December 14, 1989.

A.2 ANSI C Library Functions

The library contains all of the ANSI defined subroutines. The C and assembly language source for each library routine is distributed free of charge with the compiler.

A.2.1 Hosted vs. Non-Hosted Library Routines

Some of the standard ANSI defined routines perform I/O. Programs that use these functions will not encounter problems when run using **gdb561** or **run561**. Extra work may be needed to port hosted I/O routines to custom hardware configurations. Non-hosted routines will not encounter any problems on custom hardware.

For a description of run561, see Appendix C.

A.3 Forcing Library Routines Out-of-line

For performance reasons, several run-time library routines have been created to be used in-line by the compiler. The compiler in-lines a subroutine by replacing the occurrence of the subroutine call with the body of the subroutine itself. This provides execution time benefits:

1. Eliminates subroutine call overhead. This is a substantial portion of the run-time for some library routines.
2. Exposes more optimization opportunities to the optimizer.

The following library routines are automatically in-lined by the compiler when their header file is included:

header: **ctype.h**

- isalnum
- isalpha
- iscntrl
- isdigit
- isgraph
- islower
- isprint
- ispunct
- isspace
- isupper
- isxdigit
- tolower
- toupper

header: **math.h**

- ceil
- fabs
- floor
- fmod

header: **stdlib.h**

- abs
- labs

header: **string.h**

- strcmp
- strcpy

When it is necessary to disable this feature, possibly for debugging or decreasing program size, simply do one of the following:

1. Add the following line to each C module (or once to a common header file)

   #undef ROUTINE_NAME

   where ROUTINE_NAME is the library routine that must be forced out-of-line. For example, to force the library routine **ceil** out-of-line:

   #undef **ceil**

2. Use the command-line option **-U**, see Chapter 3, Control Program Options. This will force the library routine to be called for this compilation**.** If the code is re-compiled, the **-U** option must be used again.

```
C:\> g561c -Uceil file.c
```

A.4 Function Descriptions

The following section describes each function in complete detail. The synopsis provides the syntax of the function, and the options section discusses each option in detail. Many function descriptions also include references to related functions and an example of how to use the function. The following list provides an abbreviated description of each function.

abort — Force abnormal program termination.
abs — Absolute value of integer.
acos — Arc cosine.
asin — Arc sine.
atan — Arc tangent.
atan2 — Arc tangent of angle defined by point y/x.
atexit — Register a function for execution upon normal program termination.
atof — String to floating point.
atoi — String to integer.
atol — String to long integer.
bsearch — Perform binary search.
calloc — Dynamically allocate zero-initialized storage for objects.
ceil — Ceiling function.
clearerr — Clear error indicators associated with a stream.
cos — Cosine.
cosh — Hyperbolic cosine.
div — integer division with remainder.
exit — Terminate program normally.
exp — Exponential, e^x.

fabs — Absolute value of a double.
fclose — Close a stream.
feof — Test the end-of-file indicator of a stream.
ferror — Test the error indicator of a stream.
fflush — Flush all output pending on a stream.
fgetc — Read a character from a stream.
fgetpos — Retrieve the current value of the file position indicator of a stream.
fgets — Read a string from a stream.
floor — Floor function.
fmod — Floating point remainder.
fopen — Open a named file on the disk, to be accessed via a stream.
fprintf — Write formatted output to a stream.
fputc — Write a character to a stream.
fputs — Write a string to a stream.
fread — Read unformatted input from a stream.
free — Free storage allocated by calloc, malloc, and realloc.
freopen — Open a named file on the disk, to be accessed via a stream.
frexp — Break a floating point number into mantissa and exponent.
fscanf — Read formatted input from a stream.
fseek — Set a stream's file position indicator.
fsetpos — Set a stream's file position indicator.
ftell — Retrieve the current value of a stream's file position indicator.
fwrite — Write unformatted output to a stream.
getc — Read a character from a stream (this may be a macro).
getchar — Read a character from the stream stdin (this may be a macro).
gets — Read a string from the stream stdin.
isalnum — Test for alphanumeric character.
isalpha — Test for alphabetic character.
iscntrl — Test for control character.
isdigit — Test for numeric character.
isgraph — Test for printing character, excluding space and tab.
islower — Test for lower-case alphabetic characters.
isprint — Test for printing character, excluding '\t'.
ispunct — Test for punctuation character.
isspace — Test for white-space character.
isupper — Test for upper-case alphabetic character.
isxdigit — Test for hexadecimal numeric character.
labs — Absolute value of a long integer.
ldexp — Multiply floating point number by a power of two.
ldiv — Long integer division with remainder.

log — Natural logarithm, base e.
log10 — Base ten logarithm.
longjmp — Execute a non-local jump.
malloc — Dynamically allocate uninitialized storage.
mblen — Length of a multibyte character.
mbstowcs — Convert multibyte string to wide character string.
mbtowc — Convert a multibyte character to a wide character.
memchr — Find a character in a memory area.
memcmp — Compare portion of two memory areas.
memcpy — Copy from one area to another.
memmove — Copy from one area to another (source and destination may overlap).
memset — Initialize memory area.
modf — Break a double into it's integral and fractional parts.
perror — Print error message indicated by errno.
pow — Raise a double to a power.
printf — Write formatted output to the stream stdout.
putc — Write a character to a stream (this may be a macro).
putchar — Write a character to the stream stdout (this may be a macro).
puts — Write a string to the stream stdout.
qsort — Quick sort.
raise — Raise a signal.
rand — Pseudo- random number generator.
realloc — Change size of dynamically allocated storage area.
remove — Remove a file from the disk.
rename — Rename a file on the disk.
rewind — Reset the file position indicator of a stream to the beginning of the file on the disk.
scanf — Read formatted input from the stream stdin.
setjmp — Save a reference of the current calling environment for later use by longjmp.
setbuf — Associate a buffer with a stream.
setvbuf — Associate a buffer with a stream, while also specifying the buffering mode and buffer size.
signal — Set up signal handler.
sin — Sine.
sinh — Hyperbolic Sine.
sprintf — Write formatted output to a string.
sqrt — Square root.
srand — Seed the pseudo-random number generator.
sscanf — Read formatted input from a string.
strcat — Concatenate two strings.

strchr — Find first occurrence of a character in a string.
strcmp — Compare two strings.
strcoll — Compare two strings based on current locale.
strcpy — Copy one string into another.
strcspn — Compute the length of the prefix of a string not contained in a second string.
strerror — Map error code into an error message string.
strlen — Determine length of a string.
strncat — Concatenate a portion of one string to another.
strncmp — Compare a portions of two strings.
strncpy — Copy a portion of one string into another.
strpbrk — Find the first occurrence of a character from one string in another.
strrchr — Find the last occurrence of a character in a string.
strspn — Compute the length of the prefix of a string contained in a second string.
strstr — Find the first occurrence of one string in another.
strtod — String to double.
strtok — Break string into tokens.
strtol — String to long integer.
strtoul — String to unsigned long integer.
strxfrm — Transform a string into locale-independent form.
tan — Tangent.
tanh — Hyperbolic tangent.
tmpfile — Create a temporary binary file on the disk to be referenced via a stream.
tmpnam — Generate a unique, valid file name.
tolower — Convert uppercase character to lowercase.
toupper — Convert lowercase character to uppercase.
ungetc — Push a character back onto a specified input stream.
vfprintf — Write formatted output to a stream, using a va_list.
vprintf — Write formatted output to the stream stdout, using a va_list.
vsprintf — Write formatted output to a string, using a va_list.
wcstombs — Convert wchar_t array to multibyte string.
wctomb — Convert wchar_t character to multibyte character.

NAME

abort — Force abnormal program termination**.**

SYNOPSIS

```
#include <stdlib.h>
void abort (void);
```

DESCRIPTION

The **abort** function causes the program to terminate abnormally unless the signal **SIGABRT** is being caught and the signal handler does not return. The unsuccessful termination value, **-1**, is returned to the host environment (**gdb561**, **run561**). The **abort** function will not return to its caller.

SEE ALSO

exit — Terminate a program normally.

signal — Set up a signal handler.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        printf("-- make abort call --\n");
        abort();
        printf("this line not reached\n");
}
```

prints to standard output:

```
-- make abort call --
```

NAME

abs — Absolute value of integer.

SYNOPSIS

```
#include <stdlib.h>
int abs (int j);
```

DESCRIPTION

The **abs** function returns the absolute value of **j**.

When the header file **stdlib.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

SEE ALSO

fabs — Absolute value of a double.

labs — Absolute value of a long.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        int neg = -709;
        printf("-- abs(%d) == %d --\n", neg,abs( neg ));
}
```

prints to standard output:

```
-- abs(-709) == 709 --
```

NAME

acos — Arc cosine.

SYNOPSIS

```
#include <math.h>
double acos ( double x );
```

DESCRIPTION

The **acos** function computes the principal value of the arc cosine of **x** in the range [0.0, π], where **x** is in radians. If **x** is not in the range [-1, +1], a domain error occurs, **errno** is set to **EDOM** and a value of 0.0 is returned.

SEE ALSO

cos — Cosine.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        double point;

        for ( point = -0.8 ; point < 1.0 ; point += 0.2 )
        {
                printf( "%f ", acos( point ) );
                if ( point >= 0.0 ) printf( "\n" );
        }
}
```

prints to standard output:

```
2.498090 2.214290 1.982310 1.772150 1.570790 1.369430
1.159270
0.927295
0.643501
0.000345
```

NAME

asin — Arc sine.

SYNOPSIS

```
#include <math.h>
double asin ( double x );
```

DESCRIPTION

The **asin** function computes the principal value of the arc sine of **x** in the range [-π/2, +π/2], where **x** is in radians. If **x** is not in the range [-1, +1], a domain error occurs, **errno** is set to **EDOM** and a value of 0.0 is returned.

SEE ALSO

sin — Sine.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        double point;

        for ( point = -0.8 ; point < 1.0 ; point += 0.2 )
        {
                printf( "%f ", asin( point ) );
                if ( point >= 0.0 ) printf( "\n" );
        }
}
```

prints to standard output:

```
-0.927295 -0.643501 -0.411516 -0.201357 -0.000000 0.201357
0.411516
0.643501
0.927295
1.570450
```

NAME

atan — Arc tangent.

SYNOPSIS

```
#include <math.h>
double atan ( double x );
```

DESCRIPTION

The **atan** function computes the principal value of the arc tangent of **x** in the range [-π/2, +π/2], where **x** is in radians.

SEE ALSO

tan — Tangent.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        double point;

        for ( point = -0.8 ; point < 1.0 ; point += 0.2 )
        {
                printf( "%f ", atan( point ) );
                if ( point >= 0.0 ) printf( "\n" );
        }
}
```

prints to standard output:

```
-0.674740 -0.540419 -0.380506 -0.197395 -0.000000 0.197395
0.380506
0.540419
0.674740
0.785398
```

NAME

atan2 — Arc tangent of angle defined by point y/x.

SYNOPSIS

```
#include <math.h>
double atan2 ( double y, double x );
```

DESCRIPTION

The **atan2** function computes the principal value of the arc tangent of **y/x** using the signs of both arguments to determine the quadrant of the return value. If both arguments are zero, **errno** is set to **EDOM** and 0.0 is returned.

argument range	output range
$y \geq 0.0, x \geq 0.0$	$[0.0, \pi/2]$
$y \geq 0.0, x < 0.0$	$[\pi/2, \pi]$
$y < 0.0, x < 0.0$	$[-\pi, -\pi/2]$
$y < 0.0, x \geq 0.0$	$[-\pi/2, 0.0]$

SEE ALSO

atan — Arc tangent.

tan — Tangent.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf("atan2(7.09,7.09)  == %f\n", atan2(7.09,7.09));
        printf("atan2(-7.09,7.09) == %f\n", atan2(-7.09,7.09));
        printf("atan2(7.09,-7.09) == %f\n", atan2(7.09,-7.09));
        printf("atan2(-7.09,-7.09) == %f\n",atan2(-7.09,-7.09));
}
```

prints to standard output:

```
atan2( 7.09, 7.09 ) == 0.785398
atan2( -7.09, 7.09 ) == -0.785398
atan2( 7.09, -7.09 ) == 2.356190
atan2( -7.09, -7.09 ) == -2.356190
```

NAME

atexit — Register a function for execution at normal program termination.

SYNOPSIS

```
#include <stdlib.h>
int atexit ( void (*func) (void) );
```

DESCRIPTION

The **atexit** registers a function **func** that will be called at normal program execution. The registered function is called without arguments and returns nothing.

A total of 32 functions may be registered and will be called in the reverse order of their registration. The **atexit** function returns zero if registration succeeds and a non-zero value for failure.

SEE ALSO

exit — Terminate a program normally.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void func_1 ( void )
{
        printf ( "first function called\n" );
}

void func_2 ( void )
{
        printf ( "second function called\n" );
}

void main ( )
{
        atexit ( func_1 );
        atexit ( func_2 );
        printf ( "-- testing atexit --\n" );
}
```

prints to standard output:

```
-- testing atexit --
second function called
first function called
```

NAME

atof — String to floating point.

SYNOPSIS

```
#include <stdlib.h>
double atof ( const char* nptr );
```

DESCRIPTION

The **atof** function converts the string pointed to by **nptr** to a double. If the result can not be represented, the behavior is undefined. This is exactly equivalent to:

```
strtod ( nptr, (char **) NULL );
```

SEE ALSO

atoi — String to integer.
atol — String to integer.
strtod — String to double.
strtol — String to long integer.
strtoul — String to unsigned long integer.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        printf( "atof ( \"7.09\" ) == %f\n", atof ( "7.09" ) );
}
```

prints to standard output:

```
atof( "7.09" ) == 7.089990
```

NAME

atoi — String to integer.

SYNOPSIS

```
#include <stdlib.h>
int atoi ( const char* nptr );
```

DESCRIPTION

The **atoi** function converts the string pointed to by **nptr** to an integer. If the result can not be represented, the behavior is undefined. This is exactly equivalent to:

```
(int) strtol ( nptr, (char **) NULL, 10 );
```

SEE ALSO

atof — String to double.
atol — String to long integer.
strtod — String to double.
strtol — String to long integer.
strtoul — String to unsigned long integer.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        printf( "atoi( \"709\" ) == %d\n", atoi( "709" ) );
}
```

prints to standard output:

```
atoi( "709" ) == 709
```

NAME

atol — String to long integer.

SYNOPSIS

```
#include <stdlib.h>
long atol ( const char* nptr );
```

DESCRIPTION

The **atol** function converts the string pointed to by **nptr** to a long integer. If the result can not be represented, the behavior is undefined. This is exactly equivalent to:

```
strtol( nptr, (char **) NULL, 10 );
```

SEE ALSO

atof — String to double.
atoi — String to integer.
strtod — String to double.
strtol — String to long integer.
strtoul — String to unsigned long integer.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
    printf( "atol( \"709\" ) == %ld\n", atol( "709" ) );
}
```

prints to standard output:

```
atol( "709" ) == 709
```

NAME

bsearch — Perform binary search.

SYNOPSIS

```
#include <stdlib.h>
void bsearch (      const void* key, const void* base,
                    size_t nmemb, size_t size,
                    int (*compare) (const void*, const void* ) );
```

DESCRIPTION

The **bsearch** function searches an array of **nmemb** objects (the initial element of which is pointed to by **base**) for an element that matches the object pointed to by **key**. The size of each element is specified by **size**.

The contents of the array must be in ascending order according to a user supplied comparison function, **compare**. The **compare** function is called with two arguments that must point to the **key** object and to an array member, in that order. Also, **compare** must return an integer that is less than, equal to, or greater than zero for the **key** object to be respectively considered less than, equal to or greater than the array element.

SEE ALSO

qsort — Perform quick sort.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

char* stuff[6] =
{
        "bald", "driving", "feet", "flintstone", "fred", "on"
};

int compare ( const void *key, const void *aelement )
{
        return ( strcmp( *(char*) key, *(char*) aelement ) );
}


void main()
{
        char* p;
        char* key = "bald";
        p = bsearch( &key, stuff, 6, sizeof(char*), compare );
        if ( p )
        {
                printf( "YES, fred flintstone drives on bald feet\n" );
        }

        else
        {
                printf( "NO, sam the butcher brings alice the meat\n" );
        }
}
```

prints to standard output:

```
YES, fred flintstone drives on bald feet
```

NAME

calloc — Dynamically allocate zero-initialized storage for objects.

SYNOPSIS

```
#include <stdlib.h>
void* calloc ( size_t nmemb, size_t size );
```

DESCRIPTION

The **calloc** function allocates space for an array of **nmemb** objects, each of whose size is **size**. The space is initialized to all bits equal zero. If space can not be allocated, **calloc** returns a **NULL** pointer.

SEE ALSO

free — Free dynamically allocated storage.

malloc — Dynamically allocate uninitialized storage.

realloc — Alter size of previously dynamically allocated storage.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

int* iptr;

/* allocate space for 709 integers */
void main()
{
        iptr= (int*) calloc( 709, sizeof(int) );

        if ( iptr != NULL )
        {
                /* check first entry for zero initialization */
                if ( *iptr != 0 )
                {
                        printf( "error: calloc failed to initialize\n" );
                }

                else
                {
                        printf( "success: calloc ok\n" );
                }
        }

        else
        {
                printf( "error: calloc failed\n" );
        }
}
```

prints to standard output:

```
success: calloc ok
```

NAME

ceil — Ceiling function.

SYNOPSIS

```
#include <math.h>
double ceil ( double x );
```

DESCRIPTION

The **ceil** function returns the smallest integer greater than or equal to **x**.

When the header file **math.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

SEE ALSO

floor — Floor function.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "ceil( 7.09 ) == %f\n", ceil( 7.09 ) );
}
```

prints to standard output:

```
ceil( 7.09 ) == 8.000000
```

NAME

clearerr — Clear any error indicators associated with a specified stream.

SYNOPSIS

```
#include <stdio.h>
void clearerr ( FILE *stream );
```

DESCRIPTION

The **clearerr** function clears the end-of-file and error indicators for the specified stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        FILE *stream = tmpfile (); /* initially empty. */
        clearerr ( stream );
        printf ( “end-of-file indicator is: %d\n”, feof ( stream ));
}
```

prints to standard output:

```
end-of-file indicator is: 0
```

NAME

cos — Cosine.

SYNOPSIS

```
#include <math.h>
double cos ( double x );
```

DESCRIPTION

The **cos** function computes and returns the cosine of **x**, measured in radians.

SEE ALSO

acos — Arc cosine of an angle.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "cos( 45.0 ) == %f\n", cos( 45.0 ) );
}
```

prints to standard output:

```
cos( 45.0 ) == 0.525322
```

NAME

cosh — Hyperbolic cosine.

SYNOPSIS

```
#include <math.h>
double cosh ( double x );
```

DESCRIPTION

The **cosh** function computes and returns the hyperbolic cosine of **x**. If the value of **x** is too large, a range error occurs, setting errno to **ERANGE** and causes **cosh** to return **HUGE_VAL**.

SEE ALSO

sinh — Hyperbolic sin.

tanh — Hyperbolic tangent.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "cosh( 3.1415 ) == %f\n", cosh( 3.1415 ) );
}
```

prints to standard output:

```
cosh( 3.1415 ) == 11.590800
```

NAME

div — Integer division with remainder.

SYNOPSIS

```
#include <stdlib.h>
div_t div ( int numer, int denom );
```

DESCRIPTION

The **div** function computes the quotient and remainder of the division of the numerator **numer** by the denominator **denom** and returns them in a structure of type **div_t**. If the result can not be represented, the behavior is undefined.

SEE ALSO

ldiv — Long integer division with remainder.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        div_t   result;
        int     numer = 709, denom = 56;

        result = div( numer, denom );
        printf( "quotient == %d\t", result.quot );
        printf( "remainder == %d\n", result.rem);
}
```

prints to standard output:

```
quotient == 12 remainder == 37
```

NAME

exit — Terminate program normally.

SYNOPSIS

```
#include <stdlib.h>
void exit ( int status );
```

DESCRIPTION

The **exit** function causes normal program termination to occur. Any functions registered with the function **atexit** are called in the order in which they where registered. Status is returned to the environment (**gdb561**, **run561**). If more than one call is made to **exit**, the result is undefined.

SEE ALSO

abort — Cause a program to terminate abnormally.

atexit — Register functions to be called at normal program termination.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        printf( "-- exit test --\n" );
        exit ( 0 );/* return with 0 status */
        printf( "Error: exit made this unreachable\n" );
}
```

prints to standard output:

```
-- exit test --
```

NAME

exp — Exponential, e^x.

SYNOPSIS

```
#include <math.h>
double exp ( double x );
```

DESCRIPTION

The **exp** function computes and returns $e^{\mathbf{x}}$**.** If the value of **x** is too large, a range error occurs with errno being set to **ERANGE** and **exp** returning **HUGE_VAL**. If the value of **x** is too small, a range error will also occur with errno being set to **ERANGE** and exp returning 0.0.

SEE ALSO

ldexp — Multiplying a number by a power of two.

pow — Raising a number to a power.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "exp( 7.09 ) == %f\n", exp( 7.09 ) );
}
```

prints to standard output:

```
exp( 7.09 ) == 1199.900000
```

NAME

fabs — Absolute value of a double.

SYNOPSIS

```
#include <math.h>
double fabs ( double x );
```

DESCRIPTION

The **fabs** function computes and returns the absolute value of **x**.

When the header file **math.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

SEE ALSO

abs — Absolute value of an integer.

labs — Absolute value of a long integer.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        double pos, neg = -7.09;

        pos = fabs( neg );
        printf( "-- absolute value of %f == %f --\n", neg, pos );
}
```

prints to standard output:

```
-- absolute value of -7.090000 == 7.090000 --
```

NAME

fclose — Close a stream.

SYNOPSIS

```
#include <stdio.h>
int fclose ( FILE * );
```

DESCRIPTION

The function **fclose** flushes all output on the specified stream, and disassociates the stream from the file on the host. The function **fclose** returns **EOF** if there are any problems, otherwise 0.

SEE ALSO

fprintf — Used to write formatted output to a stream.

EXAMPLE

```
#include <stdio.h>

void main()
{
        fprintf ( stdout, “see me second” );
        fprintf ( stderr, “see me first\n” );
        fclose ( stdout );
}
```

prints to combined standard error and standard output:

```
see me first
see me second
```

Note that **stdout** is by default line buffered, while **stderr** is not. The call to **fclose** causes the pending output on **stdout** to be flushed.

NAME

feof — Test the end-of-file indicator of a specified stream.

SYNOPSIS

```
#include <stdio.h>
int feof ( FILE * );
```

DESCRIPTION

The function **feof** function tests the end-of-file indicator associated with the specified stream. It returns non-zero if and only if the end-of-file indicator is set.

SEE ALSO

fopen — Used to associate a stream with a file on the host's disk.

fseek — Used to alter the file position indicator associated with a stream.

fprintf — Used to write formatted output to a stream.

EXAMPLE

```
#include <stdio.h>

void main()
{
        FILE *somefile = fopen ( "somefile", "rb+" );
        (void) fseek ( somefile, 0L, SEEK_END );
        (void) fgetc ( somefile );
        fprintf ( stdout, "are we at the file's end? %s\n",
                        feof ( somefile ) ? "yes" :  "no" );
}
```

prints to standard output:

```
are we at the file's end? yes
```

NAME

ferror — Test the error indicator of a stream.

SYNOPSIS

```
#include <stdio.h>
int ferror ( FILE * );
```

DESCRIPTION

The function **ferror** function tests the error indicator associated with the specified stream. It returns non-zero if and only if the error indicator is set. **ferror** should be used following one or more stream I/O function calls.

NAME

fflush — Flush all pending output associated with a stream.

SYNOPSIS

```
#include <stdio.h>
void fflush ( FILE* );
```

DESCRIPTION

The function **fflush** causes any pending output associated with the specified stream to be written to the output device.

SEE ALSO

fprintf — Used to write formatted output to a stream.

EXAMPLE

```
#include <stdio.h>

void main()
{
        fprintf ( stdout, “see me second” );
        fprintf ( stderr, “see me first\n” );
        fflush ( stdout );
}
```

prints to combined standard error and standard output:

```
see me first
see me second
```

Note that **stdout** is by default line buffered, while **stderr** is not. The call to **fflush** causes the pending output on **stdout** to be flushed.

NAME

fgetc — Read a character from the specified stream.

SYNOPSIS

```
#include <stdio.h>
int fgetc ( FILE *stream );
```

DESCRIPTION

The function **fgetc** will retrieve the next input character from the specified stream. If the stream is associated with a file on the disk, then the file position indicator is advanced. On error, **fgetc** returns **EOF**.

SEE ALSO

fputc — Write a character to a stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        char value = (char) fgetc ( stdin );

        while ( EOF != value )
        {
                fputc ( value, stdout );
                value = (char) fgetc ( stdin );
        }
}
```

will echo all characters from standard input to standard output until the input is exhausted.

NAME

fgetpos — Get the value of the file position indicator associated with a stream.

SYNOPSIS

```
#include <stdio.h>
int fgetpos ( FILE *stream, fpos_t *pos );
```

DESCRIPTION

The function **fgetpos** fetches the value of the file position indicator associated with **stream** and stores it in the object pointed to by **pos**. **fgetpos** returns zero if it was successful. The value of the file position indicator is meaningless except as an argument to the function fsetpos.

SEE ALSO

fopen — Open a file on the host's disk and associate it with a stream.

fseek — Used to alter the file position indicator associated with a stream.

fsetpos — Set the value of the file position indicator associated with a stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        FILE *preexisting = fopen ( "already.here", "r" );
        fpos_t pos;

        (void) fgetpos ( preexisting, & pos );
        (void) fseek ( preexisting, 0L, SEEK_END );
        (void) fsetpos ( preexisting, & pos );
}
```

will open a hypothetical pre-existing file on the disk, record the initial position in pos, seek to the end of the file, and finally restore the initial value of the file position indicator.

NAME

fgets — Read a string from the specified stream.

SYNOPSIS

```
#include <stdio.h>
char *fgets ( char *s, int n, FILE *stream );
```

DESCRIPTION

The function **fgets** will read at most **n** -1 characters from the specified stream. **fgets** will not read past a newline character. The characters are stored in memory starting at the location pointed to by **s**. **fgets** returns **s** if it was successful, **NULL** otherwise. **fgets** will update the file position indicator for any characters read.

SEE ALSO

fputs — Write a string to a stream.

rewind — Reset the file position indicator associated with a stream to the beginning of the file.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        FILE *disk_file = fopen ( “newfile”, “a+” );
        char one_line[64];

        fputs ( “read this line\n” “but not this line.\n”, disk_file );
        rewind ( disk_file );
        fgets ( one_line, 64, disk_file );
        fputs ( one_line, stdout );
}
```

will open a new file on the disk named “newfile”. Two lines will be written to the new file, and the first line will be read back using fgets. The retrieved line is then printed to standard output as follows:

```
read this line
```

NAME

floor — Floor function.

SYNOPSIS

```
#include <math.h>
double floor ( double x );
```

DESCRIPTION

The **floor** function returns the largest integer not greater than **x**.

When the header file **math.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

SEE ALSO

ceil — Ceiling function.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "floor( 7.09 ) == %f\n", floor( 7.09 ) );
}
```

prints to standard output:

```
floor( 7.09 ) == 7.000000
```

NAME

fmod — Floating point remainder.

SYNOPSIS

```
#include <math.h>
double fmod ( double x, double y );
```

DESCRIPTION

The **fmod** function computes and returns the floating point remainder r of **x** / **y**. The remainder, r, has the same sign as **x** and **x** == i * **y** + r, where |r| < |**y**|. If **x** and **y** can not be represented, the result is undefined.

When the header file **math.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "fmod( -10.0, 3.0 ) == %f\n", fmod( -10.0, 3.0 ) );
}
```

prints to standard output:

```
fmod( -10.0, 3.0 ) == -1.000000
```

NAME

fopen — Open a named file on the host's disk.

SYNOPSIS

```
#include <stdio.h>
void fopen ( const char *filename, const char *mode );
```

DESCRIPTION

The **fopen** function attempts to open a named file for access via a stream. If **fopen** is able to open the specified file, then the new stream associated with that file is returned. If fopen fails, then it returns **NULL**. The **mode** argument indicates the type of the stream, and how the stream may be accessed:

"r"	—	text type, read only,
"w"	—	text type, write only,
"a"	—	text type, append only (write after end of current file),
"rb"	—	binary type, read only,
"wb"	—	binary type, write only,
"ab"	—	binary type, append only (write after end of current file),
"r+"	—	text type, read and write,
"w+"	—	text type, read and write (any pre-existing file is destroyed),
"a+"	—	text type, append only (read/write after end of current file),
"rb+"	—	binary type, read and write,
"wb+"	—	binary type, read and write (any pre-existing file is destroyed),
"ab+"	—	binary type, append only (read/write after end of current file).

Note that opening a file that does not exist will fail if **r** is the first character in the **mode** string. When opened, the stream is initially line buffered.

SEE ALSO

fputs	—	Write a string to a stream.
fgets	—	Read a string from a stream.
fprintf	—	Used to write formatted output to a stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        FILE *stream = fopen ( “file.new”, “w” );
        char data[64];

        fprintf ( stream, “verify this\n” );
        fclose ( stream );

        stream = fopen ( “file.new”, “r” );
        fgets ( data, 64, stream );
        fputs ( data, stdout );
}
```

This example opens an new text file, writes to the associated stream, and closes that stream. It then reopens the file and displays the first line of that file on standard output:

```
verify this
```

NAME

fprintf — Write formatted output to a stream.

SYNOPSIS

```
#include <stdio.h>
int fprintf ( FILE *stream, const char *format, ... );
```

DESCRIPTION

The function **fprintf** functions exactly like the function **printf**, except that the output is directed to the specified stream rather than being automatically directed to standard output. Please use the description of argument values in the description of the **printf** function.

SEE ALSO

printf — Used to write formatted output to a standard output.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        fprintf ( stdout, “hello world\n” );
}
```

Will cause the following output to be printed to standard output:

```
hello world
```

NAME

fputc — Write a single character to a stream.

SYNOPSIS

```
#include <stdio.h>
int fputc ( int c, FILE *stream );
```

DESCRIPTION

The function **fputc** writes the character **c** to the specified stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        fputc ( (int) 'S', stdout );
        fputc ( (int) 'h', stdout );
        fputc ( (int) 'a', stdout );
        fputc ( (int) 'd', stdout );
        fputc ( (int) 'r', stdout );
        fputc ( (int) 'a', stdout );
        fputc ( (int) 'c', stdout );
        fputc ( (int) 'k', stdout );
        fputc ( (int) '\n', stdout );
}
```

Will cause the following output to be printed to standard output:

```
Shadrack
```

NAME

fputs — Write a string to a stream.

SYNOPSIS

```
#include <stdio.h>
int fputs ( const char *s, FILE *stream );
```

DESCRIPTION

The function **fputc** writes the string **s** to the specified stream. The trailing '\0' in s is not written to the stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        fputs ( "hand me down pumas\n", stdout );
}
```

Will cause the following output to be printed to standard output:

```
hand me down pumas
```

NAME

fread — Read data directly from a stream.

SYNOPSIS

```
#include <stdio.h>
size_t fread ( void *ptr, size_t size, size_t nmemb, FILE *stream );
```

DESCRIPTION

The function fread reads raw data from the specified stream. The data is stored in memory starting with the location pointed to by **ptr**. The quantity of data is **size** * **nmemb**. **fread** returns the number of elements successfully read.

SEE ALSO

printf — Used to write formatted output to a standard output.

fopen — Open a file and associate it with a stream.

EXAMPLE

Assume that the disk file “professor” has as its contents the following string, including the trailing ‘\0’:

“What’s another word for pirate treasure?”

The following C program uses fread:

```
#include <stdio.h>

void main ()
{
        FILE *booty = fopen ( “professor”, “r” );
        char buffer[64];

        fread ( buffer, 63, sizeof ( char ), booty );
        fprintf ( stdout, buffer );
}
```

and will cause the following output to be printed to standard output:

What’s another word for pirate treasure?”

NAME

free — Free storage allocated by calloc, malloc, and realloc.

SYNOPSIS

```
#include <stdlib.h>
void free( void* ptr);
```

DESCRIPTION

The **free** function causes the space pointed to by **ptr** to be deallocated. Once deallocated it is available to be used again by future dynamic memory allocation requests. If **ptr** is **NULL**, **free** returns immediately. If the space pointed to by **ptr** has already been deallocated by a previous call to **free** or **realloc**, the behavior is undefined.

SEE ALSO

calloc — Dynamically allocate zero-initialized storage.
malloc — Dynamically allocate uninitialized storage.
realloc — Alter size of previously dynamically allocated storage.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        char* alloc;
        if (  ( alloc = (char*) malloc( 709 ) ) == NULL )
        {
                printf( "malloc error\n" );
                exit ( -1 );
        }

        /* free 709 words of memory */
        free( alloc );
}
```

NAME

freopen — Open a named file on the disk, to be accessed via the specified stream.

SYNOPSIS

```
#include <stdio.h>
FILE *freopen ( const char *filename, const char *mode, FILE *stream );
```

DESCRIPTION

The function **freopen** opens the named disk file in the same manner as **fopen**. However, **freopen** associates that file with the specified stream. If successful, **freopen** returns its argument **stream**, and if unsuccessful, it returns **NULL**. The range of acceptable values for the **mode** argument are the same as those for **fopen**.

SEE ALSO

printf — Used to write formatted output to standard output.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        freopen ( “diskfile”, “w”, stdout );
        printf ( “hello world\n” );
}
```

This example redirects standard output to a file on the disk via **freopen**. The “hello world” output will not appear on the normal standard output device, but rather in the file “diskfile”.

NAME

frexp — Break a floating point number into mantissa and exponent.

SYNOPSIS

```
#include <math.h>
double frexp ( double value, int* exp );
```

DESCRIPTION

The **frexp** function breaks a floating point number into a normalized fraction (the mantissa) and an integral power of 2 (the exponent). The **frexp** function returns the mantissa and stores the exponent in the integer pointed to by **exp**. The mantissa is returned with a magnitude in the range [1/2, 1] or zero, such that value equals the mantissa times $2^{*\mathbf{exp}}$. If value is zero, both the exponent and mantissa are zero.

SEE ALSO

modf — Decomposing a double into mantissa and exponent.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        int exp;
        double mant;

        mant = frexp( 70.9, &exp );
        printf( "mantissa == %f\texponent == %d\n", mant, exp );
}
```

prints to standard output:

```
mantissa == 0.553906 exponent == 7
```

NAME

fscanf — Read formatted input from a stream.

SYNOPSIS

```
#include <stdio.h>
int fscanf ( FILE *stream, const char *format, ... );
```

DESCRIPTION

The function **fscanf** reads input from the specified stream. It uses the string **format** as a guide for interpreting the input and storing values in memory. Subsequent arguments to **fscanf** are used as pointers to objects in memory that will receive the input values read from the stream.

The format string is composed of directives. These are parsed from left to right from the format string, and indicate how the input from the specified stream should be processed.

If **fscanf** fails to apply a directive, then it returns. Directives are composed of either white-space characters or normal characters. White space character sequences indicate that **fscanf** should read input from the specified stream up to the first non-white-space character. Directives that consist of non-white-space characters are processed in the following manner: input is read from the specified stream until the input character is not a member of the set of characters comprising the directive. Finally, directives can be conversion specifications; these directives begin with the ‘%’ character. They describe how **fscanf** should parse input, and how **fscanf** should synthesize a value to be stored in memory.

Conversion specifications are processed as follows. First, the stream is read until all white-space characters have been exhausted, unless ‘[‘, ‘c’, or ‘n’ is part of the conversion specification. Second, a value is derived from the input stream according to the conversion specifier. A conversion specifier may be one of the following:

‘d’ — match a signed, decimal integer.

‘i’ — match a signed integer, whose base is determined in the same manner as a C integer constant.

‘o’ — match an octal integer.

‘u’ — match an unsigned, decimal integer.

‘x’ — match a signed, hexadecimal integer. (**‘X’** is also valid).

‘e’,’f’,’g’ — match a floating-point number. (**‘E’**,**’F’** and **’G’** are also valid).

‘s’ — match a sequence of non-white-space characters, essentially scan a token string.

‘[‘ — match a non-empty sequence of characters from a set of expected characters, which are bounded by a following **‘]’**.

'c' — match a sequence of characters, as specified by the field width. As a default, scan only one character.

'n' — don't match anything, just store the number of characters read from the input stream during this call to **fscanf**.

'%' — match a '**%'** character.

fscanf returns **EOF** if an input failure is detected before any conversions take place. Otherwise it returns the number of assignments made. Note that an optional assignment suppression character '*' may follow the initial '%'. This character will cause **fscanf** to discard the converted value without advancing along the list of object pointers.

SEE ALSO

scanf — Read formatted input from standard input.

sscanf — Read formatted input from a string.

EXAMPLES

(a) The following program will, assuming that the input pending on standard input is "my 98", store the three characters 'm', 'y', '\0' will be stored in word[], and 98 will be stored in number.

```
#include <stdio.h>

void main ()
{
        char word[8];
        int number;
        fscanf ( stdin, " %s %d", word, & number );
}
```

(b) The following program will, assuming that the input pending on standard input is "yall come", store the following five characters in the array word: 'y', 'a', 'l', 'l', '\0'.

```
#include <stdio.h>

void main ()
{
        char word[8];
        fscanf ( stdin, "%[lay]", word );
}
```

NAME

fseek — Set the file position indicator associated with a stream.

SYNOPSIS

```
#include <stdio.h>
int fseek ( FILE *stream, long int offset, int whence );
```

DESCRIPTION

The function **fseek** will set the file position indicator associated with the specified stream, according to the values of offset plus an initial value indicated by **whence**. Initial values derived of **whence** values are as follows:

SEEK_SET — The initial value is the beginning of the file.
SEEK_CUR — The initial value is the current position in the file.
SEEK_END — The initial value is the end of the file.

The value of **offset** must either be zero or the value returned by a call to **ftell**.

SEE ALSO

fopen — Open a disk file and associate it with a stream.
fgetc — Read a single character from a stream.
fclose — Close a stream.

EXAMPLES

The following function will read the last character in a text file specified by the parameter **name**.

```
#include <stdio.h>

char last_in_file ( char *name )
{
        FILE *tmp = fopen ( name, “r” );
        char return_value;

        (void) fseek ( tmp, -1L, SEEK_END );
        return_value = (char) fgetc ( tmp );
        fclose ( tmp );
        return return_value;
}
```

NAME

fsetpos — Set the file position indicator associated with a stream.

SYNOPSIS

```
#include <stdio.h>
int fsetpos ( FILE *stream, const fpos_t *pos );
```

DESCRIPTION

The function **fsetpos** will change the file position indicator associated with the specified stream. The value of **pos** must be the return value from a prior call to **fgetpos**. Note that a successful call to **fsetpos** will undo any effect of an immediately preceding **ungetc** on the same stream. If it is successful, **fsetpos** returns zero.

SEE ALSO

fgetpos — Obtain the file position indicator value associated with a stream.

EXAMPLES

```
#include <stdio.h>

void main ()
{
        FILE *preexisting = fopen ( “already.here”, “r” );
        fpos_t pos;

        (void) fgetpos ( preexisting, & pos );
        (void) fseek ( preexisting, 0L, SEEK_END );
        (void) fsetpos ( preexisting, & pos );
}
```

will open a hypothetical pre-existing file on the disk, record the initial position in pos, seek to the end of the file, and finally restore the initial value of the file position indicator.

NAME

ftell — Get the file position indicator associated with a stream.

SYNOPSIS

```
#include <stdio.h>
long int ftell ( FILE *stream );
```

DESCRIPTION

The function **ftell** will return the value of the file position indicator for the specified stream. The return value is usable only by the function fseek. **ftell** returns -1L.

SEE ALSO

fopen — Open a file and associate it with a stream.
fread — Read data from a stream.
putchar — Send character data to standard output.
fseek — Change the file position indicator associated with a stream.

EXAMPLE

```
#include <stdio.h>

main ()
{
        FILE *stream = fopen ( “file.abc”, “r” );
        long int beginning = ftell ( stream );
        char send;

        (void) fread ( & send, sizeof ( char ), 1, stream );
        putchar ( send );
        fseek ( stream, beginning, SEEK_SET );
        (void) fread ( & send, sizeof ( char ), 1, stream );
        putchar ( send );
}
```

will read and print the first character in the file “file.abc” twice. **ftell** is used to reset the file position indicator to the beginning of the file.

NAME

fwrite — Write data directly to a stream.

SYNOPSIS

```
#include <stdio.h>
size_t fwrite ( const void *ptr, size_t size, size_t nmemb, FILE *stream );
```

DESCRIPTION

The function **fwrite** writes raw data to the specified stream. The data is drawn from memory starting with the location pointed to by **ptr**. The quantity of data is **size** * **nmemb**. **fwrite** returns the number of elements successfully written.

EXAMPLE

```
#include <stdio.h>

main ()
{
        char message[] = “hand me down pumas”;

        fwrite ( message, sizeof ( char ), strlen ( message ), stdout );
}
```

will write the message “hand me down pumas” onto standard output.

NAME

getc — Read a character from the specified stream.

SYNOPSIS

```
#include <stdout.h>
int fgetc ( FILE *stream );
```

DESCRIPTION

getc is equivalent to **fgetc**, except that **getc** may be implemented as a macro. If such is the case, the argument **stream** may be evaluated more than once. This only becomes a problem if evaluation of the argument has side effects.

SEE ALSO

fgetc — Read a character from a stream.

fputc — Write a character to a stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        char value = (char) getc ( stdin );

        while ( EOF != value )
        {
                fputc ( value, stdout );
                value = (char) getc ( stdin );
        }
}
```

will echo all characters from standard input to standard output until the input is exhausted.

NAME

getchar — Read a character from standard input.

SYNOPSIS

```
#include <stdio.h>
int getchar ( void );
```

DESCRIPTION

The function **getchar** reads the next character from standard input. If there is no pending input, **getchar** returns **EOF**, otherwise the read character is cast to type **int** and returned.

SEE ALSO

fputc — Write a character to a stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        char value = (char) getchar ();

        while ( EOF != value )
        {
                fputc ( value, stdout );
                value = (char) getchar ( );
        }
}
```

will echo all characters from standard input to standard output until the input is exhausted.

NAME

gets — Read a string from standard input.

SYNOPSIS

```
#include <stdio.h>
char *gets ( char *s );
```

DESCRIPTION

The function **fgets** will read characters from standard input, and place them sequentially in memory, starting with the location pointed to by **s**. **gets** will not read past a newline character, or past the end of the file. The characters are stored in memory starting at the location pointed to by **s**. **gets** returns **s** if it was successful, **NULL** otherwise. **gets** will update the file position indicator for any characters read. If **gets** encounters the end of file on its first read of standard input, **NULL** is returned. **gets** does not append a '\0' to the array of characters read.

SEE ALSO

fgets — Read a string from a stream.

puts — Read a string from a stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        char line_buffer[BUFSIZ];

        puts ( gets ( line_buffer ));
}
```

will echo a newline-terminated line of input from standard input onto standard output. Note that **gets** doesn't read past the newline; **puts** supplies one by definition.

NAME

isalnum — Test for alphanumeric character.

SYNOPSIS

```
#include <ctype.h>
int isalnum( int c );
```

DESCRIPTION

The **isalnum** function returns a nonzero value for any alphabetic or numeric character; zero is returned in all other cases. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ((isalnum('c')) && (isalnum('1')))
        {
                printf("c, 1 -- alpha and numeric\n" );
        }

        if ( ! ( isalnum( '@' ) ) )
        {
                printf( "@ -- neither alpha nor numeric\n" );
        }
}
```

prints to standard output:

```
c, 1 -- alpha and numeric
@ -- neither alpha nor numeric
```

NAME

isalpha — Test for alphabetic character.

SYNOPSIS

```
#include <ctype.h>
int isalpha( int c );
```

DESCRIPTION

The **isalpha** function returns a nonzero value for any alphabetic character; zero is returned in all other cases. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ( ( isalpha( 'c' ) ) )
        {
                printf( "c -- alpha\n" );
        }

        if ( ! ( isalpha( '@' ) ) && ! ( isalpha( '1' ) ) )
        {
                printf( "@, 1 -- non alpha\n" );
        }
}
```

prints to standard output:

```
c -- alpha
@, 1 -- non alpha
```

NAME

iscntrl — Test for control character.

SYNOPSIS

```
#include <ctype.h>
int iscntrl( int c );
```

DESCRIPTION

The **iscntrl** function returns a nonzero value for any control character; zero is returned in all other cases. A control character is any character that is NOT a letter, digit, punctuation, or ‘ ’ (the space character). This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        /* check the "beep" character */
        if ( ( iscntrl( 0x07 ) ) )
        {
                printf( "\"beep\" (0x07) -- control character\n" );
        }

        if ( ! ( iscntrl( '@' ) ) )
        {
                printf( "@ -- not control character\n" );
        }
}
```

prints to standard output:

```
"beep" (0x07) -- control character
@ -- not control character
```

NAME

isdigit — Test for numeric character.

SYNOPSIS

```
#include <ctype.h>
int isdigit( int c );
```

DESCRIPTION

The **isdigit** function returns a nonzero value for any decimal character; zero is returned in the false case. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if (( isdigit( '1' ) ) )
        {
                printf( "1 -- is a decimal character\n" );
        }

        if ( ! ( isdigit( 'f' ) ) )
        {
                printf( "f -- not a decimal character\n" );
        }
}
```

prints to standard output:

```
1 -- is a decimal character
f -- not a decimal character
```

NAME

isgraph — Test for printing character, excluding space and tab.

SYNOPSIS

```
#include <ctype.h>
int isgraph( int c );
```

DESCRIPTION

The **isgraph** function returns a nonzero value for any printable character, excluding space (‘ ’) and tab (‘\t’); zero is returned in all other cases. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        /* check the "beep" character */
        if ( ! ( isgraph ( ' ' ) ) )
        {
                printf( "space -- not \"graph\" character\n" );
        }

        if ( ( isgraph ( 'f' ) ) )
        {
                printf( "f -- \"graph\" character\n" );
        }
}
```

prints to standard output:

```
space -- not "graph" character
f -- "graph" character
```

NAME

islower — Test for lower-case alphabetic characters.

SYNOPSIS

```
#include <ctype.h>
int islower( int c );
```

DESCRIPTION

The **islower** function returns a nonzero value for any lower-case alphabetic character; zero is returned in all other cases. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ( ( islower( 'a' ) ) )
        {
                printf( "a -- lower case character\n" );
        }

        if ( ! ( islower( 'F' ) ) )
        {
                printf( "F -- not a lower case character\n" );
        }
}
```

prints to standard output:

```
a -- lower case character
F -- not a lower case character
```

NAME

isprint — Test for printing character, excluding '\t'.

SYNOPSIS

```
#include <ctype.h>
int isprint( int c );
```

DESCRIPTION

The **isprint** function returns a nonzero value for any printable character, excluding the tab character ('\t'); zero is returned in all other cases. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ( ( isprint( ' ' ) ) )
        {
                printf( "space -- \"print\" character\n" );
        }

        if ( ! ( isprint( '\t' ) ) )
        {
                printf( "tab -- not \"print\" character\n" );
        }
}
```

prints to standard output:

```
space -- "print" character
tab -- not "print" character
```

NAME

ispunct — Test for punctuation character.

SYNOPSIS

```
#include <ctype.h>
int ispunct ( int c );
```

DESCRIPTION

The **ispunct** function returns a nonzero value for any punctuation character; zero is returned in all other cases. A punctuation character is one that is printable, not a digit, not a letter, and not a space (‘ ’ or ‘\t’).This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ( ( ispunct( ’,’ ) ) )
        {
                printf( "comma -- \"punct\" character\n" );
        }

        if ( ! ( ispunct( ’\t’ ) ) )
        {
                printf( "tab -- not \"punct\" character\n" );
        }
}
```

prints to standard output:

```
comma -- "punct" character
tab -- not "punct" character
```

NAME

isspace — Test for white-space character.

SYNOPSIS

```
#include <ctype.h>
int isspace( int c );
```

DESCRIPTION

The **isspace** function returns a nonzero value for any standard white-space character; zero is returned in all other cases. The standard white-space characters are space (‘ ’), form feed (‘\f’), new-line (‘\n’), carriage return (‘\r’), horizontal tab (‘\t’), and vertical tab (‘\v’). This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ( ( isspace( ' ' ) ) )
        {
                printf( "space -- white-space character\n" );
        }

        if ( ! ( isspace( '@' ) ) )
        {
                printf( "@ -- not white-space character\n" );
        }
}
```

prints to standard output:

```
space -- white-space character
@ -- not white-space character
```

NAME

isupper — Test for upper-case alphabetic character.

SYNOPSIS

```
#include <ctype.h>
int isupper( int c );
```

DESCRIPTION

The **isupper** function returns a nonzero value for any upper-case alphabetic character; zero is returned in all other cases. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ( ( isupper( 'F' ) ) )
        {
                printf( "F -- upper-case character\n" );
        }

        if ( ! ( isupper( 'f' ) ) )
        {
                printf( "f -- not an upper-case character\n" );
        }
}
```

prints to standard output:

```
F -- upper-case character
f -- not an upper-case character
```

NAME

isxdigit — Test for hexadecimal numeric character.

SYNOPSIS

```
#include <ctype.h>
int isxdigit ( int c );
```

DESCRIPTION

The **isxdigit** function returns a nonzero value for any hexadecimal digit; zero is returned in all other cases. This function is provided both as an in-line and out-of-line function.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        if ( ( isxdigit ( 'F' ) ) )
        {
                printf( "F -- hexadecimal character\n" );
        }

        if ( ! ( isxdigit ( 'G' ) ) )
        {
                printf( "G -- not a hexadecimal character\n" );
        }
}
```

prints to standard output:

```
F -- hexadecimal character
G -- not a hexadecimal character
```

NAME

labs — Absolute value of a long integer.

SYNOPSIS

```
#include <stdlib.h>
long int labs ( long int j );
```

DESCRIPTION

The **labs** function returns the absolute value of the long integer **j**.

SEE ALSO

abs — Absolute value of an integer.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main ()
{
        long int j = -19089709L;

        printf ( "labs ( -19089709l ) == %ld\n", labs ( j ) );
}
```

prints to standard output:

```
labs ( -19089709l ) == 19089709
```

NAME

ldexp — Multiply floating point number by a power of two.

SYNOPSIS

```
#include <math.h>
double ldexp( double x, int exp );
```

DESCRIPTION

The **ldexp** function returns **x** * $2^{\mathbf{exp}}$. If the result exceeds **HUGE_VAL**, errno is set to **ERANGE** and the value **HUGE_VAL** is returned with the same sign as **x**.

SEE ALSO

exp — Raising e to a power.

pow — Raising a floating point number to a power.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "ldexp(7.09,4) == %f\n", ldexp(7.09,4) );
}
```

prints to standard output:

```
ldexp(7.09,4) == 113.440000
```

NAME

ldiv — Long integer division with remainder.

SYNOPSIS

```
#include <stdlib.h>
ldiv_t ldiv( long int numer, long int denom );
```

DESCRIPTION

The **ldiv** function computes the quotient and remainder of **numer** / **denom** and returns the result in a structure of type **ldiv_t**. If the result cannot be represented, the result is undefined.

SEE ALSO

div — Integer division with remainder.

EXAMPLE

Please see the include file **stdlib.h** for the definition of **ldiv_t**.

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        result;
    long    numer = 709, denom = 56;

    result = ldiv( numer, denom );
    printf( "quotient == %ld\t", result.quot );
    printf( "remainder == %ld\n", result.rem);
}
```

prints to standard output:

```
quotient == 12 remainder == 37
```

NAME

log — Natural logarithm, base e.

SYNOPSIS

```
#include <math.h>
double log( double x );
```

DESCRIPTION

The **log** function computes the natural logarithm of **x**. If the value of **x** is less than zero, **errno** is set to **EDOM** and the value **HUGE_VAL** is returned. If **x** is equal to zero, **errno** is set to **ERANGE** and the value **HUGE_VAL** is returned.

SEE ALSO

exp — Raising e to a power.

log10 — Base 10 logarithm.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "log( 7.09 ) == %f\n", log( 7.09 ) );
}
```

prints to standard output:

```
log( 7.09 ) == 1.958680
```

NAME

log10 — Base ten logarithm.

SYNOPSIS

```
#include <math.h>
double log10( double x );
```

DESCRIPTION

The **log10** function computes the natural logarithm of **x**. If the value of **x** is less than zero, **errno** is set to **EDOM** and the value **HUGE_VAL** is returned. If **x** is equal to zero, **errno** is set to **ERANGE** and the value **HUGE_VAL** is returned.

SEE ALSO

exp — Raising e to a power.

log — Natural logarithm.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "log10( 7.09 ) == %f\n", log10( 7.09 ) );
}
```

prints to standard output:

```
log10( 7.09 ) == 0.850646
```

NAME

longjmp — Execute a non-local jump.

SYNOPSIS

```
#include <setjmp.h>
void longjmp( jmp_buf env, int val );
```

DESCRIPTION

The **longjmp** function restores the calling environment referenced by **env** which must have been initialized by a previous call to **setjmp**. If there has been no invocation of **setjmp**, or if the function containing the call to **setjmp** has returned before the call to **longjmp**, the behavior is undefined.

Upon completion of **longjmp**, program execution continues as if the corresponding call to **setjmp** had returned with a value **val**; if **val** is zero, 1 is returned.

All global and **volatile** variables have defined values as of the point in time that **longjmp** was called; all **register** and non-volatile automatic variables will have undefined values.

For more information, see Chapter 6.

SEE ALSO

setjmp — Save a reference of the current calling environment for later use by **longjmp**.

EXAMPLE

```
#include <stdio.h>
#include <setjmp.h>

jmp_buf env;

void func( void )
{
        longjmp( env, -709 );
}

main()
{
        if ( setjmp( env ) != 0 )
        {
```

```
                printf( "-- longjmp has been called --\n" );
                exit( 1 );
        }
        printf( "-- setjmp called --\n" );
        func();
}
```

prints to standard output:

```
-- setjmp called --
-- longjmp has been called --
```

NAME

malloc — Dynamically allocate uninitialized storage.

SYNOPSIS

```
#include <stdlib.h>
void* malloc( size_t size );
```

DESCRIPTION

The **malloc** function returns a pointer to the lowest word of a block of storage space that is **size** words in size. If **size** exceeds the amount of memory available, **malloc** returns **NULL**.

SEE ALSO

calloc — Dynamically allocate zero-initialized storage.

free — Free dynamically allocated memory.

realloc — Alter size of dynamically allocated storage.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        char *char_array;

        if((char_array=(char*) malloc(709*sizeof(char))) == NULL)
        {
                printf( "error: not enough memory\n" );
                exit( 1 );
        }
        else
        {
                printf("-- space for 709 chars allocated OK --\n" );
        }
}
```

prints to standard output:

```
-- space for 709 chars allocated OK --
```

NAME

mblen — Length of a multibyte character.

SYNOPSIS

```
#include <stdlib.h>
int mblen( const char* s, size_t n );
```

DESCRIPTION

The **mblen** function determines the number of characters in the multibyte character pointed to by **s**. The **mblen** function is equivalent to

```
mbtowc ( (wchar_t*) 0, s, n );
```

If **s** is a NULL pointer, **mblen** returns a zero. If **s** is not NULL, **mblen** returns

1. zero if **s** points to a NULL character,
2. the number of characters that comprise the multibyte character, or
3. -1 if an invalid multi-byte character is formed.

In no case will the return value exceed **n** or the **MB_CUR_MAX** macro.

SEE ALSO

mbtowc — Convert multibyte characters into wide characters.

wctomb — Convert wide characters into multibyte characters.

SPECIAL NOTE

The DSP56100 does not provide byte addressing, thus characters always require an entire word of memory each. One way to better utilize data memory (with a run-time cost) is to use the ANSI data type **wchar_t** and the special ANSI multibyte and wide character library routines.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

char* gstr = NULL;

void main()
{
        int max = MB_CUR_MAX;
        char* strnull = gstr;
        char* str1 = "709";

        printf("mblen(strnull,5)==%d\n", mblen( strnull,5));
        printf("mblen(str1, max ) == %d\n", mblen(str1,max));
        printf("mblen(\"abcdef\",5) == %d\n", mblen("abcedf",5));
        printf("mblen(\"abcdef\",2) == %d\n", mblen("abcedf",2));
}
```

prints to standard output:

```
mblen( strnull, 5 ) == 0
mblen( str1, max ) == 2
mblen( "abcdef", 5 ) == 2
mblen( "abcdef", 2 ) == 2
```

NAME

mbstowcs— Convert multibyte string to wide character string.

SYNOPSIS

```
#include <stdlib.h>
int mbstowcs( wchar_t* pwcs, const char* s, size_t n );
```

DESCRIPTION

The **mbstowcs** function converts the character string pointed to by **s** into a wide character string pointed to by **pwcs**. Each character of the multibyte string is converted as if by the **mbtowc** function. At most, **n** characters will be converted and stored in the wide character string. Multibyte characters that follow a **NULL** character will not be examined or converted. If **s** and **pwcs** overlap, the behavior is undefined.

If an invalid character is encountered, **mbstowcs** returns (**size_t**) -1. Otherwise, **mbstowcs** returns the number of characters converted, not including the terminating **NULL** character.

SEE ALSO

wcstombs— Convert wide character strings into multibyte strings.

SPECIAL NOTE

The DSP56100 does not provide byte addressing, thus characters always require an entire word of memory each. One way to better utilize data memory (with a run-time cost) is to use the ANSI data type **wchar_t** and the special ANSI multibyte and wide character library routines.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

wchar_t warray[10];

void main()
{
        char *array = "abcdefgh";
        char *ptr = array;
        int convert;

        convert = mbstowcs( warray, array, 10 );

        printf( "unpacked array looks like:\n" );
        while ( *ptr != 0 )
        {
                printf( "%0.6x ", *ptr++ );
        }
        printf( "\n\n" );

        printf( "%d chars packed, packed array looks like:\n", 8 );
        ptr = warray;
        while ( *ptr != 0 )
        {
                printf( "%0.6x \n", *ptr++ );
        }
        printf( "\n" );
}
```

prints to standard output:

```
unpacked array looks like:
000061 000062 000063 000064 000065 000066 000067 000068

8 chars packed, packed array looks like:
006162
```

```
006364
006564
006768
000075
006e70
006163
006b65
006420
006172
000001
0015eb
```

NAME

mbtowc — Convert a multibyte character to a wide character.

SYNOPSIS

```
#include <stdlib.h>
int mbtowc( wchar_t* pwc, const char* s, size_t n );
```

DESCRIPTION

The **mbtowc** function examines the multibyte (i.e., multi-character) string pointed to by **s** and converts it into a wide character (**wchar_t**). At most, **n** and never more than **MB_CUR_MAX** characters from **s** will be examined and converted.

If **s** is a **NULL** pointer, **mbtowc** returns zero. If **s** is not NULL, **mbtowc** returns

1. zero if **s** points to a NULL character,
2. the number of characters that comprise the multibyte character, or
3. -1 if an invalid multibyte character is formed.

In no case will the return value exceed **n** or the **MB_CUR_MAX** macro.

SEE ALSO

mblen — Determine the length of a multibyte character.

mbstowcs— Convert a multibyte string into a wide character string.

wctomb — Convert a wide character into a multibyte character.

SPECIAL NOTE

The DSP56100 does not provide byte addressing, thus characters always require an entire word of memory each. One way to better utilize data memory (with a run-time cost) is to use the ANSI data type **wchar_t** and the special ANSI multibyte and wide character library routines.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        wchar_t wide = 0;
        char* mbstr = "abcde";
        int convert;

        convert = mbtowc( (wchar_t*) NULL, mbstr, 2 );
        printf("%d chars packed. wide == %0.6x\n", convert, wide);

        convert = mbtowc( &wide, mbstr, strlen( mbstr ) );
        printf("%d chars packed. wide == %0.6x\n", convert, wide);

        convert = mbtowc( &wide, mbstr, 2 );
        printf("%d chars packed. wide == %0.6x\n", convert, wide);
}
```

prints to standard output:

```
2 chars packed. wide == 000000
2 chars packed. wide == 006162
2 chars packed. wide == 006162
```

NAME

memchr — Find a character in a memory area.

SYNOPSIS

```
#include <string.h>
int memchr( const void* s, int c, size_t n );
```

DESCRIPTION

The **memchr** function finds the first occurrence of **c** (converted to an **unsigned char**) in the memory area pointed to by **s**. The terminating null character is considered to be part of the string. The **memchr** function returns a pointer to the located char or a **NULL** pointer if the character is not found.

SEE ALSO

strchr — Find the first occurrence of a character in a string.

strcspn — Compute the length of the prefix of a string not containing any characters contained in another string.

strpbrk — Find the first occurrence of a character from one string in another string.

strrchr — Find the last occurrence of a character in a string.

strspn — Compute the length of the prefix of a string contained in another string.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char*  string = "fred flintstone driving on bald feet";
        char*  result;

        /* locate the occurrence of 'b' */
        result = memchr( string, 'b', strlen( string ) );
        printf( "-- %s --\n", result );
}
```

prints to standard output:

```
-- bald feet --
```

NAME

memcmp — Compare portion of two memory areas.

SYNOPSIS

```
#include <string.h>
int memcmp( const void* s1, const void* s2, size_t n );
```

DESCRIPTION

The **memcmp** function compares the first **n** words of the object pointed to by **s1** with the first **n** words of the object pointed to by **s2**. The comparison is lexicographical. The **memcmp** function returns zero if the two areas compared are equal, a value greater than zero if **s1** is greater, or a value less than zero if **s1** is smaller.

SEE ALSO

strncmp — Compare portion of two strings.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

struct test
{
        char cartoon[20];
        int value;
}       g1 = { "flintstones", 709 },
        g2 = { "flintstones", 709 },
        g3 = { "jetsons", 709 };

void main()
{
        if ( memcmp( &g1, &g2, sizeof( struct test ) ) != 0 )
        {
                printf( "error: flintstones differ\n" );
        }
        else
        {
                printf( "-- flintstones are flintstones --\n" );
        }

        if ( memcmp( &g1, &g3, sizeof( struct test ) ) != 0 )
        {
                printf( "-- flintstones are not jetsons --\n" );
        }
        else
        {
                printf( "error: flintstones are NOT jetsons\n" );
        }

}
```

prints to standard output:

```
-- flintstones are flintstones --
-- flintstones are not jetsons --
```

NAME

memcpy — Copy from one area to another.

SYNOPSIS

```
#include <string.h>
int memcpy( void* s1, const void* s2, size_t n );
```

DESCRIPTION

The **memcpy** function copies **n** words from the area referenced by **s2** into the area specified by **s1**. If the source and destination areas overlap, the results are undefined. The **memcpy** function returns the value of **s1**.

SEE ALSO

strcpy — Copy one string to another.

strncpy — Copy a portion of one string to another.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

struct test
{
        char cartoon[20];
        int value;
}       g1, g2 = { "flintstones", 709 };

void main()
{
        memcpy( &g1, &g2, sizeof( struct test ) );
        printf( "-- I watch the %s --\n", g1.cartoon );
}
```

prints to standard output:

```
-- I watch the flintstones --
```

NAME

memmove— Copy storage.

SYNOPSIS

```
#include <string.h>
int memmove( void* s1, const void* s2, size_t n );
```

DESCRIPTION

The **memmove** function copies **n** words from the area referenced by **s2** into the area specified by **s1**. The copy is done by first placing the **n** words into a temporary buffer and then moving the temporary buffer into the final location, this allows the source and destination areas to overlap.

SEE ALSO

memcpy — Copy one memory area to another.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

struct test
{
        char cartoon[20];
        int value;
} g1, g2 = {"flintstones", 709 };

void main()
{
        memmove( &g1, &g2, sizeof( struct test ) );
        printf( "-- I watch the %s --\n", g1.cartoon );
}
```

prints to standard output:

```
-- I watch the flintstones --
```

NAME

memset — Initialize memory area.

SYNOPSIS

```
#include <string.h>
int memset( void* s, int c, size_t n );
```

DESCRIPTION

The **memset** function copies the value **c** (converted to an **unsigned char**) into the first **n** words of the object pointed to by **s**.

SEE ALSO

memcpy — Copy one memory area to another.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

struct  test
{
        char    cartoon[20];
        int value;
};

void main()
{
        struct test local;

        /* auto struct local is initialized to all nines */
        memset( &local, 9, sizeof( struct test ) );

        /* random check */
        if ( local.cartoon[7] != 9 )
        {
                printf( "error: memset busted\n" );
        }
        else
        {
                printf( "-- memset OK --\n" );
        }
}
```

prints to standard output:

```
-- memset OK --
```

NAME

modf — Break a **double** into it’s integral and fractional parts.

SYNOPSIS

```
#include <math.h>
double modf( double value, double* iptr );
```

DESCRIPTION

The **modf** function breaks **value** into its fractional and integral parts. The **modf** function returns the fractional portion of **value** and stores the integral portion in the double object pointed to by **iptr**.

SEE ALSO

frexp — Break a double into its mantissa and exponent

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        double result;

        printf( "-- fractional == %f\t", modf( 7.09, &result ));
        printf( "integral == %f --\n", result );
}
```

prints to standard output:

```
-- fractional == 0.090000 integral == 7.000000 --
```

NAME

perror — Print error message.

SYNOPSIS

```
#include <stdio.h>
void perror( const char* s );
```

DESCRIPTION

The **perror** function prints out the string **s** followed by ": " and the error message associated with **errno**.

SEE ALSO

strerror — Print out error message associated with errno.

EXAMPLE

```
#include <stdio.h>
#include <math.h>
#include <errno.h>

void main()
{
        double result;

        result = asin( 7.09 );

        if ( result == 0.0 && errno == EDOM )
        {
                perror( "asin perror test" );
        }
}
```

prints to standard output:

```
asin perror test: domain error
```

NAME

pow — Raise a double to a power.

SYNOPSIS

```
#include <math.h>
double pow( double x, double y );
```

DESCRIPTION

The **pow** function computes and returns $\mathbf{x}^{\mathbf{y}}$. If **x** is zero and **y** is less than zero, a domain error occurs setting **errno** to **EDOM** and returning 0.0. If $|\mathbf{x}^{\mathbf{y}}|$ is greater than **HUGE_VAL**, **errno** is set to **ERANGE** and **HUGE_VAL** is returned.

SEE ALSO

exp — Raising e to a power.

ldexp — Multiplying a number by a power of 2.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "-- pow( 2.0, 2.0 ) == %f --\n", pow( 2.0, 2.0 ) );
}
```

prints to standard output:

```
-- pow( 2.0, 2.0 ) == 4.000000 --
```

NAME

printf — Print to standard output.

SYNOPSIS

```
#include <stdio.h>
int printf( const char* format, … );
```

DESCRIPTION

The **printf** function formats and writes a string to the standard output. Interpreting the format specifier **format** left to right.

The format specifier, **format**, consists of ordinary characters, escape sequences, and conversion specifications. The conversion specifications describe how arguments passed to **printf** are converted for output. All non-conversion specifying portions of **format** are sent directly to the standard output. If the number of arguments passed is less than specified by the **format** string, **printf** will write non-deterministic garbage to the standard output. If too many arguments are provided to **printf**, the extras will be evaluated but otherwise ignored.

A conversion specification is introduced by the character **%**, and has the following form:

%[flags][field width][**.**precision][size]**conversion character**

where flags, field width, precision, h, l, L are optional.

Flags are for justification of output and printing of signs, blanks, decimal points, octal and hexadecimal prefixes. Multiple flags may be utilized at once. The ANSI flags are:

- Left justify the result within the field. The default is right justified.

+ The result of a signed conversion will always have a sign (+ or -). The default case provides only for -.

space If the first character of a signed conversion is not a sign, or if a signed conversion results in no characters, a space character will be prefixed to the result. If the **space** and the **+** flags both appear, the **space** flag is ignored. The default mode is no **space**.

The result is converted to an alternate form specified by the conversion character. For **o** conversion, it forces the first digit of the result to be a zero. For **x** (or **X**) conversion, the non-zero result will have 0x (0X) prefixed to it. For **e**, **E**, **f**, **g**, and **G** conversions, the result will always contain a decimal point character, even if no digits follow it. Additionally for **g** and **G**, trailing zeros will not be removed.

0 For **d**, **i**, **o**, **u**, **x**, **X**, **e**, **E**, **f**, **g**, and **G** conversions, leading zeros (following any indication of sign or base) are used to pad to the **field width**; no space padding is performed. If the **0** and **-** flags both appear, the **0** flag will be ignored.

Each conversion takes place in character fields. The minimum size of the field can be specified with the field width. If the converted result contains fewer characters than specified by field width, the result will be left padded with spaces by default (see flags above). The field width takes the form of a decimal integer or an asterisk '*'. When the field width is an asterisk, the value is to be taken from an integer argument that precedes the argument to be converted.

Precision specifies the minimum number of digits to appear for the d, i, o, u, x, X conversions, the number of digits appear after the decimal point character for e, E, and f conversions, the maximum number of significant digits for the g and G conversions, or the maximum number of characters to be written from a string in the s conversion. The precision takes the form of a '.' followed by '*', or by an optional decimal integer; if only the period is specified, the precision is taken to be zero**.** If precision appears with any other conversion character, the behavior is undefined.

Size specifies the argument size expected. There are three size specifiers defined by ANSI. The h specifies that the argument for the conversion characters d, i, o, u, x, or X will be unsigned short. The l specifies that the argument for the conversion characters d, i, o, u, x, or X will be long integer. The L specifies that the argument for the conversion characters e, E, f, g, or G will be long double.

There are 16 conversion characters; each is described below.

d, **i** The **int** argument is printed as a signed decimal number. The precision specifies the minimum number of digits to appear; if the value being printed can be represented in fewer digits, it is expanded with leading zeros. The default **precision** is 1. The result of printing a zero with **precision** zero is no characters (this is independent of padding specified by **field width**).

o The **unsigned int** argument is printed as an unsigned octal number. When used in association with the # flag, 0 will be prefixed to non-zero results. The **precision** specifies the minimum number of digits to appear; if the value can be represented in fewer digits, it will be expanded with leading zeros. The default **precision** is 1. The result of printing a zero with **precision** zero is no characters (this is independent of padding specified by **field width**).

u The **unsigned int** argument is printed as an unsigned decimal number. The precision specifies the minimum number of digits to appear; if the value can be represented in fewer digits, it will be expanded with leading zeros. The default precision is 1. The result of printing a zero with precision zero is no characters (this is independent of padding specified by field width).

x, **X** The **unsigned int** argument is printed as an unsigned hexadecimal number. Hexadecimal alpha characters (a,b,c,d,e,f) will be printed in lower case when **x** is used and in upper case when **X** is used. When used in association with the # flag, 0x will be prefixed to the result (0X in the **X** case). Precision specifies the minimum number of digits to appear; if the value can be represented in fewer digits, it will be expanded with leading zeros. The default precision is 1. The result of printing a zero with precision zero is no characters (this is independent of padding specified by field width).

f The **double** argument is printed out in decimal notation of the form [**-**]ddd.ddd, where precision specifies the number of digits to follow the decimal point. The default precision 6. When precision is 0 and the # flag is not specified, no decimal point character will be printed. A decimal digit will always follow at least one digit. The value printed is rounded to the appropriate number of digits.

e, **E** The **double** argument is printed out in the form [**-**] d.ddd**e**±dd, where precision specifies the number of digits to follow the decimal point. The default precision 6. When precision is 0 and the # flag is not specified, no decimal point character will be printed. A decimal digit will always follow at least one digit. The exponent always contains at least two digits.

g, **G** The **double** argument is printed in the **f**, **e**, or **E** form. The **f** form is used unless the exponent to be printed is less than **-4** or greater than the precision. If precision is zero, the printed value consists of no characters (this is independent of padding specified by field width). Trailing zeros are removed from the fractional portion of the result; a decimal point character is printed only if it is followed by a digit.

c The **int** argument is printed as an unsigned character.

s The argument is a pointer to a character string (**(char*)**). Characters from the string are printed up to (but not including) a terminating null character or until precision characters have been printed. If precision is not explicitly specified or is greater than the length of the string, the string will be printed until the null character is encountered.

p The argument is a pointer to the void data type (**(void*)**). The value of the pointer is printed out as a hexadecimal digit.

n The argument is a pointer to an integer (**(int*)**) which is the number of characters printed so far by the current call to **printf**.

% Print the percent character, **%**. Note that the complete specifier is %%.

On successful completion, **printf** returns an integer equal to the number of characters printed. On failure, **printf** returns an integer less than 0.

SEE ALSO

scanf — Read values from standard input.
sscanf — Read values from a string.
sprintf — Multiplying a number by a power of 2.

EXAMPLE

```
#include <stdio.h>

char* lib_name = "printf";
void main()
{
        int i = 709;
        double d = 7.09;

        printf("Show several %s examples\n", lib_name );
        printf("\tintegers:\n" );
        printf("\t\toctal == %o\n", i );
        printf("\t\toctal == %#.9o ", i );
        printf("(force leading 0 and zero pad)\n");
        printf("\t\tdecimal == %d\n", i );
        printf("\t\tdecimal == % d (force leading blank)\n", i );
        printf("\t\thex     == %x\n", i );
        printf("\t\thex     == %#X (force leading 0X)\n", i );
        printf("\tfloating point:\n" );
        printf("\t\tdouble  == %f\n", d );
        printf("\t\tdouble  == %e\n", d );
}
```

prints to standard output:

```
Show several printf examples
        integers:
                octal == 1305
                octal == 000001305 (force leading 0 and zero pad)
                decimal == 709
                decimal ==  709 (force leading blank)
                hex     == 2c5
                hex     == 0X2C5 (force leading 0X)
        floating point:
                double  == 7.090000
                double  == 7.090000e+00
```

NAME

putc — Write a single character to a stream.

SYNOPSIS

```
#include <stdio.h>
int putc ( int c, FILE *stream );
```

DESCRIPTION

The function **putc** writes the character **c** to the specified stream. It is identical to the function **fputc**, except that **putc** may be implemented as a macro. This means that arguments to **putc** may be evaluated more than once. This is only a problem for function arguments that have side effects when evaluated.

SEE ALSO

fputc — Write a single character to a stream.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        putc ( (int) 'S', stdout );
        putc ( (int) 'h', stdout );
        putc ( (int) 'a', stdout );
        putc ( (int) 'd', stdout );
        putc ( (int) 'r', stdout );
        putc ( (int) 'a', stdout );
        putc ( (int) 'c', stdout );
        putc ( (int) 'k', stdout );
        putc ( (int) '\n', stdout );
}
```

Will cause the following output to be printed to standard output:

```
Shadrack
```

NAME

putchar — Write a character to standard output.

SYNOPSIS

```
#include <stdio.h>
int putchar ( int c );
```

DESCRIPTION

The **putchar** function prints a character to standard output.

SEE ALSO

gets — Get a line of text from standard input.

EXAMPLE

```
#include <stdio.h>

char* str = "bald feet\n";

void main()
{
        while ( *str != '\0' )
        {
                putchar ( *str++ );
        }
}
```

prints to standard output:

```
bald feet
```

NAME

puts — Write a string to standard output.

SYNOPSIS

```
#include <stdio.h>
int puts( const char* s );
```

DESCRIPTION

The **puts** function prints a string to standard output, appending a newline character. The **puts** function returns a zero if operation is successful and a non-zero value on failure.

SEE ALSO

gets — Get a line of text from standard input.

EXAMPLE

```
#include <stdio.h>

char* str = "bald feet";

void main()
{
        puts ( str );
}
```

prints to standard output:

```
bald feet
```

NAME

qsort — Quick sort.

SYNOPSIS

```
#include <stdlib.h>
void qsort(    void* base, size_t nmemb, size_t size,
               int (*compar) (const void*, const void* ) );
```

DESCRIPTION

The **qsort** function sorts an array of **nmemb** objects of size **size**, pointed to by **base**.

The array is sorted in ascending order according to a comparison function pointed to by **compar** which is called with two pointers to the array members. The **compar** function must return an integer less than, equal to, or greater than zero if the first argument is considered to be respectively less than, equal to, or greater than the second argument.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

char* stuff[] = {
        "fred", "flintstone", "driving", "bald", "on", "feet"
        };

static int compare( const char** a1, const char** a2 )
{
        return( strcmp( *a1, *a2 ) );
}


main()
{
        int i;

        qsort(stuff, (size_t)6, (size_t)sizeof(char*), compare);

        for ( i = 0 ; i < 6 ; i++ )
        {
                printf( "%s\t", stuff[i] );
        }

        printf( "\n" );
}
```

prints to standard output:

```
bald    driving     feet     flintstone     fred       on
```

NAME

raise — Raise a signal.

SYNOPSIS

```
#include <signal.h>
int raise( int sig );
```

DESCRIPTION

The **raise** function sends the signal **sig** to the executing program and returns 0 if successful or non-zero if unsuccessful. See **signal.h** for list of available signals and their default actions.

For more information, see Chapter 6.

SEE ALSO

signal — Set up a signal handler.

EXAMPLE

```
#include <stdio.h>
#include <signal.h>

void main()
{
        int onintr();

        signal (SIGINT, onintr);
        raise( SIGINT );
}

onintr()
{
        printf( "caught SIGINT, see ya ...\n" );
        exit( -9 );
}
```

prints to standard output:

```
caught SIGINT, see ya ...
```

NAME

rand — Pseudo- random number generator.

SYNOPSIS

```
#include <stdlib.h>
int rand( void );
```

DESCRIPTION

The **rand** function computes and returns a sequence of pseudo-random integers in the range of 0 to 32767.

SEE ALSO

srand — Seed the pseudo-random number generator.

EXAMPLE

```
#include <stdio.h>

void main()
{
        /* seed the random number sequence */
        srand( 1638 );

        /* spew out random numbers in the range 0 to 709 */
        for ( ; ; )
        {
                printf( "%d\n", ( rand() ) % 709 );
        }
}
```

prints to standard output:

```
569
303
194
224
58
30
...
```

NAME

realloc — Change size of dynamically allocated storage area.

SYNOPSIS

```
#include <stdlib.h>
int realloc( void* ptr, size_t size );
```

DESCRIPTION

The **realloc** function changes the size of the storage area pointed to by **ptr** to a new size, **size**. The contents of the storage area are unchanged. If the new storage area is larger, the value of the new area is indeterminate. If **ptr** is null, **realloc** acts like **malloc**. If **ptr** was not dynamically allocated or the area was previously deallocated by a call to **free**, the behavior is undefined.

If **realloc** is unable to allocate the new size storage area, **NULL** is returned and the original storage area is unchanged.

SEE ALSO

calloc — Dynamically allocate zero-initialized storage.

free — Free dynamically allocated storage.

malloc — Dynamically allocate uninitialized storage.

EXAMPLE

```
#include <stdio.h>

void main()
{
        char* str;

        if ( ( str = (char*) malloc( (size_t) 15 ) ) == NULL )
        {
                perror( "malloc failed" );
                exit (-8);
        }

        strcpy( str, "short string" );
        printf( "%s\n", str );

        /* allocate space for 40 character string */
        if ((str = (char*)realloc(str, 40*sizeof(char)) )== NULL )
        {
                perror( "realloc test" );
                exit ( -9 );
        }

        strcat( str, " becomes a long string" );
        printf( "%s\n", str );
}
```

prints to standard output:

```
short string
short string becomes a long string
```

NAME

remove — Remove a file from the disk.

SYNOPSIS

```
#include <stdio.h>
int remove ( char *filename );
```

DESCRIPTION

The function **remove** will eliminate the file associated with the specified **filename**. The effect of this call on open files may vary from host to host, and is considered undefined.

EXAMPLE

```
#include <stdio.h>

void main()
{
        remove ( “foo.exe” );
}
```

will remove the file “foo.exe” on the disk, if such a file exists.

NAME

rename — Rename a file on the disk.

SYNOPSIS

```
#include <stdio.h>
int rename ( const char *old, const char *new );
```

DESCRIPTION

The function **rename** disassociates the a disk file from the name **old**, and associates it with the name **new**. The behavior of this call is undefined if there already exists a file associated with the name **new**. **rename** returns zero if it is successful. If it fails, the file remains associated with the old name, and is not altered in any way.

EXAMPLE

```
#include <stdio.h>

void main()
{
        rename ( “old.exe”, “new.exe” );
}
```

will rename the file “old.exe” to “new.exe”, provided that “old.exe” actually exists on the disk. Note that “old.exe” will cease to exist.

NAME

rewind — Reset the file position indicator to the beginning of the file.

SYNOPSIS

```
#include <stdio.h>
void rewind ( FILE *stream );
```

DESCRIPTION

The function **rewind** will reset the file position indicator associated with the specified stream. Any pending error is also cleared.

SEE ALSO

fgetpos — Obtain the file position indicator value associated with a stream.

fsetpos — Set the file position indicator value associated with a stream.

EXAMPLES

```
#include <stdio.h>

void main ()
{
        FILE *preexisting = fopen ( “already.here”, “r” );

        putchar ( fgetc ( preexisting ));
        rewind ( preexisting );
        putchar ( fgetc ( preexisting ));
}
```

will print the first character in the file “already.here” onto standard output twice.

NAME

scanf — Read formatted input from standard input.

SYNOPSIS

```
#include <stdio.h>
int scanf (char *format, ... );
```

DESCRIPTION

The function **scanf** is equivalent to the **fscanf** function, except that input is always read from standard input. Please use the description of argument values in the description of the **fscanf** function.

SEE ALSO

fscanf — Read formatted input from a stream.

EXAMPLES

See the manual entry for **fscanf** for examples. The only difference between **scanf** and **fscanf** is that **scanf** does not require a **FILE*** argument; **stdin** is implied.

NAME

setjmp — Save a reference of the current calling environment for later use by longjmp.

SYNOPSIS

```
#include <setjmp.h>
int setjmp( jmp_buf env );
```

DESCRIPTION

The **setjmp** function saves its calling environment in **env** for later use by **longjmp**. If the return is direct from **setjmp**, the value zero is returned. If the return is from the **longjmp** function, the value returned is non-zero.

For more information, see Chapter 6.

SEE ALSO

longjmp — Execute a non-local jump.

EXAMPLE

```
#include <stdio.h>
#include <setjmp.h>

jmp_buf env;

void func( void )
{
        longjmp( env, -709 );
}

void main()
{
        if ( setjmp( env ) != 0 )
        {
                printf( "-- longjmp has been called --\n" );
                exit( 1 );
        }
        printf( "-- setjmp called --\n" );
        func();
}
```

prints to standard output:

```
-- setjmp called --
-- longjmp has been called --
```

NAME

setbuf — Read formatted input from standard input.

SYNOPSIS

```
#include <stdio.h>
void setbuf ( FILE *stream,  char *buf );
```

DESCRIPTION

If **buf** is **NULL**, the specified stream will be unbuffered. If buf is non-**NULL**, then the stream will be fully buffered with a buffer of size **BUFSIZ**. Note that **setbuf** must be used only before any other operations are performed on the specified stream, and that the stream argument must be associated with an opened file. Calling **setbuf** is equivalent to calling **setvbuf** using _**IOBUF** for the **mode** argument, and **BUFSIZ** for the **size** argument.

SEE ALSO

setvbuf — Read formatted input from a stream.

NAME

setvbuf — Alter stream buffering.

SYNOPSIS

```
#include <stdio.h>
int setvbuf ( FILE *stream,  char *buf, int mode, size_t size );
```

DESCRIPTION

The function **setvbuf** is used to alter the way a specified stream is buffered. It must only be used before any other operation is performed on the specified stream. The argument **mode** determines the buffering policy:

_**IOFBF**	—	Use the full size of the buffer in the most efficient way.
_**IOLBF**	—	Use a line buffering policy: flush on newlines.
_**IONBF**	—	Do not buffer the stream at all.

The argument **size** specified the buffer size for this stream. The pointer **buf**, if non-**NULL**, may be used for stream buffering. If **buf** is **NULL**, then **setvbuf** will allocate any needed buffer.

SEE ALSO

setbuf — A restricted form of **setvbuf**.

NAME

signal — Set up signal handler.

SYNOPSIS

```
#include <setjmp.h>
void (*signal( int sig, void (*func)(int) ) ) (int);
```

DESCRIPTION

The **signal** function chooses one of three ways in which to handle the receipt of the signal **sig**:

1. If the value of **func** is the macro **SIG_DFL**, default handling for the signal will occur.
2. If the value of **func** is the macro **SIG_IGN**, the signal is ignored.
3. Otherwise, **func** is a pointer to a function that will be called on the receipt of signal **sig**.

When a signal occurs, the signal handler for **sig** is reset to **SIG_DFL**; this is equivalent to making the call **signal** (**sig**, **SIG_DFL**). The function **func** terminates by executing the **return** statement or by calling the **abort**, **exit**, or **longjmp** function. If the function **func** terminates with a **return** statement, execution continues at the point the signal was caught. Note that if the value of **sig** was **SIGFPE**, the behavior is undefined.

Also note that in order to continue catching signal **sig**, the signal handler must reissue the signal call.

For more information, see Chapter 6.

SEE ALSO

raise — Raise a signal.

EXAMPLE

```
#include <stdio.h>
#include <signal.h>

void main()
{
        int onintr();

        signal (SIGINT, onintr);
        raise( SIGINT );
}

onintr()
{
        printf( "caught SIGINT, see ya ...\n" );
        exit( -9 );
}
```

prints to standard output:

```
caught SIGINT, see ya ...
```

NAME

sin — Sine.

SYNOPSIS

```
#include <math.h>
double sin( double x );
```

DESCRIPTION

The **sin** function computes and returns the sine of **x**, measured in radians.

SEE ALSO

asin — The arc sine of an angle.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "sin( 45.0 ) == %f\n", sin( 45.0 ) );
}
```

prints to standard output:

```
sin( 45.0 ) == 0.850903
```

NAME

sinh — Hyperbolic Sine.

SYNOPSIS

```
#include <math.h>
double sinh( double x );
```

DESCRIPTION

The **sinh** function computes and returns the hyperbolic sine of **x**, measured in radians. When the value of **x** is too large, **errno** will be set to **ERANGE** and the return value will be **HUGE_VAL** with the sign of **x**.

SEE ALSO

cosh — Hyperbolic cosine of an angle.

tanh — Hyperbolic tangent of an angle.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "sinh( 3.1415 ) == %f\n", sinh( 3.1415 ) );
}
```

prints to standard output:

```
sinh ( 3.1415 ) == 11.547600
```

NAME

sprintf — Print to a string.

SYNOPSIS

```
#include <stdio.h>
int sprintf ( char *s, const char *format, … );
```

DESCRIPTION

The **sprintf** function is equivalent to **printf** except that **s** specifies a string that the generated output is printed to rather than standard output. A null character is written at the end of the string. The **sprintf** function returns the number of characters written to the string.

SEE ALSO

printf — Print to a standard output.

EXAMPLE

```
#include <stdio.h>

void main()
{
        char buffer[256];
        char* bptr = buffer;
        char* str = "strings";
        int  i = 709, count;
        double d = 7.09;

        bptr += sprintf( bptr,"testing sprintf with:\n" );
        sprintf( bptr, "\tstrings\t(%s)\n%n", str, &count );
        bptr += count;
        bptr += sprintf( bptr, "\thex digits\t%x\n", i );
        bptr += sprintf( bptr, "\tfloating point\t%f\n", d );

        puts( buffer );
}
```

prints to standard output:

```
testing sprintf with:
        strings (strings)
        hex digits 2c5
        floating point 7.090000
```

NAME

sqrt — Square root.

SYNOPSIS

```
#include <math.h>
double sqrt( double x );
```

DESCRIPTION

The **sqrt** function computes and returns the nonnegative square root of **x**. If **x** is less than zero, **errno** is set to **EDOM** and 0.0 is returned.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        double d = 50.2681;

        printf( "sqrt( 50.2681 ) == %.2f\n", sqrt( d ) );
}
```

prints to standard output:

```
sqrt( 50.2681 ) == 7.09
```

NAME

srand — Seed the pseudo-random number generator.

SYNOPSIS

```
#include <stdlib.h>
void sqrt( unsigned int seed );
```

DESCRIPTION

The **srand** function uses the argument as a seed for a new sequence of pseudo-random numbers to be returned by **rand**. When **srand** is called with the same argument, the sequence of pseudo-random numbers will be repeated. If **srand** is not called, the default seed is 1.

SEE ALSO

rand — Generate a pseudo-random number sequence.

EXAMPLE

```
#include <stdio.h>

void main()
{
        /* seed the random number sequence */
        srand( 1638 );

        /* spew out random numbers in the range 0 to 709 */
        for ( ; ; )
        {
                printf( "%d\n", ( rand() ) % 709 );
        }
}
```

prints to standard output:

```
569
303
194
224
58
30
...
```

NAME

sscanf — Read formatted input from a string.

SYNOPSIS

```
#include <stdio.h>
int sscanf ( const char *s, const char *format, ... );
```

DESCRIPTION

The function **sscanf** reads formatted input from the string argument **s**, according to the format string **format**. The operation of **sscanf** is identical to fscanf except that input is read from a string.

SEE ALSO

fscanf — Read formatted input from a string.

NAME

strcat — Concatenate two strings.

SYNOPSIS

```
#include <string.h>
char* strcat( char* s1, const char* s2 );
```

DESCRIPTION

The **strcat** function appends a copy of the string pointed to by **s2** (including the terminating null character) to the end of the string pointed to by **s1**. The first character of the second string is written over the first strings terminating character. The **strcat** function returns the pointer **s1**.

SEE ALSO

strncat — Concatenate n characters from one string to another.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char bigstr[80] = "string 1";
        char smallstr[20] = " string 2";

        printf("concatenate (%s) and (%s)\n", bigstr, smallstr);
        (void) strcat( bigstr, smallstr );
        puts( bigstr );
}
```

prints to standard output:

```
concatenate (string 1) and ( string 2)
string 1 string 2
```

NAME

strchr — Find first occurrence of a character in a string.

SYNOPSIS

```
#include <string.h>
char* strchr( const char* s, int c );
```

DESCRIPTION

The **strchr** function locates the first occurrence of **c** (converted to a **char**) in the string pointed to by **s**. The terminating null character is considered part of the string. The **strchr** function returns a pointer to the located character or a null pointer if the character is not found in the string.

SEE ALSO

memchr — Find a character in a memory area.

strcspn — Compute the length of the prefix of a string not containing any characters contained in another string.

strpbrk — Find the first occurrence of a character from one string in another string.

strrchr — Find the last occurrence of a character in a string.

strspn — Compute the length of the prefix of a string contained in another string.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char* string = "fred flintstone driving on bald feet";
        char* found;

        found = strchr( string, 'b' );
        puts( found );
}
```

prints to standard output:

```
bald feet
```

NAME

strcmp — Compare two strings.

SYNOPSIS

```
#include <string.h>
int strcmp( const char* s1, const char* s2 );
```

DESCRIPTION

The **strcmp** function compares the string pointed to by **s1** to the string pointed to by **s2**. If string **s1** is lexicographically greater than, equal to, or less than **s2**; an integer respectively greater than, equal to, or less than zero will be returned. The comparison of two strings of unequal length in which the longer string contains the smaller string yields the results that the longer string compares greater than.

i.e. strcmp("xxx", "xxxyz") < 0 **or** strcmp("xxxyz", "xxx") > 0

When the header file string.h is included, the default case will be in-line [see section A.3, Forcing Library Routines Out-of-line].

SEE ALSO

memcmp — Compare two memory areas.
strcoll — Compare two strings based on current locale.
strncmp — Compare portions of two strings.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        if ( strcmp( "xxx", "xxxyz" ) < 0 )
        {
                puts( "xxx is less than xxxyz" );
        }
        else
        {
                puts( "xxx is greater than xxxyz" );
        }

        if ( strcmp( "xxxyz", "xxx" ) < 0 )
        {
                puts( "xxxyz is less than xxx" );
        }
        else
        {
                puts( "xxxyz is greater than xxx" );
        }

        if ( strcmp( "xxxyz", "xxxyz" ) == 0 )
        {
                puts( "xxxyz is equal to xxxyz" );
        }
}
```

prints to standard output:

```
xxx is less than xxxyz
xxxyz is greater than xxx
xxxyz is equal to xxxyz
```

NAME

strcoll — Compare two strings based on current locale.

SYNOPSIS

```
#include <string.h>
int strcoll( const char* s1, const char* s2 );
```

DESCRIPTION

The **strcoll** function compares the string pointed to by **s1** to the string pointed to by **s2**, both strings are interpreted using the **LC_COLLATE** category of the current locale. If string **s1** is lexicographically greater than, equal to, or less than **s2**, an integer greater than, equal to, or less than zero will be returned. The comparison of two strings of unequal length in which the longer string contains the smaller string yields the result that the longer string compares greater than.

For **DSP561CCC**, **strcoll** functions exactly like **strcmp**.

SEE ALSO

strxfrm — Transform a string into locale-independent form.

strcmp — Compare two strings.

NAME

strcpy — Copy one string into another.

SYNOPSIS

```
#include <string.h>
int strcpy( char* s1, const char* s2 );
```

DESCRIPTION

The **strcpy** function copies the characters of string **s2**, including the terminating character, into the string pointed to by **s1**. If the strings overlap, the behavior is undefined. The value of **s1** is returned.

When the header file **string.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

SEE ALSO

memcpy — Copy one memory area to another.
memset — Initialize a memory area.
strncpy — Copy a portion of one string to another.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char string[80];

        strcpy( string, "-- no bald feet for george jetson --" );
        puts( string );
}
```

prints to standard output:

```
-- no bald feet for george jetson --
```

NAME

strcspn — Compute the length of the prefix of one string consisting entirely of characters from another.

SYNOPSIS

```
#include <string.h>
int strcspn( const char* s1, const char* s2 );
```

DESCRIPTION

The **strcspn** function computes and returns the length of the prefix of the string pointed to by **s1** that consists entirely of characters not found in the string pointed to by **s2**.

SEE ALSO

memchr — Find first occurrence of a character in a memory area.

strchr — Find first occurrence of a character in a string.

strpbrk — Find first occurrence of any character from one string in another string.

strrchr — Find last occurrence of a character in a string.

strspn — Compute the length of the prefix of one string that consists only of characters from another string.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        int i;

        i = strcspn( "azbyfghjki", "fkjeughtrg" );
        printf( "-- prefix length == %d --\n", i );
}
```

prints to standard output:

```
-- prefix length == 4 --
```

NAME

strerror — Map error code into an error message string.

SYNOPSIS

```
#include <string.h>
char* strerror( int errnum );
```

DESCRIPTION

The **strerror** function maps **errnum** to an error message string. A pointer to the string is returned. The string returned should not be modified by the programmer.

SEE ALSO

perror — Print error message.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        int i;

        for ( i = 1; i < 5; ++ i )
        {
                printf ( “message %d:%s\n”, i, strerror( i ));
        }
}
```

prints to standard output:

```
message 1:  domain error
message 2:  range error
message 3:  out of heap memory
message 4:  bad format for conversion string
```

NAME

strlen — Determine length of a string.

SYNOPSIS

```
#include <string.h>
size_t strlen( const char* s );
```

DESCRIPTION

The **strlen** function computes and returns the number of characters preceeding the terminating character.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char* s = "is your name michael diamond?";

        printf( "strlen( \"%s\" ) == %d\n", s, strlen( s ) );
}
```

prints to standard output:

```
strlen( "is your name michael diamond?" ) == 29
```

NAME

strncat — Concatenate a portion of one string to another.

SYNOPSIS

```
#include <string.h>
char* strncat( char* s1, const char* s2, size_t n );
```

DESCRIPTION

The **strncat** function appends, at most**, n** characters from the string pointed by **s2** to the end of the string pointed to by **s1**. The first character of the second string is written over the first strings terminating character and a new terminating character is appended. The **strncat** function returns a pointer to **s1**. If **s1** does not have **n** words allocated past the terminating character, the behavior is undefined.

SEE ALSO

strcat — **C**oncatenate one string to another.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char bstr[80] = "string 1";
        char sstr[20] = " string 2";

        printf("paste 5 chars of (%s) on to (%s)\n", sstr, bstr);
        (void) strncat( bstr, sstr, 5 );
        puts( bstr );
}
```

prints to standard output:

```
paste 5 chars of (string 2) on to ( string 1)
string 1 stri
```

NAME

strncmp — Compare a portion of two strings.

SYNOPSIS

```
#include <string.h>
int strncmp( const char* s1, const char* s2, size_t n );
```

DESCRIPTION

The **strncmp** function compares **n** characters of the string pointed to by **s2** with the string pointed to by **s1**. If string **s1** is lexicographically greater than, equal to, or less than **s2**; an integer respectively greater than, equal to, or less than zero will be returned. This is similar to **strcmp**.

SEE ALSO

strcmp — **C**ompare two strings.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char bigstr[80] = "string 1";
        char smallstr[20] = "string 2";

        if ( strncmp( bigstr, smallstr, 5 ) == 0 )
        {
                printf( "-- strncmp ok --\n" );
        }
        else
        {
                printf( "?? strncmp error ??\n" );
        }
}
```

prints to standard output:

```
-- strncmp ok --
```

NAME

strncpy — Copy a portion of one string into another.

SYNOPSIS

```
#include <string.h>
char* strncpy( char* s1, const char* s2, size_t n );
```

DESCRIPTION

The **strncpy** function copies exactly **n** characters from a string pointed to by **s2** into a string pointed to by **s1**. If **strlen** (**s2**) is less than **n**, the string **s1** is null padded. If **strlen** (**s2**) is greater than or equal to **n**, no null termination character is copied to **s1**. The **s1** pointer is returned.

Note that the behavior of non null terminated strings is undefined.

SEE ALSO

memcpy — Copy one memory area to another.

strcpy — **C**opy one string to another.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char bigstr[80] = "string 1";
        char smallstr[20] = "spanky 2";

        ( void ) strncpy( bigstr, smallstr, 6 );
        puts( bigstr );
}
```

prints to standard output:

```
spanky 1
```

NAME

strpbrk — Find the first occurrence of a character from one string in another.

SYNOPSIS

```
#include <string.h>
char* strpbrk( char* s1, const char* s2 );
```

DESCRIPTION

The **strpbrk** function finds the first occurrence of **any** character in the string pointed to by **s2** in the string pointed to by **s1**. If a character is found, a pointer to the character is returned. If a character is not found, a null pointer is returned.

SEE ALSO

memchr — Find a character in a memory area.

strchr — Find the first occurrence of a character in a string.

strcspn — Compute the length of the prefix of a string not containing any characters contained in another string.

strrchr — Find the last occurrence of a character in a string.

strspn — Compute the length of the prefix of a string contained in another string.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char* string = "abcde random characters fghijkl";
        char* fndstr = "klmnopqr";
        char* found;

        if ( ( found = strpbrk( string, fndstr ) ) != NULL )
        {
                puts( found );
        }

        else
        {
                puts( "can’t find a character" );
        }
}
```

prints to standard output:

```
random characters fghijkl
```

NAME

strrchr — Find the last occurrence of a character from one string in another.

SYNOPSIS

```
#include <string.h>
char* strpbrk( char* s1, const char* s2 );
```

DESCRIPTION

The **strrchr** function locates the last occurrence of **c** (converted to a char) in the string pointed to by **s**. The terminating null character is considered part of the string. **strrchr** returns a pointer to the located character, or **NULL**, if the character is not found in the string.

SEE ALSO

memchr — Find a character in a memory area.

strchr — Find the first occurrence of a character in a string.

strcspn — Compute the length of the prefix of a string not containing any characters contained in another string.

strpbrk — Find the first occurrence of a character from one string in another string.

strspn — Compute the length of the prefix of a string contained in another string.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char* string = "fred flintstone driving on bald feet";
        char* found;

        found = strrchr( string, 'f' );
        puts( found );
}
```

prints to standard output:

```
feet
```

NAME

strspn — Find the maximal initial substring that is composed from a specified set of characters.

SYNOPSIS

```
#include <string.h>
size_t strstr ( const char* s1, const char* s2 );
```

DESCRIPTION

The **strspn** function computes a maximal initial substring from **s1**. This substring will only contain characters from the set of characters contained in the string **s2**. The return value of **strspn** is the length of the computed substring.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main ()
{
        char* string = "bow wow, yippie yay yippie yay";
        char* ok_set = "wob ";

        printf ( “%*s\n”, (int) strspn ( string, ok_set ), string );
}
```

prints to standard output:

```
bow wow
```

NAME

strstr — Find the first occurrence of one string in another.

SYNOPSIS

```
#include <string.h>
char* strstr( const char* s1, const char* s2 );
```

DESCRIPTION

The **strstr** function locates the first occurrence of the string pointed to by **s2** (excluding the termination character) in the string pointed to by **s1**. If the string **s2** is found, a pointer to it is returned. If the string **s2** is not found, **NULL** returned. If **s2** has a length of zero, a pointer to **s1** is returned.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char* string = "abcdef random characters ghijkl";
        char* fndstr = "random";
        char* found;

        if ( ( found = strstr( string, fndstr ) ) != NULL )
        {
                puts( found );
        }
        else
        {
                puts( "can’t find the string" );
        }
}
```

prints to standard output:

```
random characters ghijkl
```

NAME

strtod — String to double.

SYNOPSIS

```
#include <stdlib.h>
double strtod( const char* nptr, char** endptr );
```

DESCRIPTION

The **strtod** function converts and returns the string pointed to by **nptr** to floating point number. First **strtod** decomposes **nptr** into three sections;

1. an initial, possibly empty, sequence of white space characters,
2. a subject in the form of a floating point constant; and
3. a final string of one or more unrecognized characters, including the terminating null character of the input string.

If the first unrecognized character is not null, a pointer to that character is stored into the object that **endptr** points to. If the string is empty or the subject contains no floating point constant description, zero is returned.

SEE ALSO

atof — String to double.
atoi — String to integer.
atol — String to long integer.
strtol — String to long integer.
strtoul — String to unsigned long integer.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        char* string = "7.09strtod stopped";
        char* stopped;
        double result;

        result = strtod( string, &stopped );
        printf( "string == (%s)\n", string );
        printf( "result == %f\n", result );
        printf( "stop string == (%s)\n", stopped );
}
```

prints to standard output:

```
string == (7.09strtod stopped)
result == 7.089990
stop string == (strtod stopped)
```

NAME

strtok — Break string into tokens.

SYNOPSIS

```
#include <stdlib.h>
char* strtok( char* s1, const char* s2 );
```

DESCRIPTION

The **strtok** function breaks the string pointed to by **s1** into tokens and each token is delimited by characters from the string pointed to by **s2**. The first call in the sequence has **s1** as its first argument and is followed by calls with a null pointer as the first argument. The separator string, **s2,** may be different from call to call. If a token is not found, a null pointer is returned. If a token is found, a null terminated token is returned.

EXAMPLE

```
#include <stdio.h>
#include <string.h>

void main()
{
        char* str1 = "$%^this#is string\tnumber!one.";
        char  str2[] = "?a???b,,,#c";
        char* token;

        while ( ( token = strtok( str1, "$%^#\t! " ) ) != NULL )
        {
                printf( "%s ", token );
                str1 = NULL;
        }

        printf( "\n" );

        token = strtok( str2, "?" ); printf( "%s ", token );
        token = strtok( NULL, "," ); printf( "%s ", token );
        token = strtok( NULL, "#," ); printf( "%s\n", token );

        if ( ( token = strtok( NULL, "?" ) ) != NULL )
        {
                printf( "error: strtok busted\n" );
        }
}
```

prints to standard output:

```
this is string number one.
a ??b c
```

NAME

strtol — String to long integer.

SYNOPSIS

```
#include <stdlib.h>
long int strtol( const char* nptr, char** endptr, int base );
```

DESCRIPTION

The **strtol** function converts and returns the string pointed to by **nptr** to a long integer. First **strtol** decomposes **nptr** into three sections;

1. an initial, possibly empty, sequence of white space characters,
2. a subject in the form of an integer constant; and
3. a final string of one or more unrecognized characters, including the terminating null character of the input string.

If the first unrecognized character is not null, a pointer to that character is stored in to the object that **endptr** points to. If the string is empty or the subject contains no floating-point constant description, zero is returned.

If **base** is between 2 and 36, the expected form of the long integer subject is a sequence of letters and digits with the radix specified by base. The letters **a** (or **A**) through **z** (or **Z**) are ascribed values 10 to 35; only letters whose value is less than **base** are valid. If **base** is 16, **0x** or **0X** may optionally preceed the long integer subject. If **base** is zero, the long integer subject determines its own base.

Leading 0x, or 0X	base == 16
Leading 0	base == 8
otherwise	base == 10

If the value of the return value is too large to be expressed by a long int, **errno** is set to **ERANGE** and **LONG_MAX** is returned.

SEE ALSO

atof — String to double.
atoi — String to integer.
atol — String to long integer.
strtod — String to double.
strtoul — String to unsigned long integer.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        char* hexstr = "0x3cdef709hexstr stopped";
        char* decstr = "709709709decstr stopped";
        char* octstr = "012341234octstr stopped";
        char* stopped;
        long result;

        printf( "result\t\tstop string\n" );
        result = strtol( hexstr, &stopped, 16 );
        printf( "%lx\t\t%s\n", result, stopped );

        result = strtol( decstr, &stopped, 10 );
        printf( "%ld\t\t%s\n", result, stopped );

        result = strtol( octstr, &stopped, 8 );
        printf( "%lo\t\t%s\n", result, stopped );
}
```

prints to standard output:

```
result          stop string
3cdef709        hexstr stopped
709709709       decstr stopped
12341234        octstr stopped
```

NAME

strtoul — String to unsigned long integer.

SYNOPSIS

```
#include <stdlib.h>
unsigned long int strtoul( const char* nptr, char** endptr, int base );
```

DESCRIPTION

The **strtoul** function converts and returns the string pointed to by **nptr** to a long integer. First **strtoul** decomposes **nptr** into three sections; an initial, possibly empty, sequence of white space characters, a subject in the form of an integer constant; and a final string of one or more unrecognized characters, including the terminating null character of the input string.

If the first unrecognized character is not null, a pointer to that character is stored in to the object that **endptr** points to. If the string is empty or the subject contains no floating point constant description, zero is returned.

If **base** is between 2 and 36, the expected form of the long integer subject is a sequence of letters and digits with the radix specified by base. The letters **a** (or **A**) through **z** (or **Z**) are ascribed values 10 to 35; only letters whose value is less than **base** are valid. If **base** is 16, **0x** or **0X** may optionally preceed the long integer subject. If **base** is zero, the long integer subject determines its own base.

Leading 0x, or 0X	base == 16
Leading 0	base == 8
otherwise	base == 10

If the value of the return value is too large to be expressed by a long int, **errno** is set to **ERANGE**, and **ULONG_MAX** is returned.

SEE ALSO

atof — String to double.
atoi — String to integer.
atol — String to long integer.
strtod — String to double.
strtol — String to long integer.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

void main()
{
        char* hexstr = "0xbcdef709hexstr stopped";
        char* decstr = "709709709decstr stopped";
        char* octstr = "012341234octstr stopped";
        char* stopped;
        unsigned long result;

        printf( "result\t\tstop string\n" );
        result = strtoul( hexstr, &stopped, 16 );
        printf( "%lu\t\t%s\n", result, stopped );

        result = strtoul( decstr, &stopped, 10 );
        printf( "%lu\t\t%s\n", result, stopped );

        result = strtoul( octstr, &stopped, 8 );
        printf( "%lu\t\t%s\n", result, stopped );
}
```

prints to standard output:

```
result          stop string
3168728841      hexstr stopped
709709709       decstr stopped
2736796         octstr stopped
```

NAME

strxfrm — Transform a string into locale-independent form.

SYNOPSIS

```
#include <string.h>
size_t strxfrm( char* s1, const char* s2, size_t n );
```

DESCRIPTION

The **strxfrm** function transforms the string pointed to by **s2** and places the resulting string in the array pointed to by **s1**. The transformation is such that if the **strcmp** function is applied to the two transformed strings, it returns a value greater than, equal to, or less than zero, corresponding to the result of the **strcoll** function applied to the same two original strings. No more than **n** characters are placed into **s1**, including the terminating null character. If **s1** and **s2** overlap, the behavior is undefined.

The **strxfrm** function returns the length of the transformed string excluding the terminating null character. If the value returned is **n** or more, the contents of **s1** are indeterminate.

SEE ALSO

strcoll — Compare two strings based on current locale.

strcmp — Compare two strings.

SPECIAL NOTE

DSP561CCC only supports the standard locale, so no transformation is done.

NAME

tan — Tangent.

SYNOPSIS

```
#include <math.h>
double tan( double x );
```

DESCRIPTION

The **tan** function computes and returns the tangent of **x**, where **x** is in radians.

SEE ALSO

atan — Compute the arc tangent.

atan2 — Compute the arc tangent of a point.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "tan( 45 ) == %f\n", tan( 45 ) );
}
```

prints to standard output:

```
tan( 45 ) == 1.619770
```

NAME

tanh — Hyperbolic tangent.

SYNOPSIS

```
#include <math.h>
double tanh( double x );
```

DESCRIPTION

The **tanh** function computes and returns the hyperbolic tanget of **x,**

tanh(**x**) == **sinh**(**x**) / **cosh**(**x**)

If the value of **x** is too large, **errno** is set to **ERANGE** and the value **HUGE_VAL** is returned with the sign of **x.**

SEE ALSO

cosh — Compute the hyperbolic cosine.

sinh — Compute the hyperbolic sine.

EXAMPLE

```
#include <stdio.h>
#include <math.h>

void main()
{
        printf( "tanh( 45 ) == %f\n", tanh( 45 ) );
}
```

prints to standard output:

```
tanh( 45 ) == 1.000000
```

NAME

tmpfile — Create a temporary binary file.

SYNOPSIS

```
#include <stdio.h>
FILE *tmpfile (  void );
```

DESCRIPTION

The function tmpfile will create a temporary file on the disk. The file will be automatically removed when the program terminates. The file will be opened with the mode “**wb+**”. If tmpfile fails, it returns a **NULL** pointer.

SEE ALSO

tmpnam — Generate a valid temporary file name.

NAME

tmpnam — Create a temporary file name.

SYNOPSIS

```
#include <stdio.h>
char *tmpnam (  char *s );
```

DESCRIPTION

The function **tmpnam** will create a string that could be used as a unique temporary file name. This function may be called as many as **TMP_MAX** times. Each time it will return a different string. If the argument **s** is **NULL**, then **tmpnam** will return an internal static buffer that may be clobbered by subsequent calls. If s is non-**NULL**, then it must point to a writable buffer of at least **L_tmpnam** characters.

SEE ALSO

tmpfile — Create a temporary binary file.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        char buffer[L_tmpnam];

        (void) fopen ( tmpnam ( buffer ), “w+” );
}
```

will create a temporary text file on the disk. Note that unlike when **tmpfile** is called, one must remove any files created using **fopen** and **tmpnam**.

NAME

tolower — Convert uppercase character to lowercase.

SYNOPSIS

```
#include <ctype.h>
int tolower( int c );
```

DESCRIPTION

The **tolower** function converts uppercase to lowercase**.** If **c** is an uppercase letter, return the corresponding lowercase letter; otherwise return **c**.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        printf( "tolower( 'A' ) == %c\n", tolower( 'A' ) );
        printf( "tolower( 'z' ) == %c\n", tolower( 'z' ) );
        printf( "tolower( '#' ) == %c\n", tolower( '#' ) );
}
```

prints to standard output:

```
tolower( 'A' ) == a
tolower( 'z' ) == z
tolower( '#' ) == #
```

NAME

toupper — Convert lowercase character to uppercase.

SYNOPSIS

```
#include <ctype.h>
int toupper( int c );
```

DESCRIPTION

The **toupper** function converts lowercase to uppercase**.** If **c** is a lowercase letter, return the corresponding uppercase letter; otherwise return **c**.

When the header file **ctype.h** is included, the default case will be **in-line** [see section A.3, Forcing Library Routines Out-of-line].

EXAMPLE

```
#include <stdio.h>
#include <ctype.h>

void main()
{
        printf( "toupper( 'A' ) == %c\n", toupper( 'A' ) );
        printf( "toupper( 'z' ) == %c\n", toupper( 'z' ) );
        printf( "toupper( '#' ) == %c\n", toupper( '#' ) );
}
```

prints to standard output:

```
toupper( 'A' ) == A
toupper( 'z' ) == Z
toupper( '#' ) == #
```

NAME

ungetc — Push a character back onto an input stream.

SYNOPSIS

```
#include <stdio.h>
int ungetc ( int c, FILE *stream );
```

DESCRIPTION

The function **ungetc** converts the argument **c** to an **unsigned char**, and pushes it back onto the specified input stream. Pushed characters will be read back in reverse order by any functions reading from said stream. If a call is made to a file positioning function, such as **fseek**, all pushed characters will be lost. Only one call to **ungetc** before a read from the stream is allowed. **EOF** cannot be pushed. **ungetc** returns **EOF** upon failure, while the converted value is returned upon success.

SEE ALSO

tmpfile — Create a temporary file.

EXAMPLE

```
#include <stdio.h>

void main ()
{
        char peek = getchar ();
        putchar ( peek );
        ungetc ( peek, stdin );
        putchar ( getchar ());
}
```

will print the first character from standard input twice on standard output.

NAME

vfprintf — Write formatted output to a stream using a va_list.

SYNOPSIS

```
#include <stdio.h>
int vfprintf ( FILE *stream, const char *format, va_list arg );
```

DESCRIPTION

The function **vfprintf** is exactly the same as the function **fprintf** except that an existing **va_list** is used in place of a series of arguments. The macro **va_start** must have been invoked on the argument arg before the call to **vfprintf** is made. **vfprintf** returns the number of characters printed. On error, **vfprintf** returns a negative value.

SEE ALSO

fprintf — Write formatted output to a stream.

EXAMPLE

```
#include <stdio.h>

int printf ( const char *format, ... )
{
        va_list ap;
        int result;

        va_start ( ap, format );
        result = vfprintf ( stdout, format, ap );
        va_end ( ap );
        return result;
}
```

is essentially the library function **printf**.

NAME

vprintf — Write formatted output to standard output using a va_list.

SYNOPSIS

```
#include <stdio.h>
int vprintf ( const char *format, va_list arg );
```

DESCRIPTION

The function **vprintf** is exactly the same as the function **printf** except that an existing **va_list** is used in place of a series of arguments. The macro **va_start** must have been invoked on the argument arg before the call to **vprintf** is made. **vprintf** returns the number of characters printed. On error, **vprintf** returns a negative value.

SEE ALSO

printf — Write formatted output to standard output.

EXAMPLE

```
#include <stdio.h>

int printf ( const char *format, ... )
{
        va_list ap;
        int result;

        va_start ( ap, format );
        result = vprintf ( format, ap );
        va_end ( ap );
        return result;
}
```

is essentially the library function **printf**.

NAME

vsprintf — Write formatted output to a string using a va_list.

SYNOPSIS

```
#include <stdio.h>
int vsprintf ( char *s, const char *format, va_list arg );
```

DESCRIPTION

The function **vsprintf** is exactly the same as the function **printf** except that an existing **va_list** is used in place of a series of arguments. The macro **va_start** must have been invoked on the argument arg before the call to **vsprintf** is made. **vsprintf** returns the number of characters printed. On error, **vsprintf** returns a negative value.

SEE ALSO

sprintf — Write formatted output to a string.

EXAMPLE

```
#include <stdio.h>

int sprintf ( char *s, const char *format, ... )
{
        va_list ap;
        int result;

        va_start ( ap, format );
        result = vsprintf ( s, format, ap );
        va_end ( ap );
        return result;
}
```

is essentially the library function **sprintf**.

NAME

wcstombs— Convert wchar_t array to multibyte string.

SYNOPSIS

```
#include <stdlib.h>
size_t wcstombs( char* s, const wchar_t* pwcs, size_t n );
```

DESCRIPTION

The **wcstombs** function converts a wide character string pointed to by **pwcs** into the character string pointed to by **s**. Each character of the wide character string is converted into the corresponding multibyte character as if by the **wctomb** function. Conversion will stop when **n** total characters have been converted or a null character is encountered. If **s** and **pwcs** overlap, the behavior is undefined.

If an invalid character is encountered, **wcstombs** returns (size_t) -1. Otherwise, **wcstombs** returns the number of characters converted not including the terminating **NULL** character, if any.

SEE ALSO

mbtowcs — Convert a multibyte string to a wchar_t array.

SPECIAL NOTE

The DSP56100 does not provide byte addressing, thus characters always require an entire word of memory each. One way to better utilize data memory (with a run-time cost) is to use the ANSI data type **wchar_t** and the special ANSI **multibyte** and **wide character** library routines.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

char array[16];
wchar_t wstr[] = L"abcdefgh";

void main()
{
        char* ptr = (char*) wstr;
        int convert;

        convert = wcstombs( array, wstr, 10 );

        printf( "packed array:\n" );
        while ( *ptr != 0 )
        {
                printf( "%0.4x ", *ptr++ );
        }
        printf( "\n\n" );

        printf("%d chars extracted, unpacked array:\n", convert );
        ptr = array;
        while ( *ptr != 0 )
        {
                printf( "%0.4x ", *ptr++ );
        }
        printf( "\n" );
}
```

prints to standard output:

```
packed array:
6162 6364 6566 6768

8 chars extracted, unpacked array:
0061 0062 0063 0064 0065 0066 0067 0068
```

NAME

wctomb — Convert wchar_t character to multibyte character.

SYNOPSIS

```
#include <stdlib.h>
int wctomb( char* s, wchar_t wchar );
```

DESCRIPTION

The **wctomb** function examines and converts the wide character **wchar** into a string of characters pointed to by **s**. At most, **MB_CUR_MAX** characters will be stored in **s**.

If **s** is **NULL**, **wctomb** returns zero. If **s** is not **NULL**, **wctomb** returns the number of characters that comprise the converted multibyte character unless an invalid multibyte character is detected in which case -1 will be returned.

SEE ALSO

mblen — Determine the length of a multibyte character.

mbstowcs— Convert a multibyte string into a wide character string.

mbtowc — Convert a multibyte character into a wide character.

SPECIAL NOTE

The DSP56100 does not provide byte addressing, thus characters always require an entire word of memory each. One way to better utilize data memory (with a run-time cost) is to use the ANSI data type **wchar_t** and the special ANSI **multibyte** and **wide character** library routines.

EXAMPLE

```
#include <stdio.h>
#include <stdlib.h>

char mbarray[8];

void main()
{
        wchar_t wide = L’ab’;
        char* ptr = mbarray;
        int convert;

        convert = wctomb( mbarray, wide );

        printf( "packed char looks like:\n" );
        printf( "%0.4x\n\n", wide );

        printf( "%d extracted chars looks like:\n", convert );
        while ( *ptr != 0 )
        {
                printf( "%0.4x ", *ptr++ );
        }
        printf( "\n" );
}
```

prints to standard output:

```
packed char looks like:
6162

2 extracted chars looks like:
0061 0062
```

Appendix B
DSP56100 Family Instruction Set and Assembler Directive Summary

B.1 Overview

This appendix is intended to assist the C programmer in understanding the C compiler's output. For a more in-depth discussion of assembler and assembly language issues, see the DSP56100 Digital Signal Processor Family Manual or the DSP56100 Assembler User's Manual (not included).

B.2 Instruction Set

Instructions can be grouped by function into six types:

1. Arithmetic instructions
2. Logical instructions
3. Bit manipulation instructions
4. Loop instructions
5. Move instructions
6. Program control instructions

B.2.1 Arithmetic Instructions

The instructions used for arithmetic operations are:

ABS — Absolute value
ADC — Add long with carry
ADD — Add
ASL — Arithmetic shift accumulator left
ASL4 — 4-bit arithmetic shift accumulator left
ASR — Arithmetic shift accumulator right
ASR4 — 4-bit arithmetic shift accumulator right

ASR16 — 16-bit arithmetic shift accumulator right
CLR — Clear accumulator
CLR24 — Clear 24 MS-bits of accumulator
CMP — Compare
CMPM — Compare magnitude
DEC — Decrement accumulator
DEC24 — Decrement 24 MS-bits of accumulator
DIV — Divide iteration
DMAC — Double precision multiply-accumulate with 16-bit right shift
EXT — Sign extend accumulator
IMAC — Integer multiply-accumulate
IMPY — Integer multiply
INC — Increment accumulator
INC24 — Increment 24 MS-bits of accumulator
MAC — Signed multiply-accumulate
MACR — Signed multiply-accumulate and round
MAC(su,uu) — Mixed multiply-accumulate
MPY — Signed multiply
MPYR — Signed multiply and round
MPY(su,uu) — Mixed multiply
NEG — Negate accumulator
NEGC — Negate accumulator with carry
NORM — Normalize accumulator iteration
RND — Round accumulator
SBC — Subtract long with carry
SUB — Subtract
SUBL — Shift left and subtract accumulators
SUBR — Shift right and subtract accumulators
SWAP — Shift accumulator words
TST — Test accumulator
TST2 — Test data ALU register
ZERO — Zero extend accumulator

B.2.2 Logical Instructions

The instructions used for logical operations are:

AND — Logical AND
ANDI — AND Immediate with control register
EOR — Logical exclusive OR
LSL — Logical shift accumulator left
LSR — Logical shift accumulator right
NOT — Logical complement on accumulator
OR — Logical inclusive OR
ORI — OR immediate with control register
ROL — Rotate accumulator left
ROR — Rotate accumulator right

B.2.3 Bit Field Manipulation Instructions

The instructions used for bit field manipulation are:

BFCHG — Bit field test and change
BFCLR — Bit field test and clear
BFSET — Bit field test and set
BFTSTH — Bit field test high
BFTSTL — Bit field test low

B.2.4 Loop Instructions

The instructions used for loop operations are:

BRKcc — Exit current DO loop conditionally
DO — Start hardware loop
ENDDO — Exit from hardware loop
REP — Repeat next instruction
REPcc — Repeat next instruction conditionally

B.2.5 Move Instructions

The instructions used for move operations are:

LEA — Load effective address
MOVE — Move data
MOVEC — Move control register
MOVEM — Move program memory
MOVEP — Move peripheral data
Tcc — Transfer conditionally
TFR — Transfer data ALU register

TFR2 — Two word data ALU register transfer
TFR3 — Transfer data ALU register

B.2.6 Program Control Instructions

The instructions used for program control are:

Bcc — Branch conditionally
BRA — Branch
BScc — Branch to subroutine conditionally
BSR — Branch to subroutine
DEBUG — Enter debug mode
DEBUGcc — Enter debug mode conditionally
ILLEGAL — Illegal instruction interrupt
Jcc — Jump conditionally
JMP — Jump
JScc — Jump to subroutine conditionally
JSR — Jump to subroutine
NOP — No operation
RESET — Reset on-chip peripheral devices
RTI — Return from interrupt
RTS — Return from subroutine
STOP — Stop processing (low power stand-by)
SWI — Software interrupt
WAIT — Wait for interrupt (low power stand-by)

B.3 Directive Summary

Directives can be grouped by function into seven types:

1. Assembly control
2. Symbol definition
3. Data definition / storage allocation
4. Listing control and options
5. Object file control
6. Macros and conditional assembly
7. Structured programming

B.3.1 Assembly Control

The directives used for assembly control are:

COMMENT — Comment line(s)
DEFINE — Define substitution strings
END — End of source program
FAIL — Programmer generated error message
INCLUDE — Include secondary file
MSG — Program generated message
ORG — Initialize memory space and location counters
RADIX — Change input radix for constants
RDIRECT — Remove directive / mnemonic from assembler table
UNDEF — Undefine DEFINE symbol
WARN — Programmer generated warning message

B.3.2 Symbol Definition

The directives used to control symbol definition are:

ENDSEC — End section
EQU — Equate symbol to a value
SET — Set symbol to a value
SECTION — Start section
XDEF — External section symbol definition
XREF — External section symbol reference

B.3.3 Data Definition/Storage Allocation

The directives used to control constant data definition and storage allocation are:

BSC — Block storage of a constant
DC — Define constant
DS — Define storage
DSM — Define modulo storage
DSR — Define reverse carry storage

B.3.4 Listing Control and Options

The directives used to control the output listing are:

LIST — List the assembly
LSTCOL — Set listing field widths
NOLIST — Stop assembly listing
OPT — Assembler options
PAGE — Top of page / define page size
PRCTL — Send control string to printer
STITLE — Initialize program sub—title
TITLE — Initialize program title

B.3.5 Object File Control

The directives used to control the object file are:

COBJ — Comment object code
IDENT — Object code identification record
SYMOBJ — Write symbol information to object file

B.3.6 Macros and Conditional Assembly

The directives used for macros and conditional assembly are:

DUP — Duplicate a sequence of source lines
DUPA — Duplicate sequence with arguments
DUPC — Duplicate sequence with characters
ENDIF — End of conditional assembly
ENDM — End of macro definition
EXITM — Exit macro
IF — Conditional assembly directive
MACLIB — Macro library
MACRO — Macro definition
PMACRO — Purge a macro definition

B.3.7 Structured Programming

The directives used for structured programming are:

.BREAK — Exit from structured loop construct
.CONTINUE— Continue next iteration of structured loop
.ELSE — Perform following statements when .IF false
.ENDF — End of .FOR loop
.ENDI — End of .IF condition
.ENDL — End of hardware loop
.ENDW — End of .WHILE loop
.FOR — Begin .FOR loop
.IF — Begin .IF condition
.LOOP — Begin hardware loop
.REPEAT — Begin .REPEAT loop
.UNTIL — End of .REPEAT loop
.WHILE — Begin .WHILE loop

Appendix C
Utilities

There are nine utility programs available with the DSP561CCC Rev. g1.11 compiler. They are:

1. asm56100
2. cldinfo
3. cldlod
4. cofdmp
5. dsplib
6. dsplnk
7. gdb561
8. run561
9. srec

These programs are described in detail in the following pages.

NAME

asm56100 — Motorola DSP56100 Family COFF Assembler

SYNOPSIS

asm56100 [**-A**] [**-B** [<objfil>]] [**-D** <symbol> <string>] [**-F** <argfil>]

[**-G**] [**-I** <ipath>] [**-L** [<lstfil>]] [**-M** <mpath>] [**-O** <opt> [, <opt> ...]]

[**-R** <rev> [, <rev>...]] [**-V**] [**-Z**] <files...>

DESCRIPTION

asm56100 is a program that processes source program statements written in DSP56100 assembly language, translating these source statements into object programs compatible with other DSP56100 software and hardware products.

files is a list of operating system compatible file names including optional pathnames. If no extension is supplied for a given file, the assembler will first attempt to open the file using the file name as supplied. If that is not successful, the assembler appends .asm to the file name and tries to open the file again. If no path is given for a particular file, the assembler will look for that file in the current directory. The list of files will be processed sequentially in the order given and all files will be used to generate the output listing and object file.

The assembler will redirect the output listing to the standard output if it is not redirected via the -L command line option described below. Error messages will always appear on the standard output regardless of any option settings. Note that some options (-B and -L) allow a hyphen as an optional argument which indicates that the corresponding output should be sent to the standard output stream. Unpredictable results may occur if, for example, the object file is explicitly routed to standard output while the listing file is allowed to default to the same output stream.

OPTIONS

Any of the following command line options may be specified. These can be in any order but must precede the list of source file names. Option letters may be entered in either upper or lower case.

Option arguments may immediately follow the option letter or may be separated from the option letter by blanks or tabs. However, an ambiguity arises if an option takes an optional argument. Consider the following command line:

asm56100 -b main io

In this example it is not clear whether the file main is a source file or is meant to be an argument to the -B option. If the ambiguity is not resolved, the assembler will assume that main is a source file and attempt to open it for reading. This may not be what the programmer intended.

There are several ways to avoid this ambiguity. If main is supposed to be an argument to the -B option, it can be placed immediately after the option letter, without intervening white space:

asm56100 -bmain io

If there are other options on the command line besides those that take optional arguments, the other options can be placed between the ambiguous option and the list of source file names:

asm56100 -b main **-v** io

Alternatively, two successive hyphens may be used to indicate the end of the option list:

asm56100 -b -- main io

In this case the assembler interprets main as a source file name and uses the default naming conventions for the -B option.

-A Indicates that the assembler should operate in absolute mode, creating a load file (.cld) if the **-B** option is given. By default, the assembler produces a link file (.cln) which is subsequently processed by the Motorola DSP linker.

-B[<objfil>]

This option specifies that an object file is to be created for assembler output. **objfil** can be any legal operating system file name, including an optional pathname. A hyphen may also be used as an argument to indicate that the object file should be sent to the standard output.

If a path is not specified, the file will be created in the current directory. If no file name is supplied, the assembler will use the basename (file name without extension) of the first file name encountered in the source input file list. The resulting output file will have an extension of .cln unless the **-A** option is given in which case the file will have a .cld extension. If the **-B** option is

not given, then the assembler will not generate an object file. The -**B** option should be specified only once.

-D<symbol> <string>

This is equivalent to a source statement of the form:

DEFINE <symbol> <string>

string must be enclosed in quotes if it contains any embedded blanks. Note that if quotes are used, they must be passed to the assembler intact, e.g. some host command interpreters will strip quotes from around arguments. The **-D**<symbol> <string> sequence may be repeated as often as desired.

-F<argfil>

This option indicates that an external file should be read for further command arguments. It is useful in host environments where the command line length is restricted. **argfil** must be present on the command line, but can be any legal operating system file name including an optional pathname.

The file may contain any legal command line options, including the **-F** option itself. The arguments need be separated only by white space (spaces, tabs, or newlines). A semicolon (;) on a line following white space causes the rest of the line in the file to be treated as a comment.

-G

Send source file line number information to the object file. This option is valid only in conjunction with -B command line option. The generated line number information can be used by debuggers to provide source-level debugging.

-I<ipath>

When the assembler encounters include files, the current directory (or the directory specified in the INCLUDE directive) is first searched for the file. If it is not found and the **-I** option is supplied, the assembler prefixes the file name (and optional pathname) specified in the INCLUDE directive with **ipath** and searches the newly formed directory pathname for the file. The **-I<ipath>** sequence may be repeated as many times as desired. The directories will be searched in the order given on the command line.

-L[<lstfil>]

This option specifies that a listing file is to be created for the assembler output. **lstfil** can be any legal operating system file name including an optional pathname. A hyphen also may be used as an argument to indicate that the listing file should be sent to the standard output.

If a path is not specified, the file will be created in the current directory. If no file name is supplied, the assembler will use the basename (file name without extension) of the first file name encountered in the source input file list. The resulting output file will have an extension of .lst. If the **-L** option is not given, then the assembler will route the listing output to the standard output. The **-L** option should be specified only once.

-M<mpath>
This is equivalent to a source statement of the form:

MACLIB <mpath>

The **-M<mpath>** sequence may be repeated as many times as desired. The directories will be searched in the order specified on the command line.

-O<opt>[,<opt>...]
opt can be any of the options that are available with the assembler **OPT** directive. If multiple options are supplied, they must be separated by commas. The -**O<opt>** sequence may be repeated for as many options as desired.

-Z
This option causes the assembler to strip symbol information from the absolute load file. Normally symbol information is retained in the object file for symbolic reference purposes. Note that this option is valid only when the assembler is in absolute mode via the **-A** command line option and when an object file is created (**-B** option).

-V Indicates that the assembler should be verbose during processing, displaying a progress report as it assembles the input files. The assembler will show the beginning of each pass and when files are opened and closed. The information is sent to the standard error output stream.

NAME

cldinfo — Memory size information from Motorola DSP COFF object file.

SYNOPSIS

cldinfo file

DESCRIPTION

cldinfo is a utility that reads an absolute or relocatable Common Object File Format (COFF) file and produces a formatted display of the program memory size, data memory size and the programs starting address.

file is the name of a Motorola DSP COFF format object file. Only a single file name may be supplied.

NAME

cldlod — Motorola COFF to LOD Format converter

SYNOPSIS

cldlod cldfile > lodfile

DESCRIPTION

cldlod is a utility that converts a binary COFF object file into an ascii LOD file.

cldfile is an operating system compatible file name which contains COFF information. Only a single file name may be supplied, and it must be explicit; there is no default extension for the input file.

lodfile is an LOD file.

NAME

cofdmp — Motorola DSP COFF File Dump Utility

SYNOPSIS

cofdmp [**-cfhlorstv**] [-d file] files

DESCRIPTION

cofdmp is a utility that reads an absolute or relocatable COFF file and produces a formatted display of the object file contents. The entire file or only selected portions may be processed depending on command line options. The program also can generate either codes or symbolic references to entities such as symbol type or storage class.

file is an operating system compatible file name. Only a single file name may be supplied, and it must be explicit; there is no default extension for the input file.

OPTIONS

Any of the following command line options may be given. Option letters may be entered in either upper or lower case. If no option is specified, the entire object file is dumped.

-c Dump the object file string table. This information may not be available if the object file has been stripped.

-d Dump to output file.

-f Dump the file header of the object file.

-h Dump the object file section headers.

-l Dump the object file line number information. This information may not be available if the object file has been stripped.

-o Dump the object file optional header.

-r Dump the object file relocation information. This information is available only in relocatable object files.

-s Dump the object file raw data contents.

-t Dump the object file symbol table.

-v Dump the object file symbolically, expanding bit flag, symbol type, and storage class names.

NAME

dsplib — Motorola DSP COFF Librarian

SYNOPSIS

dsplib [**-a** | **-c** | **-d** | **-l** | **-r** | **-u** | **-v** | **-x**] [**-f<argfil>**] library [files...]

DESCRIPTION

dsplib is a utility that allows separate files to be grouped together into a single file. The resulting library file can then be used for linking by the Motorola DSP Cross Linker program or for general-purpose archival storage.

library is an operating system compatible file name (including optional pathname) indicating the library file to create or access. If no extension is supplied, the librarian will automatically append .clb to the file name. If no pathname is specified, the librarian will look for the library in the current directory.

files is a list of operating system compatible file names. For input operations the file names may also contain an optional pathname; the path is stripped when the file is written to the library. For output operations only the file name should be used to refer to library modules.

If no arguments are given on the command line, the librarian enters an interactive mode where multiple commands may be entered without exiting the program. The syntax for the interactive mode is command library [files...] where command is an action corresponding to one of the options listed below, library is the library name, and files is the optional (based on the action requested) list of files/modules upon which to operate. For example the command add foo bar.cln adds the module bar.cln to the library foo. Because interactive input is taken from the standard input channel of the host environment, it is possible to create a batch of librarian commands and feed them to the program for execution via redirection. For more information on interactive commands, invoke the librarian without any arguments and enter help.

OPTIONS

Only one of the following command line options may be given for each invocation of the librarian. Option letters may be entered in either upper or lower case. If no option is given, the librarian operates as if the **-U** option were specified.

-a This option adds the modules in the file list to the named library. The library file must exist and the modules must not already be in the library.

-c Create a new library file and add any specified modules to it. If the library file already exists, an error is issued.

-d Delete named modules from the library. If the module is not in the library, an error is issued.

-f<argfil>
This option indicates that an external file should be read for further command arguments. It is useful in host environments where the command line length is restricted. **argfil** must be present on the command line but can be any legal operating system file name, including an optional pathname.

argfil is a text file containing module names to be passed to the librarian. The names need be separated only by white space (spaces, tabs, or newlines). A semicolon (;) on a line following white space causes the rest of the line to be treated as a comment.

-l List library contents. This option lists the module name as contained in the library header, the module size (minus library overhead), and the date and time the file was stored into the library. The listing output is routed to standard output so that it may be redirected to a file if desired.

-r This option replaces the named modules in the given library. The modules must already be present in the library file.

-u This option updates the specified modules if they exist in the library; otherwise it adds them to the end of the library file.

-v This option displays the librarian version number and copyright notice.

-x Extract named modules from the library. The resulting files are given the name of the modules as stored in the library module header. All files are created in the current working directory.

NAME

dsplnk — Motorola DSP COFF Linker

SYNOPSIS

dsplnk [**-B** [**<**lodfil**>**]] [**-F<**argfil**>**] [**-I**] [**-L<**library**>**] [**-M<**mapfil**>**] [**-N**]

[**-O<**mem**>**[**<**ctr**>**][**<**map**>**]**:<**origin**>**] [**-P<**lpath**>**] [**-R<**ctlfil**>**] [**-Z**]

[**-U<**symbol**>**] [**-V**] [**-X**<opt>[, <opt>...]] [**-Z**] **<**files...**>**

DESCRIPTION

dsplnk is a program that processes relocatable link files produced by the DSP assemblers, generating an absolute load file which can be

1. loaded directly into the Motorola DSP simulator or
2. converted to Motorola S-record format for PROM burning.

files is a list of operating system compatible file names including optional pathnames. If no extension is supplied for a given file, the linker will first attempt to open the file using the file name as supplied. If that is not successful the linker appends .cln to the file name and tries to open the file again. If no pathname is supplied for a given file, the linker will look for that file in the current directory. The list of files will be processed sequentially in the order given and all files will be used to generate the load file and map listing.

Note that some options (**-B** and **-M**) allow a hyphen as an optional argument which indicates that the corresponding output should be sent to the standard output stream. Unpredictable results may occur if, for example, the object file is explicitly routed to standard output while the listing file is allowed to default to the same output stream.

OPTIONS

Any of the following command line options may be specified. These can be in any order but must precede the list of link file names (except for the **-L** option). Option letters may be specified in either upper or lower case.

Option arguments may immediately follow the option letter or may be separated from the option letter by blanks or tabs. However, an ambiguity arises if an option takes an optional argument. Consider the following command line:

dsplnk -b main io

In this example it is not clear whether the file main is a link file or is meant to be an argument to the **-B** option. If the ambiguity is not resolved, the linker will assume that main is a link file and attempt to open it for reading. This may not be what the programmer intended.

There are several ways to avoid this ambiguity. If main is supposed to be an argument to the **-B** option, it can be placed immediately after the option letter without intervening white space:

dsplnk -bmain io

If there are other options on the command line besides those that take optional arguments the other options can be placed between the ambiguous option and the list of link file names.

dsplnk -b main **-v** io

Alternatively, two successive hyphens may be used to indicate the end of the option list:

dsplnk -b -- main io

In this case the linker interprets main as a link file name and uses the default naming conventions for the **-B** option.

-B[<objfil>]

This option specifies a name for the object file generated by the linker. **objfil** can be any legal operating system file name including an optional pathname. A hyphen may also be used as an argument to indicate that the object file should be sent to the standard output.

If a pathname is not given, the file will be created in the current directory. If no file name is supplied or if the **-B** option is not given, the linker will use the basename (file name without extension) of the first file name encountered in the link input file list. The resulting output file will have an extension of .cld. The **-B** option should be specified only once.

-F<argfil>

This option indicates that an external file should be read for further command arguments. It is useful in host environments where the command line length is restricted. **argfil** must be present on the command line but can be any legal operating system file name, including an optional pathname.

The file may contain any legal command line options including the **-F** option itself. The arguments need be separated only by white space (spaces, tabs, or newlines). A semicolon (;) on a line following white space causes the rest of the line to be treated as a comment.

-I Under normal operation, the linker produces an absolute load file as output. If the **-I** option appears on the command line, the linker combines the input files into a single relocatable link file suitable for a subsequent linker pass. No absolute addresses are assigned and no errors are issued for unresolved external references.

-L<library>
The linker ordinarily processes a list of link files which each contain a single relocatable code module. If the **-L** option is encountered, the linker treats the accompanying pathname as a library file, and searches the file for any outstanding unresolved references.

If a module is found in the library that resolves an outstanding external reference, the module is read from the library and included in the load file output. The linker continues to search a library until all external references are resolved or no more references can be satisfied within the current library. The linker searches a library only once: when it is encountered on the command line. Therefore, the position of the **-L** option on the command line is significant.

-M[<mapfil>
This option specifies that a map file is to be created. **mapfil** can be any legal operating system file name including an optional pathname.

If a pathname is not given, the file will be created in the current directory. If no file name is supplied, the linker will use the basename (file name without extension) of the first file name encountered in the link input file list. The resulting output file will have an extension of .map. The linker will not generate a map file if the **-M** option is not specified. The **-M** option should be specified only once.

-N Indicates that the linker should ignore case in symbol names. Ordinarily the linker is sensitive to upper and lower case letters in symbol names. If the **-N** option is supplied, then the linker maps all symbol characters to lower case.

-O<mem>[<ctr>][<map>]:<origin>
By default, the linker generates instructions and data for the load file beginning at absolute location zero for all DSP memory spaces. This option allows the programmer to redefine the start address for any memory space and associated location counter.

mem is one of the single-character memory space identifiers (X, Y, L, and P). The letter may be upper or lower case. The optional **ctr** is a letter indicating the high (H) or low (L) location counters. If no counter is specified, the default counter is used. **map** is also optional and signifies the desired

physical mapping for all relocatable code in the given memory space. It may be I for internal memory, E for external memory, or B for bootstrap memory (valid only in P program memory space). If **map** is not supplied, then no explicit mapping is presumed.

The **origin** is a hexadecimal number signifying the new relocation address for the given memory space. The **-O** option may be specified as many times as needed on the command line.

-P<lpath>

When the linker encounters a library specification on the command line, the current directory (or the directory given in the library specification) is first searched for the library file. If it is not found and the **-P** option is supplied, the linker prefixes the file name (and optional pathname) provided in the library specification with lpath and searches the newly formed directory pathname for the file. The directories will be searched in the order given on the command line.

-R[<ctlfil>]

This option indicates that a memory control file is to be read to determine the absolute placement of sections in DSP memory. **ctlfil** can be any legal operating system file name including an optional pathname.

If a pathname is not given, an attempt will be made to open the file in the current directory. If no file name is supplied, the linker will use the basename (file name without extension) of the first file name encountered in the link input file list, appending an extension of .ctl. If the **-R** option is not specified, then the linker will not use a memory map file. The **-R** option should be specified only once.

-U<symbol>

Causes symbol to be entered into the unresolved external reference table. This is useful when the initial or only link file is a library. Since there are no external references when the linker is invoked, the **-U** option may be used to force inclusion of a library module that resolves the undefined reference. The **-U** option may be specified as often as desired.

-V Indicates that the linker should be verbose during processing, displaying a progress report as it links the input files. The linker will show the beginning of each pass and when files are opened and closed. The information is sent to the standard error output stream.

-X<opt>[,<opt>,...,<opt>]

The -X option directs the linker to perform a little bit of different operation than standard operation of the linker.The options are described below with

their different operations performed. All options may be preceded by **NO** to reverse their meaning. The **-X**<opt> sequence can be repeated for as many options as desired.

Option	Meaning
XC	Relative terms from different sections used in an expression cause an error.
RSV	Reserve special target processor memory areas.
AEC	Check form of address expressions.
RO	Allow region overlap.
ESO	Do not allocate memory below ordered sections.
ASC	Enable absolute section bounds checking.

-Z The linker strips source file line number and symbol information from the input file. Symbol information normally is retained for debugging purposes. This option has no effect if incremental linking is being done (see the **-I** option).

NAME

gdb561 — GNU Source-level Debugger for the DSP56100 family

SYNOPSIS

gdb561 [**-s** SYMFILE] [**-e** EXECFILE] [**-se** FILE] [**-c** COREFILE] [**-x** FILE]

[**-d** directory] [**-nx**] [**-q**] [**-batch**] [**-fullname**] [**-help**] [**-tty** TTY]

[**-cd** DIR] <name> <core>

DESCRIPTION

gdb561 is a source-level symbolic debugger for C programs created by Richard Stallman for the GNU Project and distributed by the Free Software Foundation. **gdb561** has something of the flavor of the UNIX source-level debugger **dbx** but has more features and power.

gdb561 is invoked with the command gdb561. Once started, it reads commands from the terminal until given the quit command. name is the name of the executable program, and core, if specified, is the name of the DSP56100 simulator state file to be examined or have execution resumed.

gdb561 has been modified to run with both software and hardware DSP56100 execution devices.

OPTIONS

The following command-line options can be used to more precisely specify the files to be debugged. All the options and command line arguments given are processed in sequential order. The order makes a difference when the **-x** command is used.

-s SYMFILE
Read symbol table from file SYMFILE.

-e EXECFILE
Use EXECFILE as the executable file to execute when appropriate and for examining pure data in conjunction with a core dump.

-se FILE
Read symbol table from FILE and use it as the executable file.

-c COREFILE
Analyze the state file COREFILE.

-x file
Execute GDB commands from file.

-d directory
Add directory to the path to search for source files.

The following additional command-line options can be used to affect certain aspects of the behavior of gdb561:

-nx Don't execute commands from the init files .gdbinit. Normally, the commands in these files are executed after all the command options and arguments have been processed.

-q Do not print the version number on start-up.

-batch
Run in batch mode. Exit with code 1 after processing all the command files specified with **-x** (and .gdbinit, if not inhibited). Exit also if, due to an error, gdb56 would otherwise attempt to read a command from the terminal.

-fullname
This option is used when Emacs runs GDB as a subprocess. It tells GDB to produce the full file name and line number each time a stack frame is displayed (which includes each time the program stops).

-help
Print command-line argument summary.

-tty TTY
Use **TTY** for input/output by the program being debugged.

-cd DIR
Change current directory to **DIR**.

SEE ALSO

Appendix D — GNU Debugger (GDB)

NAME

run561 — Motorola DSP56100 Simulator Based Execution Device.

SYNOPSIS

run561 [**-b** BCR_VALUE] [**-s** STATE_FILE] [**-t**] [file]

DESCRIPTION

run561 is a COFF object file execution utility that provides operating system style hooks to support hosted ANSI run-time library routines such as **printf()**.

file is an operating system compatible file name. Only a single file name may be supplied and it must be explicit; there is no default extension for the input file.

OPTIONS

-b BCR_VALUE
Use BCR_VALUE to set the DSP56100 bus control register. Default **bcr** value is 0.

-s STATE_FILE
Resume the execution of the DSP56100 state file STATE_FILE.

-t Update global C variable __**time** at each clock tick. Used to benchmark code.

NAME

srec — Motorola DSP S-Record Conversion Utility

SYNOPSIS

srec [**-b** | **-w**] [**-m** | **-s**] [**-l**] [**-r**] <files ...>

DESCRIPTION

srec converts Motorola DSP .cld and .lod format files into Motorola S-record files. The S-record format was devised for the purpose of encoding programs or data files in a printable form for transportation between computer systems. Motorola S-record format is recognized by many PROM programming systems.

files is a list of operating system compatible file names. If no pathname is specified for a given file, srec will look for that file in the current directory. If the special character '-' is used as a file name srec will read from the standard input stream. The list of files will be processed sequentially in the order given.

OPTIONS

Only one of the following command line options may be given for each invocation of the librarian. Option letters may be entered in either upper or lower case. If no option is given, the librarian operates as if the **-U** option were specified.

-b Use byte addressing when transferring load addresses to S-record addresses. This means that load file DATA record start addresses are multiplied by the number of bytes per target DSP word and subsequent S1/S3 record addresses are computed based on the data byte count. The **-b** and **-w** options are mutually exclusive.

-l Use double-word addressing when transferring load addresses from L space to S-record addresses. This means that load file DATA records for L space data are moved unchanged and subsequent S1/S3 record addresses are computed based on the data word count divided by 2. This option should always be used when the source load file contains DATA records in L memory space.

-m Split each DSP word into bytes and store the bytes in parallel S-records. The **-m** and **-s** options are mutually exclusive.

-r Write bytes high to low, rather than low to high. This option has no effect when used with the **-m** option.

-s Write data to a single file, putting memory space information into the address field of the S0 header record. The **-m** and **-s** options are mutually exclusive.

-w Use word addressing when transferring load addresses to S-record addresses. This means that load file DATA record start addresses are moved unchanged and subsequent S1/S3 record addresses are computed based on the data word count.

Appendix D
GNU Debugger (GDB)

Introduction

Appendix E contains the GNU Debugger Manual. This preface to the GDB manual describes the differences between the standard gdb source level debugger and the gdb561 debugger that uses the Motorola DSP56100 family simulator.

A short description of the way the simulator is embedded in **gdb561** will help explain some of the differences. The DSP56100 device is simulated by the same non-display version of the simulator program that is supplied with the DSP56100 Development Software. The simulator is linked with the gdb program. When a program is executed on the simulated DSP56100, it is done via direct function calls to the simulator library functions rather than via ptrace calls to an inferior process as in other versions of gdb.

Commands Not Implemented

1. The attach and detach commands are not implemented because the simulator program is linked directly to the **gdb561** program. As a result, there is no ability to attach or release a separately running simulation.

2. The core-file command is not implemented at this time.

All other commands work as documented in the GDB Manual for the gnu Source-Level Debugger, Third Edition, October 1989. Some enhancements, listed below, were necessary to accommodate operation using the DSP56100.

DSP56100 Family Differences / Specific Requirements

1. Since the DSP56100 has two memory spaces, it will sometimes be necessary to use one of the prefixes “p:” or “x:” in front of an address in order to examine or modify the specific memory space. The debugger symbol information already has the proper memory space designator accompanying each symbol address so symbolic names do not require a memory space prefix; however, addresses entered as numeric constants require the prefix for x memory. P memory is the default.

2. The **gdb561** debugger operates with COFF format “.cld” files generated by the DSP56100 COFF Assembler and Linker programs. The gdb561 subdirectory “m561kinc” contains header files which define the COFF structures used by gdb561 as well as other device-specific header files.

3. The gdb561 evaluator and display routines have been enhanced to handle the 32 bit long values and special format floating-point values used by the DSP56100.

4. The simulation is able to halt at breakpoints without actually breaking the pipeline activity of the device and without actually inserting breakpoint code into the device memory. As a result, the simulator can maintain an accurate record of the device execution time regardless of the number of inserted breakpoints. The cycle count is maintained in the variable $cyc.

5. The normal gdb program uses .gdbinit as the default initialization file at start-up whereas gdb561 uses .gdbinit561.

GDB Manual
The GNU Source-Level Debugger

Third Edition, GDB version 3.4
October 1989

Richard M. Stallman

Summary of GDB

The purpose of a debugger such as GDB is to allow you to execute another program while examining what is going on inside it. We call the other program “your program” or “the program being debugged”.

GDB can do four kinds of things (plus other things in support of these):

1. Start the program, specifying anything that might affect its behavior.
2. Make the program stop on specified conditions.
3. Examine what has happened, when the program has stopped, so that you can see bugs happen.
4. Change things in the program, so you can correct the effects of one bug and go on to learn about another without having to re-compile first.

GDB can be used to debug programs written in C and C++. Pascal support is being implemented, and Fortran support will be added when a GNU Fortran compiler is written.

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Version 1, February 1989

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END OF TERMS AND CONDITIONS

Appendix: How to Apply These Terms to Your New Programs

If you develop a new program, and you want it to be of the greatest possible use to humanity, the best way to achieve this is to make it free software which everyone can redistribute and change under these terms.

To do so, attach the following notices to the program. It is safest to attach them to the start of each source file to most effectively convey the exclusion of warranty; and each file should have at least the “copyright” line and a pointer to where the full notice is found.

one line to give the program’s name and a brief idea of what it does.

Copyright (C) 19yy name of author

This program is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 1, or (at your option) any later version.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License along with this program; if not, write to the Free Software Foundation, Inc., 675 Mass Ave., Cambridge, MA 02139, USA.

Also add information on how to contact you by electronic and paper mail.

If the program is interactive, make it output a short notice like this when it starts in an interactive mode:

Gnomovision version 69, Copyright (C) 19yy name of author

Gnomovision comes with ABSOLUTELY NO WARRANTY; for details type ‘show w’.

This is free software, and you are welcome to redistribute it under certain conditions; type ‘show c’ for details.

The hypothetical commands ‘show w’ and ‘show c’ should show the appropriate parts of the General Public License. Of course, the commands you use may be called something other than ‘show w’ and ‘show c’; they could even be mouse-clicks or menu items---whatever suits your program.

You should also get your employer (if you work as a programmer) or your school, if any, to sign a “copyright disclaimer” for the program, if necessary. Here a sample; alter the names:

Yoyodyne, Inc., hereby disclaims all copyright interest in the program ‘Gnomovision’ (a program to direct compilers to make passes at assemblers) written by James Hacker.

signature of Ty Coon, 1 April 1989

Ty Coon, President of Vice

That’s all there is to it!

D.1 Input and Output Conventions

GDB is invoked with the shell command ‘gdb’. Once started, it reads commands from the terminal until you tell it to exit.

A GDB command is a single line of input. There is no limit on how long it can be. It starts with a command name, which is followed by arguments whose meaning depends on the command name. For example, the command step accepts an argument which is the number of times to step, as in **step 5**. You can also use the step command with no arguments. Some command names do not allow any arguments.

GDB command names may always be abbreviated if the abbreviation is unambiguous. Sometimes even ambiguous abbreviations are allowed; for example, ‘s’ is specially defined as equivalent to step even though there are other commands whose names start with ‘s’. Possible command abbreviations are often stated in the documentation of the individual commands.

A blank line as input to GDB means to repeat the previous command verbatim. Certain commands do not allow themselves to be repeated this way; these are commands for which unintentional repetition might cause trouble and which you are unlikely to want to repeat. Certain others (list and ‘x’) act differently when repeated because that is more useful.

A line of input starting with ‘#’ is a comment; it does nothing. This is useful mainly in command files (See section Command Files).

GDB indicates its readiness to read a command by printing a string called the prompt. This string is normally ‘(gdb)’. You can change the prompt string with the ‘set prompt’ command. For instance, when debugging GDB with GDB, it is useful to change the prompt in one of the GDBs so that you tell which one you are talking to.

set prompt newprompt

Directs GDB to use newprompt as its prompt string henceforth.

To exit GDB, use the quit command (abbreviated ‘q’). Ctrl-c will not exit from GDB, but rather will terminate the action of any GDB command that is in progress and return to GDB command level. It is safe to type Ctrl-c at any time because GDB does not allow it to take effect until a time when it is safe.

Certain commands to GDB may produce large amounts of information output to the screen. To help you read all of it, GDB pauses and asks you for input at the end of each page of output. Type RET when you want to continue the output. Normally GDB knows the size of the screen from on the termcap data base together with the value of the TERM environment variable; if this is not correct, you can override it with the ‘set screensize’ command:

set screensize lpp
set screensize lpp cpl

Specify a screen height of lpp lines and (optionally) a width of cpl characters. If you omit cpl, the width does not change.

If you specify a height of zero lines, GDB will not pause during output no matter how long the output is. This is useful if output is to a file or to an editor buffer.

Also, GDB may at times produce more information about its own workings than is of interest to the user. Some of these informational messages can be turned on and off with the ‘set verbose’ command:

set verbose off

Disables GDB’s output of certain informational messages.

set verbose on

Re-enables GDB’s output of certain informational messages.

Currently, the messages controlled by ‘set verbose’ are those which announce that the symbol table for a source file is being read (see section File Commands, in the description of the command ‘symbol-file’).

D.2 Specifying GDB's Files

GDB needs to know the file name of the program to be debugged, both in order to read its symbol table and in order to start the program. To debug a core dump of a previous run, GDB must be told the file name of the core dump.

D.2.1 Specifying Files with Arguments

The usual way to specify the executable and core dump file names is with two command arguments given when you start GDB. The first argument is used as the file for execution and symbols, and the second argument (if any) is used as the core dump file name. Thus,

gdb progm core

specifies 'progm' as the executable program and 'core' as a core dump file to examine. (You do not need to have a core dump file if what you plan to do is debug the program interactively.)

See section Options, for full information on options and arguments for invoking GDB.

D.2.2 Specifying Files with Commands

Usually you specify the files for GDB to work with by giving arguments when you invoke GDB. But occasionally it is necessary to change to a different file during a GDB session. Or you may run GDB and forget to specify the files you want to use. In these situations the GDB commands to specify new files are useful.

exec-file filename

Specify that the program to be run is found in filename. If you do not specify a directory and the file is not found in GDB's working directory, GDB will use the environment variable PATH as a list of directories to search, just as the shell does when looking for a program to run.

symbol-file filename

Read symbol table information from file filename. PATH is searched when neces-

sary. Most of the time you will use both the ‘exec-file’ and ‘symbol-file’ commands on the same file.

‘symbol-file’ with no argument clears out GDB’s symbol table.

The ‘symbol-file’ command does not actually read the symbol table in full right away. Instead, it scans the symbol table quickly to find which source files and which symbols are present. The details are read later, one source file at a time, when they are needed.

The purpose of this two-stage reading strategy is to make GDB start up faster. For the most part, it is invisible except for occasional messages telling you that the symbol table details for a particular source file are being read. (The ‘set verbose’ command controls whether these messages are printed; see section User Interface).

However, you will sometimes see in backtraces lines for functions in source files whose data has not been read in; these lines omit some of the information, such as argument values, which cannot be printed without full details of the symbol table.

When the symbol table is stored in COFF format, ‘symbol-file’ does read the symbol table data in full right away. We haven’t bothered to implement the two-stage strategy for COFF.

core-file filename

Specify the whereabouts of a core dump file to be used as the “contents of memory”. Note that the core dump contains only the writable parts of memory; the read-only parts must come from the executable file.

‘core-file’ with no argument specifies that no core file is to be used.

Note that the core file is ignored when your program is actually running under GDB. So, if you have been running the program and you wish to debug a core file instead, you must kill the sub-process in which the program is running. To do this, use the ‘kill’ command (see section Kill Process).

add-file filename address

The ‘add-file’ command reads additional symbol table information from the file filename. You would use this when that file has been dynamically loaded into the program that is running. address should be the memory address at which the file has been loaded; GDB cannot figure this out for itself.

The symbol table of the file filename is added to the symbol table originally read with the ‘symbol-file’ command. You can use the ‘add-file’ command any number

of times; the new symbol data thus read keeps adding to the old. The ‘symbol-file’ command forgets all the symbol data GDB has read; that is the only time symbol data is forgotten in GDB.

info files

Print the names of the executable and core dump files currently in use by GDB, and the file from which symbols were loaded.

While all three file-specifying commands allow both absolute and relative file names as arguments, GDB always converts the file name to an absolute one and remembers it that way.

The ‘symbol-file’ command causes GDB to forget the contents of its convenience variables, the value history, and all breakpoints and auto-display expressions. This is because they may contain pointers to the internal data recording symbols and data types, which are part of the old symbol table data being discarded inside GDB.

D.3 Compiling Your Program for Debugging

In order to debug a program effectively, you need to ask for debugging information when you compile it. This information in the object file describes the data type of each variable or function and the correspondence between source line numbers and addresses in the executable code.

To request debugging information, specify the ‘-g’ option when you run the compiler.

The Unix C compiler is unable to handle the ‘-g’ and ‘-O’ options together. This means that you cannot ask for optimization if you ask for debugger information.

The GNU C compiler supports ‘-g’ with or without ‘-O’, making it possible to debug optimized code. We recommend that you always use ‘-g’ whenever you compile a program. You may think the program is correct, but there’s no sense in pushing your luck.

GDB no longer supports the debugging information produced by giving the GNU C compiler the ‘-gg’ option, so do not use this option.

D.4 Running Your Program Under GDB

To start your program under GDB, use the ‘run’ command. The program must already have been specified using the ‘exec-file’ command or with an argument to GDB (see section Files); what ‘run’ does is create an inferior process, load the program into it, and set it in motion.

The execution of a program is affected by certain information it receives from its superior. GDB provides ways to specify this information, which you must do before starting the program. (You can change it after starting the program, but such changes do not affect the program unless you start it over again.) This information may be divided into three categories:

The arguments.

You specify the arguments to give the program as the arguments of the ‘run’ command.

The environment.

The program normally inherits its environment from GDB, but you can use the GDB commands ‘set environment’ and ‘unset environment’ to change parts of the environment that will be given to the program.

The working directory.

The program inherits its working directory from GDB. You can set GDB’s working directory with the ‘cd’ command in GDB.

After the ‘run’ command, the debugger does nothing but wait for your program to stop. See section Stopping.

Note that once your program has been started by the ‘run’ command, you may evaluate expressions that involve calls to functions in the inferior. See section Expressions. If you wish to evaluate a function simply for its side effects, you may use the ‘set’ command. See section Assignment.

D.4.1 Your Program’s Arguments

The arguments to your program are specified by the arguments of the ‘run’ command. They are passed to a shell, which expands wildcard characters and performs redirection of I/O, and thence to the program.

‘run’ with no arguments uses the same arguments used by the previous ‘run’.

The command ‘set args’ can be used to specify the arguments to be used the next time the program is run. If ‘set args’ has no arguments, it means to use no arguments the next time the program is run. If you have run your program with arguments and want to run it again with no arguments, this is the only way to do so.

D.4.2 Your Program’s Environment

The environment consists of a set of environment variables and their values. Environment variables conventionally record such things as your user name, your home directory, your terminal type, and your search path for programs to run. Usually you set up environment variables with the shell and they are inherited by all the other programs you run. When debugging, it can be useful to try running the program with different environments without having to start the debugger over again.

info environment varname

Print the value of environment variable varname to be given to your program when it is started. This command can be abbreviated ‘i env varname’.

info environment

Print the names and values of all environment variables to be given to your program when it is started. This command can be abbreviated ‘i env’.

set environment varname value
set environment varname = value

Sets environment variable varname to value, for your program only, not for GDB itself. value may be any string; the values of environment variables are just strings, and any interpretation is supplied by your program itself. The value parameter is optional; if it is eliminated, the variable is set to a null value. This command can be abbreviated as short as ‘set e’.

For example, this command:

set env USER = foo

tells the program, when subsequently run, to assume it is being run on behalf of the user named ‘foo’.

delete environment varname
unset environment varname

Remove variable varname from the environment to be passed to your program. This is different from ‘set env varname =’ because ‘delete environment’ leaves the variable with no value, which is distinguishable from an empty value. This command can be abbreviated ‘d e’.

D.4.3 Your Program’s Working Directory

Each time you start your program with ‘run’, it inherits its working directory from the current working directory of GDB. GDB’s working directory is initially whatever it inherited from its parent process (typically the shell), but you can specify a new working directory in GDB with the ‘cd’ command.

The GDB working directory also serves as a default for the commands that specify files for GDB to operate on. See section Files.

cd directory

Set GDB’s working directory to directory.

pwd

Print GDB’s working directory.

D.4.4 Your Program’s Input and Output

By default, the program you run under GDB does input and output to the same terminal that GDB uses.

You can redirect the program’s input and/or output using ‘sh’-style redirection commands in the ‘run’ command. For example,

run > outfile

starts the program, diverting its output to the file ‘outfile’.

Another way to specify where the program should do input and output is with the ‘tty’ command. This command accepts a file name as argument, and causes this file to be the default for future ‘run’ commands. It also resets the controlling terminal for the child pro-

cess, for future ‘run’ commands. For example,

tty /dev/ttyb

directs that processes started with subsequent ‘run’ commands default to do input and output on the terminal ‘/dev/ttyb’ and have that as their controlling terminal.

An explicit redirection in ‘run’ overrides the ‘tty’ command’s effect on input/output redirection, but not its effect on the controlling terminal.

When you use the ‘tty’ command or redirect input in the ‘run’ command, only the input for your program is affected. The input for GDB still comes from your terminal.

D.4.5 Debugging an Already-Running Process

Some operating systems allow GDB to debug an already running process that was started outside of GDB. To do this, you use the ‘attach’ command instead of the ‘run’ command.

The ‘attach’ command requires one argument, which is the process-id of the process you want to debug. (The usual way to find out the process-id of the process is with the ps utility.)

The first thing GDB does after arranging to debug the process is to stop it. You can examine and modify an attached process with all the GDB commands that ordinarily available when you start processes with ‘run’. You can insert breakpoints; you can step and continue; you can modify storage. If you would rather the process continue running, you may use the ‘continue’ command after attaching GDB to the process.

When you have finished debugging the attached process, you can use the ‘detach’ command to release it from GDB’s control. Detaching the process continues its execution. After the ‘detach’ command, that process and GDB become completely independent once more, and you are ready to ‘attach’ another process or start one with ‘run’.

If you exit GDB or use the ‘run’ command while you have an attached process, you kill that process. You will be asked for confirmation if you try to do either of these things.

The ‘attach’ command is also used to debug a remote machine via a serial connection. See section Attach, for more info.

D.4.6 Killing the Child Process

kill Kill the child process in which the program being debugged is running under GDB.

This command is useful if you wish to debug a core dump instead. GDB ignores any core dump file if it is actually running the program, so the ‘kill’ command is the only sure way to make sure the core dump file is used once again.

It is also useful if you wish to run the program outside the debugger for once and then go back to debugging it.

The ‘kill’ command is also useful if you wish to re-compile and re-link the program, since on many systems it is impossible to modify an executable file which is running in a process. But, in this case, it is just as good to exit GDB, since you will need to read a new symbol table after the program is re-compiled if you wish to debug the new version, and restarting GDB is the easiest way to do that.

D.5 Stopping and Continuing

When you run a program normally, it runs until it terminates. The principal purpose of using a debugger is so that you can stop it before that point; or so that if the program runs into trouble you can investigate and find out why.

D.5.1 Signals

A signal is an asynchronous event that can happen in a program. The operating system defines the possible kinds of signals, and gives each kind a name and a number. For example, SIGINT is the signal a program gets when you type Ctrl-c; SIGSEGV is the signal a program gets from referencing a place in memory far away from all the areas in use; SIGALRM occurs when the alarm clock timer goes off (which happens only if the program has requested an alarm).

Some signals, including SIGALRM, are a normal part of the functioning of the program. Others, such as SIGSEGV, indicate errors; these signals are fatal (kill the program immediately) if the program has not specified in advance some other way to handle the signal. SIGINT does not indicate an error in the program, but it is normally fatal so it can carry out the purpose of Ctrl-c: to kill the program.

GDB has the ability to detect any occurrence of a signal in the program running under GDB's control. You can tell GDB in advance what to do for each kind of signal.

Normally, GDB is set up to ignore non-erroneous signals like SIGALRM (so as not to interfere with their role in the functioning of the program) but to stop the program immediately whenever an error signal happens. You can change these settings with the 'handle' command. You must specify which signal you are talking about with its number.

info signal

Print a table of all the kinds of signals and how GDB has been told to handle each one. You can use this to see the signal numbers of all the defined types of signals.

handle signalnum keywords...

Change the way GDB handles signal signalnum. The keywords say what change

to make.

To use the ‘handle’ command you must know the code number of the signal you are concerned with. To find the code number, type ‘info signal’ which prints a table of signal names and numbers.

The keywords allowed by the handle command can be abbreviated. Their full names are

stop

GDB should stop the program when this signal happens. This implies the ‘print’ keyword as well.

print

GDB should print a message when this signal happens.

nostop

GDB should not stop the program when this signal happens. It may still print a message telling you that the signal has come in.

noprint

GDB should not mention the occurrence of the signal at all. This implies the ‘nostop’ keyword as well.

pass

GDB should allow the program to see this signal; the program will be able to handle the signal, or may be terminated if the signal is fatal and not handled.

nopass

GDB should not allow the program to see this signal.

When a signal has been set to stop the program, the program cannot see the signal until you continue. It will see the signal then, if ‘pass’ is in effect for the signal in question at that time. In other words, after GDB reports a signal, you can use the ‘handle’ command with ‘pass’ or ‘nopass’ to control whether that signal will be seen by the program when you later continue it.

You can also use the ‘signal’ command to prevent the program from seeing a signal, or cause it to see a signal it normally would not see, or to give it any signal at any time. See section Signaling.

D.5.2 Breakpoints

A breakpoint makes your program stop whenever a certain point in the program is

reached. You set breakpoints explicitly with GDB commands, specifying the place where the program should stop by line number, function name or exact address in the program. You can add various other conditions to control whether the program will stop.

Each breakpoint is assigned a number when it is created; these numbers are successive integers starting with 1. In many of the commands for controlling various features of breakpoints you use the breakpoint number to say which breakpoint you want to change. Each breakpoint may be enabled or disabled; if disabled, it has no effect on the program until you enable it again.

The command ‘info break’ prints a list of all breakpoints set and not deleted, showing their numbers, where in the program they are, and any special features in use for them. Disabled breakpoints are included in the list, but marked as disabled. ‘info break’ with a breakpoint number as argument lists only that breakpoint. The convenience variable $_ and the default examining-address for the ‘x’ command are set to the address of the last breakpoint listed (see section Memory).

0.0.1. Setting Breakpoints

Breakpoints are set with the ‘break’ command (abbreviated ‘b’). You have several ways to say where the breakpoint should go.

break function

Set a breakpoint at entry to function function.

break +offset
break -offset

Set a breakpoint some number of lines forward or back from the position at which execution stopped in the currently selected frame.

break linenum

Set a breakpoint at line linenum in the current source file. That file is the last file whose source text was printed. This breakpoint will stop the program just before it executes any of the code on that line.

break filename:linenum

Set a breakpoint at line linenum in source file filename.

break filename:function

Set a breakpoint at entry to function function found in file filename. Specifying a file name as well as a function name is superfluous except when multiple files contain similarly named functions.

break *address

Set a breakpoint at address address. You can use this to set breakpoints in parts of the program which do not have debugging information or source files.

break

Set a breakpoint at the next instruction to be executed in the selected stack frame (see section Stack). In any selected frame but the innermost, this will cause the program to stop as soon as control returns to that frame. This is equivalent to a 'finish' command in the frame inside the selected frame. If this is done in the innermost frame, GDB will stop the next time it reaches the current location; this may be useful inside of loops.

GDB normally ignores breakpoints when it resumes execution, until at least one instruction has been executed. If it did not do this, you would be unable to proceed past a breakpoint without first disabling the breakpoint. This rule applies whether or not the breakpoint already existed when the program stopped.

break ... if cond

Set a breakpoint with condition cond; evaluate the expression cond each time the breakpoint is reached, and stop only if the value is nonzero. '...' stands for one of the possible arguments described above (or no argument) specifying where to break. See section Conditions, for more information on breakpoint conditions.

tbreak args

Set a breakpoint enabled only for one stop. args are the same as in the 'break' command, and the breakpoint is set in the same way, but the breakpoint is automatically disabled the first time it is hit. See section Disabling.

GDB allows you to set any number of breakpoints at the same place in the program. There is nothing silly or meaningless about this. When the breakpoints are conditional, this is even useful (see section Conditions).

0.0.2. Deleting Breakpoints

It is often necessary to eliminate a breakpoint once it has done its job and you no longer want the program to stop there. This is called deleting the breakpoint. A breakpoint that has been deleted no longer exists in any sense; it is forgotten.

With the ‘clear’ command you can delete breakpoints according to where they are in the program. With the ‘delete’ command you can delete individual breakpoints by specifying their breakpoint numbers.

It is not necessary to delete a breakpoint to proceed past it. GDB automatically ignores breakpoints in the first instruction to be executed when you continue execution without changing the execution address.

clear

Delete any breakpoints at the next instruction to be executed in the selected stack frame (see section Selection). When the innermost frame is selected, this is a good way to delete a breakpoint that the program just stopped at.

clear function
clear filename:function

Delete any breakpoints set at entry to the function function.

clear linenum
clear filename:linenum

Delete any breakpoints set at or within the code of the specified line.

delete bnums...

Delete the breakpoints of the numbers specified as arguments.

0.0.3. Disabling Breakpoints

Rather than deleting a breakpoint, you might prefer to disable it. This makes the breakpoint inoperative as if it had been deleted, but remembers the information on the breakpoint so that you can enable it again later.

You disable and enable breakpoints with the ‘enable’ and ‘disable’ commands, specifying one or more breakpoint numbers as arguments. Use ‘info break’ to print a list of breakpoints if you don’t know which breakpoint numbers to use.

A breakpoint can have any of four different states of enablement:

- Enabled. The breakpoint will stop the program. A breakpoint made with the ‘break’ command starts out in this state.
- Disabled. The breakpoint has no effect on the program.
- Enabled once. The breakpoint will stop the program, but when it does so it will become disabled. A breakpoint made with the ‘tbreak’ command starts out in this state.

- Enabled for deletion. The breakpoint will stop the program, but immediately after it does so it will be deleted permanently.

You change the state of enablement of a breakpoint with the following commands:

disable breakpoints bnums...
disable bnums...

Disable the specified breakpoints. A disabled breakpoint has no effect but is not forgotten. All options such as ignore-counts, conditions and commands are remembered in case the breakpoint is enabled again later.

enable breakpoints bnums...
enable bnums...

Enable the specified breakpoints. They become effective once again in stopping the program, until you specify otherwise.

enable breakpoints once bnums...
enable once bnums...

Enable the specified breakpoints temporarily. Each will be disabled again the next time it stops the program (unless you have used one of these commands to specify a different state before that time comes).

enable breakpoints delete bnums...
enable delete bnums...

Enable the specified breakpoints to work once and then die. Each of the breakpoints will be deleted the next time it stops the program (unless you have used one of these commands to specify a different state before that time comes).

Aside from the automatic disablement or deletion of a breakpoint when it stops the program, which happens only in certain states, the state of enablement of a breakpoint changes only when one of the commands above is used.

0.0.4. Break Conditions

The simplest sort of breakpoint breaks every time the program reaches a specified place. You can also specify a condition for a breakpoint. A condition is just a boolean expression in your programming language. (See section Expressions). A breakpoint with a condition evaluates the expression each time the program reaches it, and the program stops only if the condition is true.

Break conditions may have side effects, and may even call functions in your program. These may sound like strange things to do, but their effects are completely predictable unless there is another enabled breakpoint at the same address. (In that case, GDB

might see the other breakpoint first and stop the program without checking the condition of this one.) Note that breakpoint commands are usually more convenient and flexible for the purpose of performing side effects when a breakpoint is reached (see section Break Commands).

Break conditions can be specified when a breakpoint is set, by using ‘if’ in the arguments to the ‘break’ command. See section Set Breaks. They can also be changed at any time with the ‘condition’ command:

condition bnum expression

Specify expression as the break condition for breakpoint number bnum. From now on, this breakpoint will stop the program only if the value of expression is true (nonzero, in C). expression is not evaluated at the time the ‘condition’ command is given. See section Expressions.

condition bnum

Remove the condition from breakpoint number bnum. It becomes an ordinary unconditional breakpoint.

A special case of a breakpoint condition is to stop only when the breakpoint has been reached a certain number of times. This is so useful that there is a special way to do it, using the ignore count of the breakpoint. Every breakpoint has an ignore count, which is an integer. Most of the time, the ignore count is zero, and therefore has no effect. But if the program reaches a breakpoint whose ignore count is positive, then instead of stopping, it just decrements the ignore count by one and continues. As a result, if the ignore count value is n, the breakpoint will not stop the next n times it is reached.

ignore bnum count

Set the ignore count of breakpoint number bnum to count. The next count times the breakpoint is reached, it will not stop.

To make the breakpoint stop the next time it is reached, specify a count of zero.

cont count

Continue execution of the program, setting the ignore count of the breakpoint that the program stopped at to count minus one. Thus, the program will not stop at this breakpoint until the count’th time it is reached.

This command is allowed only when the program stopped due to a breakpoint. At other times, the argument to ‘cont’ is ignored.

If a breakpoint has a positive ignore count and a condition, the condition is not checked. Once the ignore count reaches zero, the condition will start to be checked.

Note that you could achieve the effect of the ignore count with a condition such as '$foo-<= 0' using a debugger convenience variable that is decremented each time. See section Convenience Vars.

0.0.5. Commands Executed on Breaking

You can give any breakpoint a series of commands to execute when the program stops due to that breakpoint. For example, you might want to print the values of certain expressions, or enable other breakpoints.

commands bnum

Specify commands for breakpoint number bnum. The commands themselves appear on the following lines. Type a line containing just 'end' to terminate the commands.

To remove all commands from a breakpoint, use the command 'commands' and follow it immediately by 'end'; that is, give no commands.

With no arguments, 'commands' refers to the last breakpoint set.

It is possible for breakpoint commands to start the program up again. Simply use the 'cont' command, or 'step', or any other command to resume execution. However, any remaining breakpoint commands are ignored. When the program stops again, GDB will act according to the cause of that stop.

If the first command specified is 'silent', the usual message about stopping at a breakpoint is not printed. This may be desirable for breakpoints that are to print a specific message and then continue. If the remaining commands too print nothing, you will see no sign that the breakpoint was reached at all. 'silent' is not really a command; it is meaningful only at the beginning of the commands for a breakpoint.

The commands 'echo' and 'output' that allow you to print precisely controlled output are often useful in silent breakpoints. See section Output.

For example, here is how you could use breakpoint commands to print the value of x at entry to foo whenever it is positive.

```
break foo if x>0
commands
silent
```

```
echo x is\040
output x
echo \n
cont
end
```

One application for breakpoint commands is to correct one bug so you can test another. Put a breakpoint just after the erroneous line of code, give it a condition to detect the case in which something erroneous has been done, and give it commands to assign correct values to any variables that need them. End with the ‘cont’ command so that the program does not stop, and start with the ‘silent’ command so that no output is produced. Here is an example:

```
break 403
commands
silent
set x = y + 4
cont
end
```

One deficiency in the operation of automatically continuing breakpoints under Unix appears when your program uses raw mode for the terminal. GDB switches back to its own terminal modes (not raw) before executing commands, and then must switch back to raw mode when your program is continued. This causes any pending terminal input to be lost.

In the GNU system, this will be fixed by changing the behavior of terminal modes.

Under Unix, when you have this problem, you might be able to get around it by putting your actions into the breakpoint condition instead of commands. For example

```
condition 5 (x = y + 4), 0
```

specifies a condition expression (See section Expressions) that will change x as needed, then always have the value 0 so the program will not stop. Loss of input is avoided here because break conditions are evaluated without changing the terminal modes. When you want to have nontrivial conditions for performing the side effects, the operators ‘&&’, ‘||’ and ‘?...:’ may be useful.

0.0.6. “Cannot Insert Breakpoints” Error

Under some operating systems, breakpoints cannot be used in a program if any other process is running that program. Attempting to run or continue the program with a breakpoint in this case will cause GDB to stop it.

When this happens, you have three ways to proceed:

1. Remove or disable the breakpoints, then continue.

2. Suspend GDB, and copy the file containing the program to a new name. Resume GDB and use the ‘exec-file’ command to specify that GDB should run the program under that name. Then start the program again.

3. Re-link the program so that the text segment is non-sharable, using the linker option ‘-N’. The operating system limitation may not apply to non-sharable executables.

D.5.3 Continuing

After your program stops, most likely you will want it to run some more if the bug you are looking for has not happened yet.

cont

Continue running the program at the place where it stopped.

If the program stopped at a breakpoint, the place to continue running is the address of the breakpoint. You might expect that continuing would just stop at the same breakpoint immediately. In fact, ‘cont’ takes special care to prevent that from happening. You do not need to delete the breakpoint to proceed through it after stopping at it.

You can, however, specify an ignore-count for the breakpoint that the program stopped at, by means of an argument to the ‘cont’ command. See section Conditions.

If the program stopped because of a signal other than SIGINT or SIGTRAP, continuing will cause the program to see that signal. You may not want this to happen. For example, if the program stopped due to some sort of memory reference error, you might store correct values into the erroneous variables and continue, hoping to see more execution; but the program would probably terminate immediately as a result of the fatal signal once it sees the signal. To prevent this, you can continue with ‘signal 0’. See section Signaling. You can also act in advance to prevent the program from seeing certain kinds of signals, using the ‘handle’ command (see section Signals).

D.5.4 Stepping

Stepping means setting your program in motion for a limited time, so that control will return automatically to the debugger after one line of code or one machine instruction. Breakpoints are active during stepping and the program will stop for them even if it has not gone as far as the stepping command specifies.

step

Continue running the program until control reaches a different line, then stop it and return control to the debugger. This command is abbreviated ‘s’.

This command may be given when control is within a function for which there is no debugging information. In that case, execution will proceed until control reaches a different function, or is about to return from this function. An argument repeats this action.

step count

Continue running as in ‘step’, but do so count times. If a breakpoint is reached or a signal not related to stepping occurs before count steps, stepping stops right away.

next

Similar to ‘step’, but any function calls appearing within the line of code are executed without stopping. Execution stops when control reaches a different line of code at the stack level which was executing when the ‘next’ command was given. This command is abbreviated ‘n’.

An argument is a repeat count, as in ‘step’.

‘next’ within a function without debugging information acts as does ‘step’, but any function calls appearing within the code of the function are executed without stopping.

finish

Continue running until just after the selected stack frame returns (or until there is some other reason to stop, such as a fatal signal or a breakpoint). Print value returned by the selected stack frame (if any).

Contrast this with the ‘return’ command (see section Returning).

until

This command is used to avoid single stepping through a loop more than once. It is like the ‘next’ command, except that when ‘until’ encounters a jump, it automatically continues execution until the program counter is greater than the address of the jump.

This means that when you reach the end of a loop after single stepping though it, ‘until’ will cause the program to continue execution until the loop is exited. In contrast, a ‘next’ command at the end of a loop will simply step back to the beginning of the loop, which would force you to step through the next iteration.

‘until’ always stops the program if it attempts to exit the current stack frame.

‘until’ may produce somewhat counterintuitive results if the order of the source lines does not match the actual order of execution. For example, in a typical C for-loop, the third expression in the for-statement (the loop-step expression) is executed after the statements in the body of the loop, but is written before them. Therefore, the ‘until’ command would appear to step back to the beginning of the loop when it advances to this expression. However, it has not really done so, not in terms of the actual machine code.

Note that ‘until’ with no argument works by means of single instruction stepping, and hence is slower than ‘until’ with an argument.

until location

Continue running the program until either the specified location is reached, or the current (innermost) stack frame returns. This form of the command uses breakpoints, and hence is quicker than ‘until’ without an argument.

stepi
si

Execute one machine instruction, then stop and return to the debugger.

It is often useful to do ‘display/i $pc’ when stepping by machine instructions. This will cause the next instruction to be executed to be displayed automatically at each stop. See section Auto Display.

An argument is a repeat count, as in ‘step’.

nexti
ni

Execute one machine instruction, but if it is a subroutine call, proceed until the subroutine returns.

An argument is a repeat count, as in ‘next’.

A typical technique for using stepping is to put a breakpoint (see section Breakpoints) at the beginning of the function or the section of the program in which a problem is believed to lie, and then step through the suspect area, examining the variables that are interesting, until the problem happens.

The ‘cont’ command can be used after stepping to resume execution until the next breakpoint or signal.

D.6 Examining the Stack

When your program has stopped, the first thing you need to know is where it stopped and how it got there.

Each time your program performs a function call, the information about where in the program the call was made from is saved in a block of data called a stack frame. The frame also contains the arguments of the call and the local variables of the function that was called. All the stack frames are allocated in a region of memory called the call stack.

When your program stops, the GDB commands for examining the stack allow you to see all of this information.

One of the stack frames is selected by GDB and many GDB commands refer implicitly to the selected frame. In particular, whenever you ask GDB for the value of a variable in the program, the value is found in the selected frame. There are special GDB commands to select whichever frame you are interested in.

When the program stops, GDB automatically selects the currently executing frame and describes it briefly as the ‘frame’ command does (see section Frame Info, Info).

D.6.1 Stack Frames

The call stack is divided up into contiguous pieces called stack frames, or frames for short; each frame is the data associated with one call to one function. The frame contains the arguments given to the function, the function’s local variables, and the address at which the function is executing.

When your program is started, the stack has only one frame, that of the function main. This is called the initial frame or the outermost frame. Each time a function is called, a new frame is made. Each time a function returns, the frame for that function invocation is eliminated. If a function is recursive, there can be many frames for the same function. The frame for the function in which execution is actually occurring is called the innermost frame. This is the most recently created of all the stack frames that still exist.

Inside your program, stack frames are identified by their addresses. A stack frame con-

sists of many bytes, each of which has its own address; each kind of computer has a convention for choosing one of those bytes whose address serves as the address of the frame. Usually this address is kept in a register called the frame pointer register while execution is going on in that frame.

GDB assigns numbers to all existing stack frames, starting with zero for the innermost frame, one for the frame that called it, and so on upward. These numbers do not really exist in your program; they are to give you a way of talking about stack frames in GDB commands.

Many GDB commands refer implicitly to one stack frame. GDB records a stack frame that is called the selected stack frame; you can select any frame using one set of GDB commands, and then other commands will operate on that frame. When your program stops, GDB automatically selects the innermost frame.

Some functions can be compiled to run without a frame reserved for them on the stack. This is occasionally done with heavily used library functions to save the frame setup time. GDB has limited facilities for dealing with these function invocations; if the innermost function invocation has no stack frame, GDB will give it a virtual stack frame of 0 and correctly allow tracing of the function call chain. Results are undefined if a function invocation besides the innermost one is frameless.

D.6.2 Backtraces

A backtrace is a summary of how the program got where it is. It shows one line per frame, for many frames, starting with the currently executing frame (frame zero), followed by its caller (frame one), and on up the stack.

backtrace
bt

Print a backtrace of the entire stack: one line per frame for all frames in the stack.

You can stop the backtrace at any time by typing the system interrupt character, normally Control-C.

backtrace n
bt n

Similar, but print only the innermost n frames.

backtrace -n
bt -n

Similar, but print only the outermost n frames.

The names ‘where’ and ‘info stack’ are additional aliases for ‘backtrace’.

Every line in the backtrace shows the frame number, the function name and the program counter value.

If the function is in a source file whose symbol table data has been fully read, the backtrace shows the source file name and line number, as well as the arguments to the function. (The program counter value is omitted if it is at the beginning of the code for that line number.)

If the source file’s symbol data has not been fully read, just scanned, this extra information is replaced with an ellipsis. You can force the symbol data for that frame’s source file to be read by selecting the frame. (See section Selection).

Here is an example of a backtrace. It was made with the command ‘bt 3’, so it shows the innermost three frames.

```
#0 rtx_equal_p (x=(rtx) 0x8e58c, y=(rtx) 0x1086c4) (/gp/rms/cc/rtlanal.c
   line 337)
#1 0x246b0 in expand_call (...) (...)
#2 0x21cfc in expand_expr (...) (...)
(More stack frames follow...)
```

The functions expand_call and expand_expr are in a file whose symbol details have not been fully read. Full detail is available for the function rtx_equal_p, which is in the file ‘rtlanal.c’. Its arguments, named x and y, are shown with their typed values.

D.6.3 Selecting a Frame

Most commands for examining the stack and other data in the program work on whichever stack frame is selected at the moment. Here are the commands for selecting a stack frame; all of them finish by printing a brief description of the stack frame just selected.

frame n

Select frame number n. Recall that frame zero is the innermost (currently executing) frame, frame one is the frame that called the innermost one, and so on. The highest-numbered frame is main’s frame.

frame addr

Select the frame at address addr. This is useful mainly if the chaining of stack frames has been damaged by a bug, making it impossible for GDB to assign num-

bers properly to all frames. In addition, this can be useful when the program has multiple stacks and switches between them.

up n

Select the frame n frames up from the frame previously selected. For positive numbers n, this advances toward the outermost frame, to higher frame numbers, to frames that have existed longer. n defaults to one.

down n

Select the frame n frames down from the frame previously selected. For positive numbers n, this advances toward the innermost frame, to lower frame numbers, to frames that were created more recently. n defaults to one.

All of these commands end by printing some information on the frame that has been selected: the frame number, the function name, the arguments, the source file and line number of execution in that frame, and the text of that source line. For example:

```
#3 main (argc=3, argv=??, env=??) at main.c, line 67
67 read_input_file (argv[i]);
```

After such a printout, the ‘list’ command with no arguments will print ten lines centered on the point of execution in the frame. See section List.

D.6.4 Information on a Frame

There are several other commands to print information about the selected stack frame.

frame

This command prints a brief description of the selected stack frame. It can be abbreviated ‘f’. With an argument, this command is used to select a stack frame; with no argument, it does not change which frame is selected, but still prints the same information.

info frame

This command prints a verbose description of the selected stack frame, including the address of the frame, the addresses of the next frame in (called by this frame) and the next frame out (caller of this frame), the address of the frame’s arguments, the program counter saved in it (the address of execution in the caller frame), and which registers were saved in the frame. The verbose description is useful when something has gone wrong that has made the stack format fail to fit the usual conventions.

info frame addr

Print a verbose description of the frame at address addr, without selecting that frame. The selected frame remains unchanged by this command.

info args

Print the arguments of the selected frame, each on a separate line.

info locals

Print the local variables of the selected frame, each on a separate line. These are all variables declared static or automatic within all program blocks that execution in this frame is currently inside of.

D.7 Examining Source Files

GDB knows which source files your program was compiled from, and can print parts of their text. When your program stops, GDB spontaneously prints the line it stopped in. Likewise, when you select a stack frame (see section Selection), GDB prints the line which execution in that frame has stopped in. You can also print parts of source files by explicit command.

D.7.1 Printing Source Lines

To print lines from a source file, use the ‘list’ command (abbreviated ‘l’). There are several ways to specify what part of the file you want to print.

Here are the forms of the ‘list’ command most commonly used:

list linenum

Print ten lines centered around line number linenum in the current source file.

list function

Print ten lines centered around the beginning of function function.

list

Print ten more lines. If the last lines printed were printed with a ‘list’ command, this prints ten lines following the last lines printed; however, if the last line printed was a solitary line printed as part of displaying a stack frame (see section Stack), this prints ten lines centered around that line.

list -

Print ten lines just before the lines last printed.

Repeating a ‘list’ command with RET discards the argument, so it is equivalent to typing just ‘list’. This is more useful than listing the same lines again. An exception is made for an argument of ‘-’; that argument is preserved in repetition so that each repetition moves up in the file.

In general, the ‘list’ command expects you to supply zero, one or two linespecs.

Linespecs specify source lines; there are several ways of writing them but the effect is always to specify some source line. Here is a complete description of the possible arguments for ‘list’:

list linespec

Print ten lines centered around the line specified by linespec.

list first,last

Print lines from first to last. Both arguments are linespecs.

list ,last

Print ten lines ending with last.

list first,

Print ten lines starting with first.

list +

Print ten lines just after the lines last printed.

list -

Print ten lines just before the lines last printed.

list

As described in the preceding table.

Here are the ways of specifying a single source line--all the kinds of linespec.

linenum

Specifies line linenum of the current source file. When a ‘list’ command has two linespecs, this refers to the same source file as the first linespec.

+offset

Specifies the line offset lines after the last line printed. When used as the second linespec in a ‘list’ command that has two, this specifies the line offset lines down from the first linespec.

-offset

Specifies the line offset lines before the last line printed.

filename:linenum

Specifies line linenum in the source file filename.

function

Specifies the line of the open-brace that begins the body of the function function.

filename:function

Specifies the line of the open-brace that begins the body of the function function in the file filename. The file name is needed with a function name only for disambiguation of identically named functions in different source files.

***address**

Specifies the line containing the program address address. address may be any expression.

One other command is used to map source lines to program addresses.

info line linenum

Print the starting and ending addresses of the compiled code for source line linenum.

The default examine address for the ‘x’ command is changed to the starting address of the line, so that ‘x/i’ is sufficient to begin examining the machine code (see section Memory). Also, this address is saved as the value of the convenience variable $_ (see section Convenience Vars).

D.7.2 Searching Source Files

There are two commands for searching through the current source file for a regular expression.

The command ‘forward-search regexp’ checks each line, starting with the one following the last line listed, for a match for regexp. It lists the line that is found. You can abbreviate the command name as ‘fo’.

The command ‘reverse-search regexp’ checks each line, starting with the one before the last line listed and going backward, for a match for regexp. It lists the line that is found. You can abbreviate this command with as little as ‘rev’.

D.7.3 Specifying Source Directories

Executable programs do not record the directories of the source files from which they were compiled, just the names. GDB remembers a list of directories to search for source files; this is called the source path. Each time GDB wants a source file, it tries all the directories in the list, in the order they are present in the list, until it finds a file with the desired name. **Note that the executable search path is** not **used for this purpose. Neither is the current working directory, unless it happens to be in the source path**.

When you start GDB, its source path contains just the current working directory. To add other directories, use the ‘directory’ command.

directory dirnames...

Add directory dirname to the end of the source path. Several directory names may be given to this command, separated by whitespace or ‘:’.

directory

Reset the source path to just the current working directory of GDB. This requires confirmation.

Since this command deletes directories from the search path, it may change the directory in which a previously read source file will be discovered. To make this work correctly, this command also clears out the tables GDB maintains about the source files it has already found.

info directories

Print the source path: show which directories it contains.

Because the ‘directory’ command adds to the end of the source path, it does not affect any file that GDB has already found. If the source path contains directories that you do not want, and these directories contain misleading files with names matching your source files, the way to correct the situation is as follows:

1. Choose the directory you want at the beginning of the source path. Use the ‘cd’ command to make that the current working directory.
2. Use ‘directory’ with no argument to reset the source path to just that directory.
3. Use ‘directory’ with suitable arguments to add any other directories you want in the source path.

D.8 Examining Data

The usual way to examine data in your program is with the ‘print’ command (abbreviated ‘p’). It evaluates and prints the value of any valid expression of the language the program is written in (for now, C). You type

print exp

where exp is any valid expression, and the value of exp is printed in a format appropriate to its data type.

A more low-level way of examining data is with the ‘x’ command. It examines data in memory at a specified address and prints it in a specified format.

D.8.1 Expressions

Many different GDB commands accept an expression and compute its value. Any kind of constant, variable or operator defined by the programming language you are using is legal in an expression in GDB. This includes conditional expressions, function calls, casts and string constants. It unfortunately does not include symbols defined by preprocessor #define commands.

Casts are supported in all languages, not just in C, because it is so useful to cast a number into a pointer so as to examine a structure at that address in memory.

GDB supports three kinds of operator in addition to those of programming languages:

@ ‘@’ is a binary operator for treating parts of memory as arrays. See section Arrays, for more information.

:: ‘::’ allows you to specify a variable in terms of the file or function it is defined in. See section Variables.

{type} addr Refers to an object of type type stored at address addr in memory. addr may be any expression whose value is an integer or pointer (but parentheses are required around non-unary operators, just as in a cast). This construct is allowed regardless of what kind of data is officially supposed to reside at addr.

D.8.2 Program Variables

The most common kind of expression to use is the name of a variable in your program.

Variables in expressions are understood in the selected stack frame (see section Selection); they must either be global (or static) or be visible according to the scope rules of the programming language from the point of execution in that frame. This means that in the function

```
foo (a)
int a;
{
        bar (a);
        {
                int b = test ();
                bar (b);
        }
}
```

the variable a is usable whenever the program is executing within the function foo, but the variable b is visible only while the program is executing inside the block in which b is declared.

As a special exception, you can refer to a variable or function whose scope is a single source file even if the current execution point is not in this file. But it is possible to have more than one such variable or function with the same name (if they are in different source files). In such a case, it is not defined which one you will get. If you wish, you can specify any one of them using the colon colon construct:

block::variable

Here block is the name of the source file whose variable you want.

D.8.3 Artificial Arrays

It is often useful to print out several successive objects of the same type in memory; a section of an array, or an array of dynamically determined size for which only a pointer exists in the program.

This can be done by constructing an artificial array with the binary operator '@'. The left operand of '@' should be the first element of the desired array, as an individual object. The right operand should be the length of the array. The result is an array value whose elements are all of the type of the left argument. The first element is actually the left argument; the second element comes from bytes of memory immediately following those that hold the first element, and so on. Here is an example. If a program says

```
int *array = (int *) malloc (len * sizeof (int));
```

you can print the contents of array with

```
p *array@len
```

The left operand of '@' must reside in memory. Array values made with '@' in this way behave just like other arrays in terms of subscripting, and are coerced to pointers when used in expressions. (It would probably appear in an expression via the value history, after you had printed it out.)

D.8.4 Format options

GDB provides a few ways to control how arrays and structures are printed.

info format

Display the current settings for the format options.

set array-max number-of-elements

If GDB is printing a large array, it will stop printing after it has printed the number of elements set by the 'set array-max' command. This limit also applies to the display of strings.

set prettyprint on

Cause GDB to print structures in an indented format with one member per line, like this:

```
$1 = {
        next = 0x0,
        flags = {
                sweet = 1,
                sour = 1
        },
        meat = 0x54 "Pork"
}
```

set prettyprint off

Cause GDB to print structures in a compact format, like this:

$1 = {next = 0x0, flags = {sweet = 1, sour = 1}, meat = 0x54 "Pork"}

This is the default format.

set unionprint on

Tell GDB to print unions which are contained in structures. This is the default setting.

set unionprint off

Tell GDB not to print unions which are contained in structures.

For example, given the declarations

```
typedef enum {Tree, Bug} Species;
typedef enum {Big_tree, Acorn, Seedling} Tree_forms;
typedef enum {Caterpiller, Cocoon, Butterfly} Bug_forms;
struct thing {
        Species it;
        union {
                Tree_forms tree;
                Bug_forms bug;
        } form;
};
struct thing foo = {Tree, {Acorn}};
```

with ‘set unionprint on’ in effect ‘p foo’ would print

```
$1 = {it = Tree, form = {tree = Acorn, bug = Cocoon}}
```

and with ‘set unionprint off’ in effect it would print

```
$1 = {it = Tree, form = {...}}
```

D.8.5 Output formats

GDB normally prints all values according to their data types. Sometimes this is not what you want. For example, you might want to print a number in hex, or a pointer in decimal. Or you might want to view data in memory at a certain address as a character string or an instruction. These things can be done with output formats.

The simplest use of output formats is to say how to print a value already computed. This is done by starting the arguments of the ‘print’ command with a slash and a format letter. The format letters supported are:

‘x’ Regard the bits of the value as an integer, and print the integer in hexadecimal.

‘d’ Print as integer in signed decimal.

‘u’ Print as integer in unsigned decimal.

‘o’ Print as integer in octal.

‘a’ Print as an address, both absolute in hex and then relative to a symbol defined as an address below it.

‘c’ Regard as an integer and print it as a character constant.

‘f’ Regard the bits of the value as a floating point number and print using typical floating point syntax.

For example, to print the program counter in hex (see section Registers), type

p/x $pc

Note that no space is required before the slash; this is because command names in GDB cannot contain a slash.

To reprint the last value in the value history with a different format, you can use the ‘print’ command with just a format and no expression. For example, ‘p/x’ reprints the last value in hex.

0.0.7. Examining Memory

The command ‘x’ (for ‘examine’) can be used to examine memory without reference to the program’s data types. The format in which you wish to examine memory is instead explicitly specified. The allowable formats are a superset of the formats described in the previous section.

‘x’ is followed by a slash and an output format specification, followed by an expression for an address. The expression need not have a pointer value (though it may); it is used as an integer, as the address of a byte of memory. See section Expressions for more information on expressions. For example, ‘x/4xw $sp’ prints the four words of memory above the stack pointer in hexadecimal.

The output format in this case specifies both how big a unit of memory to examine and how to print the contents of that unit. It is done with one or two of the following letters:

These letters specify just the size of unit to examine:

‘b’ Examine individual bytes.

‘h’ Examine halfwords (two bytes each).

‘w’ Examine words (four bytes each).

Many assemblers and cpu designers still use ‘word’ for a 16-bit quantity, as a holdover from specific predecessor machines of the 1970’s that really did use two byte words. But more generally the term ‘word’ has always referred to the size of quantity that a machine normally operates on and stores in its registers. This is 32 bits for all the machines that GDB runs on.

‘g’ Examine giant words (8 bytes).

These letters specify just the way to print the contents:

‘x’ Print as integers in unsigned hexadecimal.

‘d’ Print as integers in signed decimal.

‘u’ Print as integers in unsigned decimal.

‘o’ Print as integers in unsigned octal.

‘a’ Print as an address, both absolute in hex and then relative to a symbol defined as an address below it.

‘c’ Print as character constants.

‘f’ Print as floating point. This works only with sizes ‘w’ and ‘g’.

‘s’ Print a null-terminated string of characters. The specified unit size is ignored; instead, the unit is however many bytes it takes to reach a null character (including the null character).

‘i’ Print a machine instruction in assembler syntax (or nearly). The specified unit size is ignored; the number of bytes in an instruction varies depending on the type of machine, the opcode and the addressing modes used.

If either the manner of printing or the size of unit fails to be specified, the default is to use the same one that was used last. If you don’t want to use any letters after the slash, you can omit the slash as well.

You can also omit the address to examine. Then the address used is just after the last unit examined. This is why string and instruction formats actually compute a unit size based on the data: so that the next string or instruction examined will start in the right place. The ‘print’ command sometimes sets the default address for the ‘x’ command; when the value printed resides in memory, the default is set to examine the same location. ‘info line’ also sets the default for ‘x’, to the address of the start of the machine code for the specified line and ‘info breakpoints’ sets it to the address of the last breakpoint listed.

When you use RET to repeat an ‘x’ command, it does not repeat exactly the same: the address specified previously (if any) is ignored, so that the repeated command examines the successive locations in memory rather than the same ones.

You can examine several consecutive units of memory with one command by writing a repeat-count after the slash (before the format letters, if any). The repeat count must be a decimal integer. It has the same effect as repeating the ‘x’ command that many times except that the output may be more compact with several units per line. For example,

x/10i $pc

prints ten instructions starting with the one to be executed next in the selected frame. After doing this, you could print another ten following instructions with

x/10

in which the format and address are allowed to default.

The addresses and contents printed by the ‘x’ command are not put in the value history because there is often too much of them and they would get in the way. Instead, GDB makes these values available for subsequent use in expressions as values of the convenience variables $_ and $__.

After an ‘x’ command, the last address examined is available for use in expressions in the convenience variable $_. The contents of that address, as examined, are available in the convenience variable $__.

If the ‘x’ command has a repeat count, the address and contents saved are from the last memory unit printed; this is not the same as the last address printed if several units were printed on the last line of output.

The specialized command ‘disassemble’ is also provided to dump a range of memory as machine instructions. The default memory range is the function surrounding the program counter of the selected frame. A single argument to this command is a program counter value; the function surrounding this value will be dumped. Two arguments specify a range of address (first inclusive, second exclusive) to be dumped.

D.8.6 Automatic Display

If you find that you want to print the value of an expression frequently (to see how it changes), you might want to add it to the automatic display list so that GDB will print its value each time the program stops. Each expression added to the list is given a number to identify it; to remove an expression from the list, you specify that number. The automatic display looks like this:

2: foo = 38

3: bar[5] = (struct hack *) 0x3804

showing item numbers, expressions and their current values.

If the expression refers to local variables, then it does not make sense outside the lexical context for which it was set up. Such an expression is printed only when execution is inside that lexical context. For example, if you give the command ‘display name’ while inside a function with an argument name, then this argument will be displayed whenever the program stops inside that function, but not when it stops elsewhere (since this argument doesn’t exist elsewhere).

display exp

Add the expression exp to the list of expressions to display each time the program stops. See section Expressions.

display/fmt exp

For fmt specifying only a display format and not a size or count, add the expression exp to the auto-display list but arranges to display it each time in the specified format fmt.

display/fmt addr

For fmt ‘i’ or ‘s’, or including a unit-size or a number of units, add the expression addr as a memory address to be examined each time the program stops. Examining means in effect doing ‘x/fmt addr’. See section Memory.

undisplay dnums...
delete display dnums...

Remove item numbers dnums from the list of expressions to display.

disable display dnums...

Disable the display of item numbers dnums. A disabled display item is not printed automatically, but is not forgotten. It may be re-enabled later.

enable display dnums...

Enable display of item numbers dnums. It becomes effective once again in auto display of its expression, until you specify otherwise.

display

Display the current values of the expressions on the list, just as is done when the program stops.

info display

Print the list of expressions previously set up to display automatically, each one with its item number, but without showing the values. This includes disabled expressions, which are marked as such. It also includes expressions which would not be displayed right now because they refer to automatic variables not currently available.

D.8.7 Value History

Every value printed by the ‘print’ command is saved for the entire session in GDB’s value history so that you can refer to it in other expressions.

The values printed are given history numbers for you to refer to them by. These are successive integers starting with 1. ‘print’ shows you the history number assigned to a value by printing ‘$num = ‘ before the value; here num is the history number.

To refer to any previous value, use ‘$’ followed by the value’s history number. The output printed by ‘print’ is designed to remind you of this. Just $ refers to the most recent value in the history, and $$ refers to the value before that.

For example, suppose you have just printed a pointer to a structure and want to see the contents of the structure. It suffices to type

```
p *$
```

If you have a chain of structures where the component ‘next’ points to the next one, you can print the contents of the next one with this:

```
p *$.next
```

It might be useful to repeat this command many times by typing RET.

Note that the history records values, not expressions.

If the value of x is 4 and you type this command:

```
print x
```

```
set x=5
```

then the value recorded in the value history by the ‘print’ command remains 4 even though the value of x has changed.

info values

Print the last ten values in the value history, with their item numbers. This is like ‘p $$9’ repeated ten times, except that ‘info values’ does not change the history.

info values n

Print ten history values centered on history item number n.

info values +

Print ten history values just after the values last printed.

D.8.8 Convenience Variables

GDB provides convenience variables that you can use within GDB to hold on to a value and refer to it later. These variables exist entirely within GDB; they are not part of your program, and setting a convenience variable has no effect on further execution of your program. That's why you can use them freely.

Convenience variables have names starting with '$'. Any name starting with '$' can be used for a convenience variable, unless it is one of the predefined set of register names (see section Registers).

You can save a value in a convenience variable with an assignment expression, just as you would set a variable in your program. Example:

```
set $foo = *object_ptr
```

would save in $foo the value contained in the object pointed to by object_ptr.

Using a convenience variable for the first time creates it; but its value is void until you assign a new value. You can alter the value with another assignment at any time.

Convenience variables have no fixed types. You can assign a convenience variable any type of value, even if it already has a value of a different type. The convenience variable as an expression has whatever type its current value has.

info convenience

Print a list of convenience variables used so far, and their values. Abbreviated 'i con'.

One of the ways to use a convenience variable is as a counter to be incremented or a pointer to be advanced. For example:

```
set $i = 0
print bar[$i++]->contents
...repeat that command by typing RET.
```

Some convenience variables are created automatically by GDB and given values likely to be useful.

$_ The variable $_ is automatically set by the 'x' command to the last address examined (see section Memory). Other commands which provide a default address for 'x' to examine also set $_ to that address; these commands include 'info line' and 'info breakpoint'.

$__ The variable $__ is automatically set by the 'x' command to the value found in the last address examined.

D.8.9 Registers

Machine register contents can be referred to in expressions as variables with names starting with '$'. The names of registers are different for each machine; use 'info registers' to see the names used on your machine. The names $pc and $sp are used on all machines for the program counter register and the stack pointer. Often $fp is used for a register that contains a pointer to the current stack frame, and $ps is used for a register that contains the processor status. These standard register names may be available on your machine even though the info registers command displays them with a different name. For example, on the SPARC, info registers displays the processor status register as $psr but you can also refer to it as $ps.

GDB always considers the contents of an ordinary register as an integer when the register is examined in this way. Some machines have special registers which can hold nothing but floating point; these registers are considered floating point. There is no way to refer to the contents of an ordinary register as floating point value (although you can print it as a floating point value with 'print/f $regname').

Some registers have distinct "raw" and "virtual" data formats. This means that the data format in which the register contents are saved by the operating system is not the same one that your program normally sees. For example, the registers of the 68881 floating point coprocessor are always saved in "extended" format, but all C programs expect to work with "double" format. In such cases, GDB normally works with the virtual format only (the format that makes sense for your program), but the 'info registers' command prints the data in both formats.

Register values are relative to the selected stack frame (see section Selection). This means that you get the value that the register would contain if all stack frames farther in were exited and their saved registers restored. In order to see the real contents of all registers, you must select the innermost frame (with 'frame 0').

Some registers are never saved (typically those numbered zero or one) because they are used for returning function values; for these registers, relativization makes no difference.

info registers

Print the names and relativized values of all registers.

info registers regname

Print the relativized value of register regname. regname may be any register name valid on the machine you are using, with or without the initial '$'.

0.0.8. Examples

You could print the program counter in hex with

```
p/x $pc
```

or print the instruction to be executed next with

```
x/i $pc
```

or add four to the stack pointer with

```
set $sp += 4
```

The last is a way of removing one word from the stack, on machines where stacks grow downward in memory (most machines, nowadays). This assumes that the innermost stack frame is selected. Setting $sp is not allowed when other stack frames are selected.

D.9 Examining the Symbol Table

The commands described in this section allow you to make inquiries for information about the symbols (names of variables, functions and types) defined in your program. This information is found by GDB in the symbol table loaded by the ‘symbol-file’ command; it is inherent in the text of your program and does not change as the program executes.

whatis exp

Print the data type of expression exp. exp is not actually evaluated, and any side-effecting operations (such as assignments or function calls) inside it do not take place. See section Expressions.

whatis

Print the data type of $, the last value in the value history.

info address symbol

Describe where the data for symbol is stored. For a register variable, this says which register it is kept in. For a non-register local variable, this prints the stack-frame offset at which the variable is always stored.

Note the contrast with ‘print &symbol’, which does not work at all for register variables, and for a stack local variable prints the exact address of the current instantiation of the variable.

ptype typename

Print a description of data type typename. typename may be the name of a type, or for C code it may have the form ‘struct struct-tag’, ‘union union-tag’ or ‘enum enum-tag’.

info sources

Print the names of all source files in the program for which there is debugging information.

info functions

Print the names and data types of all defined functions.

info functions regexp

Print the names and data types of all defined functions whose names contain a match for regular expression regexp. Thus, ‘info fun step’ finds all functions whose names include ‘step’; ‘info fun ^step’ finds those whose names start with ‘step’.

info variables

Print the names and data types of all variables that are declared outside of functions (i.e., except for local variables).

info variables regexp

Print the names and data types of all variables (except for local variables) whose names contain a match for regular expression regexp.

info types

Print all data types that are defined in the program.

info types regexp

Print all data types that are defined in the program whose names contain a match for regular expression regexp.

printsyms filename

Write a complete dump of the debugger’s symbol data into the file filename.

D.10 Altering Execution

Once you think you have found an error in the program, you might want to find out for certain whether correcting the apparent error would lead to correct results in the rest of the run. You can find the answer by experiment, using the GDB features for altering execution of the program.

For example, you can store new values into variables or memory locations, give the program a signal, restart it at a different address, or even return prematurely from a function to its caller.

D.10.1 Assignment to Variables

To alter the value of a variable, evaluate an assignment expression. See section Expressions. For example,

```
print x=4
```

would store the value 4 into the variable x, and then print the value of the assignment expression (which is 4).

All the assignment operators of C are supported, including the incrementation operators '++' and '--', and combining assignments such as '+=' and '<<='.

If you are not interested in seeing the value of the assignment, use the 'set' command instead of the 'print' command. 'set' is really the same as 'print' except that the expression's value is not printed and is not put in the value history (see section Value History). The expression is evaluated only for side effects.

Note that if the beginning of the argument string of the 'set' command appears identical to a 'set' sub-command, it may be necessary to use the 'set variable' command. This command is identical to 'set' except for its lack of sub-commands.

GDB allows more implicit conversions in assignments than C does; you can freely store an integer value into a pointer variable or vice versa, and any structure can be converted to any other structure that is the same length or shorter.

To store values into arbitrary places in memory, use the '{...}' construct to generate a val-

ue of specified type at a specified address (see section Expressions). For example, {int}0x83040 would refer to memory location 0x83040 as an integer (which implies a certain size and representation in memory), and

```
set {int}0x83040 = 4
```

would store the value 4 into that memory location.

D.10.2 Continuing at a Different Address

Ordinarily, when you continue the program, you do so at the place where it stopped, with the ‘cont’ command. You can instead continue at an address of your own choosing, with the following commands:

jump linenum

Resume execution at line number linenum. Execution may stop immediately if there is a breakpoint there.

The ‘jump’ command does not change the current stack frame, or the stack pointer, or the contents of any memory location or any register other than the program counter. If line linenum is in a different function from the one currently executing, the results may be bizarre if the two functions expect different patterns of arguments or of local variables. For this reason, the ‘jump’ command requests confirmation if the specified line is not in the function currently executing. However, even bizarre results are predictable based on careful study of the machine-language code of the program.

jump *address

Resume execution at the instruction at address address.

You can get much the same effect as the jump command by storing a new value into the register $pc. The difference is that this does not start the program running; it only changes the address where it will run when it is continued. For example,

```
set $pc = 0x485
```

causes the next ‘cont’ command or stepping command to execute at address 0x485, rather than at the address where the program stopped. See section Stepping.

The most common occasion to use the ‘jump’ command is when you have stepped across a function call with next, and found that the return value is incorrect. If all the relevant data appeared correct before the function call, the error is probably in the function that just returned.

In general, your next step would now be to rerun the program and execute up to this func-

tion call, and then step into it to see where it goes astray. But this may be time consuming. If the function did not have significant side effects, you could get the same information by resuming execution just before the function call and stepping through it. To do this, first put a breakpoint on that function; then, use the ‘jump’ command to continue on the line with the function call.

D.10.3 Giving the Program a Signal

signal signalnum

Resume execution where the program stopped, but give it immediately the signal number signalnum.

Alternatively, if signalnum is zero, continue execution without giving a signal. This is useful when the program stopped on account of a signal and would ordinarily see the signal when resumed with the ‘cont’ command; ‘signal 0’ causes it to resume without a signal.

D.10.4 Returning from a Function

You can cancel execution of a function call with the ‘return’ command. This command has the effect of discarding the selected stack frame (and all frames within it), so that control moves to the caller of that function. You can think of this as making the discarded frame return prematurely.

First select the stack frame that you wish to return from (see section Selection). Then type the ‘return’ command. If you wish to specify the value to be returned, give that as an argument.

This pops the selected stack frame (and any other frames inside of it), leaving its caller as the innermost remaining frame. That frame becomes selected. The specified value is stored in the registers used for returning values of functions.

The ‘return’ command does not resume execution; it leaves the program stopped in the state that would exist if the function had just returned. Contrast this with the ‘finish’ command (see section Stepping), which resumes execution until the selected stack frame returns naturally.

D.11 Canned Sequences of Commands

GDB provides two ways to store sequences of commands for execution as a unit: user-defined commands and command files.

D.11.1 User-Defined Commands

A user-defined command is a sequence of GDB commands to which you assign a new name as a command. This is done with the ‘define’ command.

define commandname

Define a command named commandname. If there is already a command by that name, you are asked to confirm that you want to redefine it.

The definition of the command is made up of other GDB command lines, which are given following the ‘define’ command. The end of these commands is marked by a line containing ‘end’.

document commandname

Give documentation to the user-defined command commandname. The command commandname must already be defined. This command reads lines of documentation just as ‘define’ reads the lines of the command definition, ending with ‘end’. After the ‘document’ command is finished, ‘help’ on command commandname will print the documentation you have specified.

You may use the ‘document’ command again to change the documentation of a command. Redefining the command with ‘define’ does not change the documentation.

User-defined commands do not take arguments. When they are executed, the commands of the definition are not printed. An error in any command stops execution of the user-defined command.

Commands that would ask for confirmation if used interactively proceed without asking when used inside a user-defined command. Many GDB commands that normally print messages to say what they are doing omit the messages when used in user-defined command.

D.11.2 Command Files

A command file for GDB is a file of lines that are GDB commands. Comments (lines starting with '#') may also be included. An empty line in a command file does nothing; it does not mean to repeat the last command, as it would from the terminal.

When GDB starts, it automatically executes its init files, command files named '.gdbinit'. GDB reads the init file (if any) in your home directory and then the init file (if any) in the current working directory. (The init files are not executed if the '-nx' option is given.) You can also request the execution of a command file with the 'source' command:

source filename

Execute the command file filename.

The lines in a command file are executed sequentially. They are not printed as they are executed. An error in any command terminates execution of the command file.

Commands that would ask for confirmation if used interactively proceed without asking when used in a command file. Many GDB commands that normally print messages to say what they are doing omit the messages when used in a command file.

D.11.3 Commands for Controlled Output

During the execution of a command file or a user defined command, the only output that appears is what is explicitly printed by the commands of the definition. This section describes three commands useful for generating exactly the output you want.

echo text

Print text. Non-printing characters can be included in text using C escape sequences, such as '\n' to print a newline. No newline will be printed unless you specify one. In addition to the standard C escape sequences a backslash followed by a space stands for a space. This is useful for outputting a string with spaces at the beginning or the end, since leading and trailing spaces are trimmed from all arguments. Thus, to print "and foo = '' , use the command "echo \ and foo = \ ''

A backslash at the end of text can be used, as in C, to continue the command onto subsequent lines. For example,

echo This is some text\n\

which is continued\n\

onto several lines.\n

produces the same output as

echo This is some text\n echo which is continued\n echo onto several lines.\n

output expression

Print the value of expression and nothing but that value: no newlines, no '$nn = '. The value is not entered in the value history either. See section Expressions for more information on expressions.

output/fmt expression

Print the value of expression in format fmt. See section Output formats, for more information.

printf string, expressions...

Print the values of the expressions under the control of string. The expressions are separated by commas and may be either numbers or pointers. Their values are printed as specified by string, exactly as if the program were to execute

printf (string, expressions...);

For example, you can print two values in hex like this:

printf "foo, bar-foo = 0x%x, 0x%x\n", foo, bar-foo

only backslash-escape sequences that you can use in the string are the simple ones that consist of backslash followed by a letter.

D.12 Options and Arguments for GDB

When you invoke GDB, you can specify arguments telling it what files to operate on and what other things to do.

D.12.1 Mode Options

‘-nx’ Do not execute commands from the init files ‘.gdbinit’. Normally, the commands in these files are executed after all the command options and arguments have been processed. See section Command Files.

‘-q’ “Quiet”. Do not print the usual introductory messages.

‘-batch’ Run in batch mode. Exit with code 0 after processing all the command files specified with ‘-x’ (and ‘.gdbinit’, if not inhibited). Exit with nonzero status if an error occurs in executing the GDB commands in the command files.

‘-fullname’ This option is used when Emacs runs GDB as a subprocess. It tells GDB to output the full file name and line number in a standard, recognizable fashion each time a stack frame is displayed (which includes each time the program stops). This recognizable format looks like two ‘\032’ characters, followed by the file name, line number and character position separated by colons, and a newline. The Emacs-to-GDB interface program uses the two ‘\032’ characters as a signal to display the source code for the frame.

D.12.2 File-specifying Options

All the options and command line arguments given are processed in sequential order. The order makes a difference when the ‘-x’ option is used.

‘-s file’ Read symbol table from file file.

‘-e file’ Use file file as the executable file to execute when appropriate, and for examining pure data in conjunction with a core dump.

‘-se file’ Read symbol table from file file and use it as the executable file.

‘-c file’ Use file file as a core dump to examine.

‘-x file’ Execute GDB commands from file file.

‘-d directory’ Add directory to the path to search for source files.

D.12.3 Other Arguments

If there are arguments to GDB that are not options or associated with options, the first one specifies the symbol table and executable file name (as if it were preceded by ‘-se’) and the second one specifies a core dump file name (as if it were preceded by ‘-c’).

D.13 Using GDB under GNU Emacs

A special interface allows you to use GNU Emacs to view (and edit) the source files for the program you are debugging with GDB.

To use this interface, use the command M-x gdb in Emacs. Give the executable file you want to debug as an argument. This command starts GDB as a subprocess of Emacs, with input and output through a newly created Emacs buffer.

Using GDB under Emacs is just like using GDB normally except for two things:

- All “terminal” input and output goes through the Emacs buffer. This applies both to GDB commands and their output, and to the input and output done by the program you are debugging.

  This is useful because it means that you can copy the text of previous commands and input them again; you can even use parts of the output in this way.

  All the facilities of Emacs’s Shell mode are available for this purpose.

- GDB displays source code through Emacs. Each time GDB displays a stack frame, Emacs automatically finds the source file for that frame and puts an arrow (‘=>’) at the left margin of the current line.

Explicit GDB ‘list’ or search commands still produce output as usual, but you probably will have no reason to use them.

In the GDB I/O buffer, you can use these special Emacs commands:

M-s Execute to another source line, like the GDB ‘step’ command.

M-n Execute to next source line in this function, skipping all function calls, like the GDB ‘next’ command.

M-i Execute one instruction, like the GDB ‘stepi’ command.

C-c C-f

Execute until exit from the selected stack frame, like the GDB ‘finish’ command.

M-c Continue execution of the program, like the GDB ‘cont’ command.

M-u Go up the number of frames indicated by the numeric argument (see section Arguments, Numeric Arguments, emacs, The GNU Emacs Manual), like the GDB ‘up’ command.

M-d Go down the number of frames indicated by the numeric argument, like the GDB ‘down’ command.

In any source file, the Emacs command C-x SPC (gdb break) tells GDB to set a breakpoint on the source line point is on.

The source files displayed in Emacs are in ordinary Emacs buffers which are visiting the source files in the usual way. You can edit the files with these buffers if you wish; but keep in mind that GDB communicates with Emacs in terms of line numbers. If you add or delete lines from the text, the line numbers that GDB knows will cease to correspond properly to the code.

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