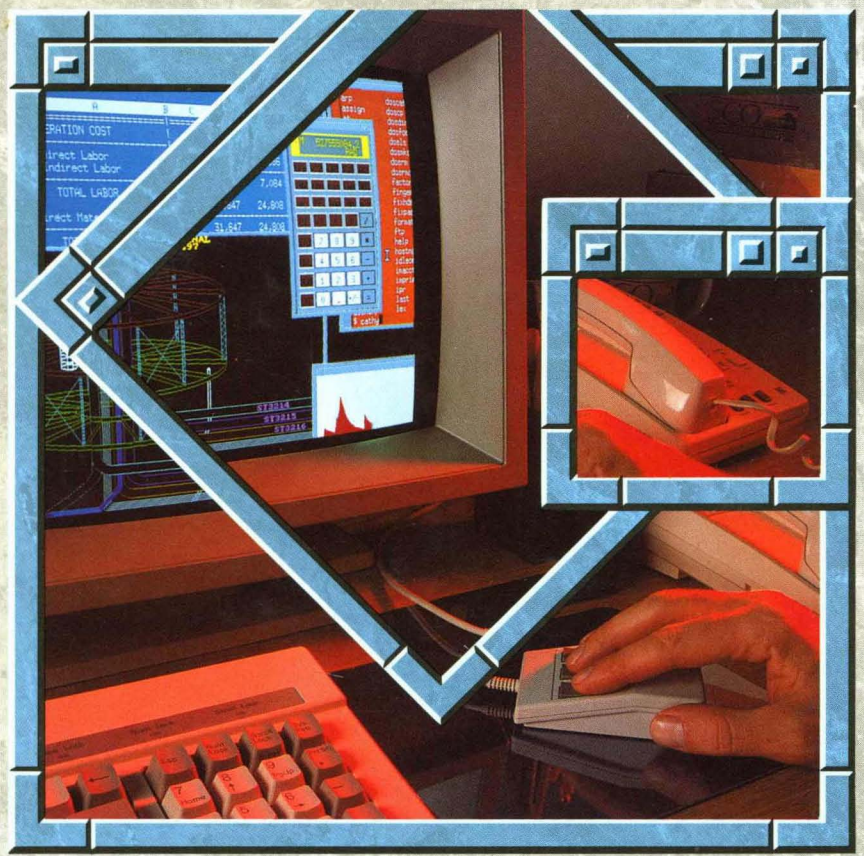
OPEN DESKTOP™

Open Desktop® Development System

C Language Guide

OPEN DESKTOP™



The Complete Graphical Operating System

SCO UNIX® System V/386

Development System

C Language Guide

The Santa Cruz Operation, Inc.

SCO Document Number: 6-26-89-6.0/3.2.0

SCO UNIX® System V/386

Development System

C User's Guide

The Santa Cruz Operation, Inc.

SCO Document Number: 6-26-89-6.0/3.2.0

Contents

1 Introduction

Overview 1-1
About This Guide 1-2
New Features 1-4
Notational Conventions 1-6
Books about C 1-9

2 Compiling with the cc Command

Introduction 2-1
The Basics: Compiling and Linking C Programs 2-2
Using cc Options 2-6

3 Linking with the cc Command

Introduction 3-1
The Default Linking Process 3-2
Passing Linker Information: The -link Option 3-3

4 Running C Programs on System V

Introduction 4-1
Passing Command-Line Data to a Program 4-2

5 Working with Memory Models

Introduction 5-1
Near, Far, and Huge Addressing 5-4
Using the Standard Memory Models 5-6
Using the near, far, and huge Keywords 5-14
Creating Customized Memory Models 5-25
Setting the Data Threshold 5-30
Naming Modules and Segments 5-31
Specifying Text and Data Segments 5-34

6 Improving Program Speed

Introduction 6-1
Using Register Variables 6-2
Optimization Options and Pragmas 6-4
Choosing the Function-Calling Convention 6-7

Efficiency in Large Data Models 6-8
Efficiency in Large Code Models 6-10

7 Object and Executable File Formats

Introduction 7-1
iAPX.....286 and .....386 System Architecture 7-2
The Intel Object Module Format 7-4
Definition of Terms 7-6
Module Identification and Attributes 7-9
Segment Definition 7-10
Segment Addressing 7-11
Symbol Definition 7-12
Indices 7-13
Conceptual Framework for Fixups 7-14
Self-Relative Fixups 7-19
Segment-Relative Fixups 7-20
Record Order 7-22
Introduction to the Record Formats 7-24
Numeric List of Record Types 7-50
Type Representations for Communal Variables 7-51
The Segmented x.out Format 7-54

8 C Language Compatibility with Assembly Language

Introduction 8-1
C Calling Sequence for 8086/80286 8-2
Entering an 8086/80286 Assembly Routine 8-3
8086/80286 Return Values 8-4
Exiting an 8086/80286 Routine 8-5
8086/80286 Program Example 8-6
80386 C-Language Calling Sequence 8-7
Entering an 80386 Assembly-Language Routine 8-8
80386 Return Values 8-9
Exiting an 80386 Routine 8-11
80386 Program Example 8-12

9 Error Processing

Introduction 9-1
Using the Standard Error File 9-2
Using the errno Variable 9-3
Printing Error Messages 9-4
Using Error Signals 9-5
Encountering System Errors 9-6

10 Common Object File Format (COFF)

The Common Object File Format (COFF) 10-1
Definitions and Conventions 10-3
File Header 10-5
Optional Header Information 10-7
Section Headers 10-9
Sections 10-12
Relocation Information 10-13
Line Numbers 10-15
Symbol Table 10-17
String Table 10-41
Access Routines 10-42

A Converting from Previous Versions of the Compiler

Introduction A-1
Differences between Versions 5.1 and 5.0 A-2
Differences between Versions 5.0 and 4.0 A-4
Differences between Versions 4.0 and 3.0 A-8

B Writing Portable Programs

Introduction B-1
Program Portability B-3
Machine Hardware B-4
Compiler Differences B-11
Environment Differences B-16
Portability of Data B-17
Type-Size Summary B-18
Byte-Ordering Summary B-20

C Writing Programs for Read-Only Memory

Introduction C-1
System V Dependent Library Routines C-2

D C Error Messages and Exit Codes

Introduction D-1
Command-Line Error Messages D-2
Compiler Error Messages D-7

Chapter 1

Introduction

Overview 1-1

About This Guide 1-2

New Features 1-4

Notational Conventions 1-6

Books about C 1-9

Overview

The C language is a powerful general-purpose programming language that can generate efficient, compact, and portable code. The Microsoft® C Optimizing Compiler (**cc**) for the UNIX System V® operating system is a full implementation of the C language as defined by its authors, Brian W. Kernighan and Dennis M. Ritchie, in *The C Programming Language*. Microsoft is actively involved in the development of the ANSI (American National Standards Institute) standard for the C language; this version of Microsoft C for UNIX System V anticipates and conforms to the forthcoming standard in many areas.

The Microsoft C Compiler offers several important features to help you increase the efficiency of your C programs. You can choose among five standard memory models (small, medium, compact, large, and huge) to set up the combination of data and code storage that best suits your program. For flexibility and even greater efficiency, the C Compiler allows you to "mix" memory models by using special declarations in your program.

The C language itself does not provide such standard features as input and output capabilities and string-manipulation features. These capabilities are provided as part of the run-time library of functions that accompanies the C Compiler.

Compared with other programming languages, Microsoft C is extremely flexible concerning data conversions and nonstandard constructions. The C Compiler offers several levels of warnings to help you control this flexibility; programs in an early stage of development can be processed using the full warning capabilities of the compiler to catch mistakes and unintentional data conversions. An experienced C programmer can use a lower warning level for programs that contain intentionally nonstandard constructions. For more information about this feature, see the "Compiling with the cc Command" chapter in this guide.

1 About This Guide

This guide explains how to use the C Compiler to compile, link, and run C programs on UNIX System V. The guide assumes that you are familiar with the C language and with UNIX System V, and that you know how to create and edit a C-language source file on your system.

If you have questions about the C language, turn to the *C Language Reference* included in this package. The *C Library Guide* documents the run-time library routines you can use in your C programs.

The remaining chapters of the *C User's Guide* are described below:

Chapter 2, "Compiling with the cc Command," describes how to compile a program using the **cc** compiler driver. This chapter describes the options most commonly used to control preprocessing, compiling, and output of files.

Chapter 3, "Linking with the cc Command," describes how to link object files using the **cc** command. This chapter explains how the linker searches for libraries, shows how to specify libraries for linking, and describes the linker options that can be used for C programs.

Chapter 4, "Running C Programs on UNIX System V," explains how to run your executable program file and discusses features specific to the UNIX System V implementation of C. This chapter tells how to pass data from UNIX System V to a program at execution time and how to return an exit code from your program to UNIX System V.

Chapter 5, "Working with Memory Models," describes methods of managing memory models. These methods are useful for writing programs that use more than 64K (kilobytes) of code or data. This chapter also discusses "mixed-model" programming (combining features from the five standard memory models).

Chapter 6, "Improving Program Speed," gives suggestions and hints for maximizing program speed.

Chapter 7, "Object and Executable File Formats," describes the system architecture of the 80x86 microprocessor family, the object module format that the C compiler follows, and the format of the **x.out** file in a segmented environment.

Chapter 8, "C Language Compatibility with Assembly Language," describes how you can embed assembly-language subroutines within C-language programs.

Chapter 9, "Error Processing," describes how to process errors detected in calls to the C library routines and explains the functions and variables a program may use to respond to these errors.

Chapter 10, "The Common Object File Format (COFF)," describes the features and contents of *COFF* files.

Appendix A, "Converting from Previous Versions of the Compiler," summarizes the differences between Version 5.1 of the C Compiler and previous versions. This appendix gives instructions for converting programs written for versions prior to 5.1 to the format accepted by Version 5.1.

Appendix B, "Writing Portable Programs," lists some of the C-language features that are implementation-dependent, and offers suggestions for increasing program portability.

Appendix C, "Writing Programs for Read-Only Memory," gives information about modifying start-up code and initializing floating-point support for programs that will be put in read-only memory.

Appendix D, "Error Messages and Exit Codes," lists and describes the error messages and exit codes generated by the C Compiler and by the **cc** command. It also lists and explains run-time error messages produced by executable programs written in C.

1 New Features

Several useful features have been added to Version 5.1 of the C Compiler. This section summarizes features added since Version 5.0. For information about differences between Version 5.1 and versions prior to 5.0, see the "Converting from Previous Versions of the Compiler" appendix in this guide.

New features include the following:

Feature	Description

New **cc** options

Option	Action
-S	Generates an assembly-language source file for the Macro Assembler, *masm*(CP).
-xenix	Produces object and/or executable files using the Intel Object Module Format (OMF).
-x2.3	Produces object and/or executable files using the Intel Object Module Format (OMF) and the XENIX System V/Release 2.3 run-time library.

New pragmas

Pragma	Action
comment	Places a comment record in the object file.
Data_seg	Specifies the data-segment name used by functions that load their own data segments. The named segment also contains all data that would normally be allocated in the **DATA** segment.
linesize	Sets the number of characters per line in the source listing.

message	Sends a message to the standard output without terminating the compilation.
page	Places a formfeed character(s) in the source listing.
pagesize	Sets the number of lines per page in the source listing.
skip	Skips the specified number of lines in the source listing. Places a comment record in the object file.
subtitle	Specifies a subtitle for the source listing.
title	Specifies a title for the source listing.

1 Notational Conventions

The following notational conventions are used throughout this guide:

Example of Convention	Description of Convention
`Examples`	The typeface shown in the left column is used to simulate the appearance of information that would be printed on the screen or by a printer. For example, the following command line is printed in this special typeface: `cc -Foout.o -DTRUE=1 file.c` When this command line is discussed in text, items appearing on the command line, such as *out.o*, also appear in the special typeface.
Language elements	Bold type indicates elements of the C language that must appear in source programs as shown. Text that is normally shown in bold type includes operators, keywords, library functions, commands, options, and preprocessor directives. Examples are shown below: **+= #if defined( ) int** **if -Fa fopen** **main sizeof**
ENVIRONMENT, VARIABLES, and **MACROS**	Bold capital letters are used for environment variables, symbolic constants, and macros.
placeholders	Words in italics are placeholders, representing a variable that you must supply in command-line examples, option specifications, and in the text. Consider the following option: **-H** *number*

Note that *number* is italicized to indicate that it represents a general form for the **-H** option. In an actual command, you would supply a particular number for the placeholder *number*.

Occasionally, italics are also used to emphasize particular words in the text.

Missing code

Vertical ellipses are used in program examples to indicate that a portion of the program is omitted. For instance, in the following excerpt, the ellipses between the statements indicate that intervening program lines occur but are not shown:

```
count = 0;
.
.
.
*pc++;
```

optional items]

Brackets enclose optional fields in command-line and option specifications. Consider the following option specification:

-D*identifier*[=[*string*]]

The placeholder *identifier* indicates that you must supply an identifier when you use the **-D** option. The outer brackets indicate that you are not required to supply an equal sign (=) and a string following the identifier. The inner brackets indicate that you are not required to enter a string following the equal sign, but if you do supply a string, you must also supply the equal sign.

Single brackets are used in C-language array declarations and subscript expressions. For instance, *a[10]* is an example of brackets in a C subscript expression.

Repeating elements...

Horizontal ellipses are used in syntax examples to indicate that more items having the same form may be entered. For example, in the Bourne shell, several paths can be specified in the **PATH** command, as shown in the following syntax:

PATH[=]*path*[;*path*]...

{*choice1*|*choice2*}

Braces and a vertical bar indicate that you have a choice of two or more items. Braces enclose the choices, and vertical bars separate them. You must choose one of these items unless all of them are also enclosed in square brackets.

For example, the **-W** (warning-level) compiler option has the following syntax:

-W {0 | 1 | 2 | 3}

You can use **-W1**, **-W2**, or **-W3** to display different levels of warning messages or **-W0** to suppress all warning messages.

''Defined terms''

Quotation marks set off terms defined in the text. For example, the term ''far'' appears in quotation marks the first time it is defined.

Some C constructs require quotation marks. Quotation marks required by the language have the form " " rather than `` ''. For example, a C string used in an example would be shown in the following form:

```
"abc"
```

KEY+KEY

Small capital letters are used for the names of keys and key sequences, such as ENTER and CTRL+C. Key sequences to be pressed simultaneously are indicated by the key names in small caps separated by a plus sign (CTRL+C).

Books about C

The manuals in this documentation package provide a complete programmer's reference for C. They do not, however, teach you how to program in C. If you are new to C or to programming, you may want to familiarize yourself with the language by reading one or more of the following books:

Hancock, Les, and Morris Krieger. *The C Primer*. New York: McGraw-Hill Book Co., Inc., 1982.

Hansen, Augie. *Proficient C*. Bellevue, Washington: Microsoft Press, 1986.

Harbison, Samuel P., and Greg L. Steele. *C: A Reference Manual*. Englewood Cliffs, New Jersey: Prentice-Hall Software Series, 1987.

Kernighan, Brian W., and Dennis M. Ritchie. *The C Programming Language*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1978.

Kochan, Stephen. *Programming in C*. Hasbrouck Heights, New Jersey: Hayden Book Company, Inc., 1983.

Plum, Thomas. *Learning to Program in C*. Cardiff, New Jersey: Plum Hall, Inc., 1983.

Schildt, Herbert. *C Made Easy*. Berkeley, California: Osborne McGraw Hill, 1985.

Schustack, Steve. *Variations in C*. Bellevue, Washington: Microsoft Press, 1985.

These books are listed for your convenience only.

hapter 2

ompiling with the c Command

troduction 2-1

ıe Basics: Compiling and Linking C Programs 2-2
The cc Command 2-2

sing cc Options 2-6
Setting Processor and Memory Model (-M) 2-6
Specifying Source Files (-Tc) 2-8
Compiling without Linking (-c) 2-9
Naming the Object File (-Fo) 2-9
Naming the Executable File (-Fe) (-o) 2-10
Creating Listings 2-11
Controlling the Preprocessor 2-28
Checking for Program Errors 2-35
Preparing for Debugging (-Zi, -Od) 2-40
Optimizing 2-41
Enabling/Disabling Language Extensions (-Ze, -Za) 2-53
Packing Structure Members (-Zp) 2-54
Setting the Stack Size (-F) 2-56
Restricting the Length of External Names (-nl) 2-57
Labeling the Object File (-V) 2-57
Changing the Default char Type (-J) 2-58
Controlling the Calling Convention (-Gc) 2-58
Compiling Programs for DOS Environment (-dos, -FP) 2-60
Displaying Compiler Passes (-d, -z) 2-61
Producing OMF Object and Executable Files (-xenix) 2-62
Miscellaneous Pragmas 2-62
Predefined Macro Names 2-65

Introduction

This chapter explains how to compile and link using the **cc** command and discusses commonly used **cc** options. The **cc** command is the only command you need to compile and link your C source files. The **cc** command executes the three compiler passes, then automatically invokes the linker, **ld**, to link your files.

Using the **cc** options described in this chapter, you can control and modify the tasks performed by the command. For example, you can direct **cc** to create an object-listing file or a preprocessed listing. Options also let you give information that applies to the compilation process; you can specify the definitions for manifest (symbolic) constants and macros, and the kinds of warning messages you want to see.

The **cc** command automatically optimizes your program. You never have to give an optimizing instruction unless you want to change the way **cc** optimizes, request more sophisticated optimizations, or disable optimization altogether. For more information on these choices, see the "Optimizing" section in this chapter.

"The Basics: Compiling and Linking C Programs" explains the basic use of the **cc** command to produce an executable program.

"Using cc Options," describes the **cc** options.

For information about linking object files and libraries using the **cc** command, see the "Linking with the cc Command" chapter of this guide.

For a discussion of the **cc** options that control memory models, see the "Working with Memory Models" chapter in this guide.

For a summary of the **cc** command and its options, see the *C Language Reference*.

The Basics: Compiling and Linking C Programs

2

This section explains how to use **cc** to compile and link C programs an discusses the rules and conventions that apply to file names and option used with **cc**.

The cc Command

The **cc** command has the following form:

cc [*option*]... *file*... [*option*... *file*...]...[-link[*link-libinfo*]]

Each *option* is one of the command-line options described in the "Usin cc Options" section, the "Working with Memory Models" chapter, or th "Improving Program Speed" chapter of this guide.

Each *file* names a source or object file to be processed or a library to b searched at link time. See the description on "Specifying Source an Object Files" later in this section for information about specifying sourc and object files.

The **cc** command automatically specifies the appropriate library to b used during linking. You can use the **-link** option with the optional *link libinfo* field to specify additional or different libraries, library searc paths, and options to be used during linking. You can also specify linke options in the *linkoptions* field. For information about specifying differer libraries and linker options, see the "Linking with the cc Command chapter of this guide.

You can give any number of options, file names, and library names on th command line, provided that the command line does not exceed 128 cha acters.

COFF and OMF

This version of the C Compiler can produce object and/or executable file that use either of two different binary file formats: COFF (Commc Object File Format) and OMF (Intel Object Module Format). COFF is th most widely used binary file format. OMF files are produced using th

-xenix option with the compiler. SCO UNIX System V can execute either file format by reading the file header and acting accordingly. Certain system calls behave differently in OMF files because they follow UNIX System V rather than XENIX system conventions. The COFF and OMF formats are described by their corresponding header files: **/usr/include/a.out.h** and **/usr/include/sys/x.out.h** respectively.

Note

The default file name produced by the linker is *a.out* regardless of the actual file format used. Any mention of *x.out* in this guide is referring only to the *format* of OMF executable files.

Table 2.1 shows the tools used with various options to the Microsoft C Compiler, and the type of object/executable file that results.

Table 2.1

Options, Tools, and Resulting Files

)ption	MS C Compiler	Assembler	Link Editor	obj form
none	MS	masm	*ld*	COFF
-c	Creates linkable x.out object file	masm	n/a	COFF
-S	Creates assembly source listing	masm	n/a	COFF
-Fa	Creates assembly source listing	masm	*ld*	COFF
xenix	Creates XENIX programs in OMF format	masm	*ld*	OMF
-xenix	Creates XENIX assembly source listing	masm	n/a	OMF
a -xenix	Creates XENIX assembly source listing	masm	*ld*	OMF

Specifying Source and Object Files

The **cc** command can process source files, object files, library files, or any combination of these. It uses the file-name extension (the period plus any letters that follow it) to determine what kind of processing the file needs, as shown in the following list:

- If the file has a **.c** extension, **cc** compiles the file.

- If the file has a **.o** extension, **cc** processes the file by invoking the linker.

- If the file has a **.a** extension, **cc** assumes the file is a library and passes it to the linker to be searched, unless the **-c** option is given to suppress linking. For a description of the **-c** option, see the section on "Compiling without Linking" under the section "Using cc Options."

- If the file has the **.asm** extension, it is passed to **masm**.

- If the extension is omitted,
  cc assumes an extension of **.o**. If the extension is anything other than **.c** , **.o** , or **.a** , **cc** assumes the file is an object file unless the file name is specified in association with the **-Tc** option. If the file name is specified with the **-Tc** option, **cc** assumes the file is a C source file. For a description of the **-Tc** option, see the section on "Specifying Source Files" under the section "Using cc Options."

Examples

```
cc a.c b.c c.o d.o
```

This command line compiles the files *a.c* and *b.c*, creating object files named *a.o* and *b.o*. These object files are then linked with the object files *c.o* and *d.o* to form an executable file named *a.out*.

```
cc a.c b.c c.o -Tcd.src
```

This command performs the same operations as the preceding command line, except that the **-Tc** option indicates that *d.src* is a source file, not an object file. Thus, the files *a.c*, *b.c*, and *d.src* are compiled, creating object files named *a.o*, *b.o*, and *d.o*. These object files are then linked with *c.o* to form an executable file named *a.out*.

Creating Executable Files

When **cc** compiles source files, it creates object files. By default, these object files use the COFF format and have the same base names as the corresponding source files, but with the extension **.o** instead of **.c**. (The base name of a file extension is the portion of the name preceding the period, but excluding the path specification, if any.) After compilation, **cc** runs a conversion program, **cvtomf**, over the object file to convert it into COFF format. For more information about the **cvtomf** conversion program, refer to the manual page **cvtomf (C)**. The converted object file can

now be linked using the AT&T link editor, **ld**. The **-xenix** option suppresses the conversion.

Unless the **-c** option is given, **cc** links these object files, along with any **.o** files you give on the command line, to form an executable file. If only **.o** files are given on the command line, **cc** skips the compilation stage and simply links the files.

Using cc Options

The **cc** command offers a large number of command options to control and modify the compiler's operation. Options begin with a dash (**-**) and contain one or more letters.

Options can appear anywhere on the **cc** command line. In general, an option applies to all files that follow it on the command line, and it does not affect files preceding it. However, not all options follow this rule; see the discussion of a particular option for information on its behavior. Keep in mind that **cc** options apply only to the compilation process. Unless specifically noted, options do not affect any object files given on the command line. The remainder of this section describes many of the options applicable to **cc**. For a concise list of all possible options, refer to the manual page, **cc(CP)**.

Setting Processor and Memory Model (-M)

The **-M** option sets the program configuration. This configuration defines the program's memory model, word order, and data threshold. It also enables C-language enhancements such as the use of the full 286 instruction set and special keywords.

```
cc -Mstring special.c
```

The *string* contains the argument that defines the configuration. It may be any combination of the following (though **s, m, c, l, h,** and **0, 1, 2, 3** are mutually exclusive):

s	Create a small model program. This is the default.
m	Create a middle model program.
c	Create a compact model program.
l	Create a large model program.
h	Create a huge model program.

e Enable the keywords: **far, near, huge, pascal** and **fortran**. Also enables certain non-ANSI extensions necessary to ensure compatibility with existing versions of the C compiler.

0 Use only 8086 instructions for code generation. This is the default on 8086/80186/80286 systems.

1 Use the extended 80186 instruction set.

2 Use the extended 80286 instruction set.

3 Use the extended 80386 instruction set. This is the default on 80386 systems.

t*num* Causes all static and global data items whose size is greater than *num* bytes to be allocated to a new data segment. *Num*, the data "threshold," defaults to 32,767. This option can only be used in large model programs (**-Ml**). Its main use is to move data out of the near data segment to allow room for the stack.

```
cc -Ml -Mt12 recursive.c
```

d Do not assume (during compilation) that the registers **SS** and **DS** will have the same contents at run time.
Warning: This option has no library or run-time support on UNIX System V. It will **not** cause the stack to be put in a separate segment. It may be of use for DOS cross-development.

-M3 is the default on 80386 systems. Although it is usually advantageous to enable the appropriate instruction set, you are not required to do so. If you have an 80286 processor, for example, but you want your code to be able to run on an 8086, you should not use the 80186/80188 or 80286 instruction set.

Note

The **m**, **c**, **l**, **h**, **b**, **t**, and **d** arguments are not compatible with the **-M3** option. The **s** and **e** arguments are compatible with **-M0**, **-M1**, **-M2**, or **-M3**.

For a complete description of memory models and segment options, see the "Working with Memory Models" chapter in this guide.

The memory-model option you choose determines the name of the standard libraries that **cc** places in the object file it creates. These libraries are then considered the default libraries, since the linker searches for them by default.

Table 2.2 shows each memory-model option and the corresponding library name that **cc** embeds in the object file.

Table 2.2
cc Options and Default Libraries

Memory-Model Option	Default Libraries
-Ms	**Slibc.a** **Slibcfp.a**
-Mm	**Mlibc.a** **Mlibcfp.a**
-Mc	**Clibc.a** **Clibcfp.a**
-Ml or **-Mh**	**Llibc.a** **Llibfp.a**

Specifying Source Files (-Tc)

Option

-Tc *sourcefile*

The **-Tc** option tells the **cc** command that the given file is a C source file. One or more spaces can appear between **-Tc** and the source-file name.

If this option does not appear, **cc** assumes that files with the extension **.c** are C source files, files with the extension **.a** are libraries, and files with any other extension or with no extension are object files. If you use the **-Tc** option, **cc** treats the given file as a C source file, regardless of its extension. A separate **-Tc** option must appear for each source file that has an extension other than **.c** .

If you have to specify more than one source file with an extension other than **.c** , you must specify each source file in a separate **-Tc** option.

Example

```
cc main.c -Tc test.prg -Tc collate.prg print.prg
```

In this example, the **cc** command compiles the three source files *main.c*, *test.prg*, and *collate.prg*. Since the file *print.prg* is given without a **-Tc** option, **cc** treats it as an object file. Thus, after compiling the three source files, **cc** links the object files *main.o*, *test.o*, *collate.o*, and *print.prg*.

Compiling without Linking (-c)

Option

-c

The **-c** (for ''compile-only'') option suppresses linking. Source files given on the command line are compiled, but the resulting object files are not linked, no executable file is created, and any object files specified on the command line are ignored. This option is useful when you are compiling individual source files that do not make up a complete program.

The **-c** option applies to the entire **cc** command line, regardless of the option's position in the command line.

Example

```
cc -c *.c
```

This command line compiles, but does not link, all files with the extension **.c** in the current working directory.

Naming the Object File (-Fo)

Option

-Fo*objfile*

By default, **cc** gives each object file it creates the base name of the corresponding source file plus the extension **.o**. The **-Fo** option lets you give different names to object files or create them in a different directory. If you are compiling more than one source file, you can give the **-Fo** option for each source file to rename the corresponding object file.

Keep the following rules in mind when using this option:

- The *objfile* argument must appear immediately after the option, with no intervening spaces.
- Each **-Fo** option applies to the next source file that appears on the command line after the option.

You are free to supply any name and any extension you like for the *objfile*. However, it is recommended that you use the conventional **.o** extension because the linker uses **.o** as the default extension when processing object files.

If you use the **-Fo** option (that is, if you do not give an object file name with a base and an optional extension), **cc** names the object files according to the following rule:

- If you give a directory specification following the **-Fo** option, **cc** creates the object file in the given directory and uses the default file name (the base name of the source file plus **.o**). Otherwise, *objfile* is created in the current directory. A **.o** extension is added if no extension is given.

To give a directory specification, it must end with a forward slash (/) so that **cc** can distinguish between a directory specification and a file name.

Example

```
cc -Fo/object1/ this.c that.c -Fo/src/newthose those.c
```

In this example, the first **-Fo** option tells the compiler to create, in the */object1* directory, the object file *this.o* (created as a result of compiling *this.c*). The compiler also creates, in the current directory, the object file *that.o* (created as a result of compiling *that.c*). The second **-Fo** option tells the compiler to create the object file named *newthose.o* (created as a result of compiling *those.c*) in the */src* directory.

Naming the Executable File (-Fe) (-o)

Option

-Fe*exefile*
-o *exefile*

By default, **cc** gives the name *a.out* to the executable file. In UNIX System V, **-Fe** and **-o** are the same, except syntactically. The file name must come immediately after **-Fe**, whereas blanks are permitted between **-o** and the file name. Either option lets you give the executable file a different name or create it in a different directory.

Since **cc** creates only one executable file, you can give the **-Fe** option anywhere on the command line. If more than one **-Fe** option appears, **cc** gives the executable file the name specified in the last **-Fe** option on the command line.

The **-Fe** option applies only in the linking stage. If you specify the **-c** option to suppress linking, **-Fe** has no effect.

Examples

```
cc -Fe/bin/process *.c
cc -o /bin/process *.c
```

These examples compile and link all source files with the extension **.c** in the current working directory. The resulting executable file is named *process.out* and is created in the directory */bin*.

Creating Listings

A number of options are available with the **cc** command for creating listings. You can create a source listing, a map listing, or one of several kinds of object listings. You can also set the title and subtitle of the source listing from the command line and control the length of source-listing lines and pages.

These options are described in the following sections.

Note

Listings produced by the **cc** command may contain names that begin with more than one underscore (for example, *__chkstk*) or that end with the suffix *QQ*. Names that use these conventions are reserved for internal use by the compiler, and should not be used in your programs, except for those documented in the *C Library Guide*. Moreover, you should avoid creating global names that begin with an underscore. Since the compiler automatically adds another leading underscore, these names will have two leading underscores and might conflict with names reserved by the compiler.

Types of Listings (-Fs, -Fl, -Fa, -Fc, -Fm -S)

Options

-Fs[*listfiles*]	Source listing
-Fl[*listfile*]	Object listing
-Fa[*listfile*]	Assembly listing
-Fc[*listfile*]	Combined source and object listing
-Fm[*mapfile*]	Map file that lists segments, in order
-S	Assembly listing

This section describes how to use command-line options to create listings. For an example of each type of listing and a description of the information it contains, see the section on "Formats for Listings."

When using an option described in this section, the *listfile* argument, if given, must follow the option immediately, with no intervening spaces. The *listfile* may be a file specification or a path specification. It may also be omitted.

Note

When you give just a path specification as the *listfile* argument, the path specification must end with a forward slash (/) so that **cc** can distinguish it from an ordinary file name.

When you give a path specification as the argument to a listing option, or if you omit the argument altogether, **cc** uses the default file name for the listing type. Table 2.3 gives the default names used for each type of listing. The table also shows the default extensions, which are used when you give a file-name argument that lacks an extension.

Table 2.3
Default File Names and Extensions

Option	Listing Type	Default File Name[1]	Default Extension[2]
-Fs	Source	Base name of source file plus **.S**	**.S**
-Fl	Object	Base name of source file plus **.L**	**.L**
-Fa	Assembly (masm)	Base name of source file plus **.asm**	**.asm**
-Fc	Combined source-object	Base name of source file plus **.L**	**.L**
-Fm	Map	Prints to standard output.	
-S	Assembly (masm)	Base name of source file plus **.asm**	**.asm**

Notes:

1 The default file name is used when the option is given with no argument or with a path specification as the argument.

2 The default extension is used when a file name lacking an extension is given.

3 The assembly-language listing produced by the **-Fa**, **-Fc**, and **-S** options uses **masm** directives.

4 The **-Fa** and **-S** options produce the same output, except that you cannot specify the list file with the -S option.

Since you can process more than one file at a time with the **cc** command, the order in which you give listing options and the kind of argument you give for each option (file specification or path specification) affect the result. Table 2.4 summarizes the effects of each option with each type of argument.

Table 2.4
Arguments to Listing Options

Option	File-Name Argument	Path Argument[1]	No Argument
-Fa, -Fc, -Fl, -Fs	Creates a listing for the next source file on the command line; uses default extension if no extension is supplied	Creates listings in the given location for every source file listed after the option on the command line; uses default names	Creates listings in the current directory for every source file listed after the option on the command line; uses default names
-Fm	Uses given file name for the map file; uses default extension if no extension is supplied	Creates map file in the given directory; uses default name	Uses default name
-S	File name argument is not allowed	Path argument is not allowed	Uses default name

Notes:

1 When you give just a path specification as the argument, the path specification must end with a forward slash (/) so that **cc** can distinguish it from an ordinary file name.

Only one type of object or assembly listing can be produced for each source file. The **-Fc** option overrides the **-Fa** and **-Fl** options and produces a combined listing. If you apply both the **-Fa** and the **-Fl** options to one source file, only the last listing specified on the command line is produced. If you specify both the **-Fa** and the **-Fs** options to one source file, a combined listing is produced. The **-Fs** option may be used with any other option.

Note

The **cc** command optimizes by default, so listing files reflect the optimized code. Since optimization may involve rearrangement of code, the correspondence between your source file and the machine instructions may not be clear, especially when you use the **-Fc** option to mingle the source and assembly codes. To produce a listing without optimizing, use the **-Od** option (discussed in "Preparing for Debugging" later in this section) with the listing option.

The map file is produced during the linking stage. If linking is suppressed with the **-c** option, the **-Fm** option has no effect.

Examples

```
cc -Fshello.src -Fchello.cmb hello.c
```

In this example, **cc** creates a source listing called *hello.src* and a combined source and object listing called *hello.cmb.* The object file has the default name *hello.o.* However, it is removed if the link was successful.

```
cc -Fshello.src -Fshello.lst -Fchello.cod hello.c
```

This command produces a source listing called *hello.lst* rather than *hello.src*, since the last name provided has precedence. This example also produces a combined source and object listing file named *hello.cod.* The object file in both of these examples has the default name *hello.o.*

Setting Titles (-St) and Subtitles (-Ss)

Options

-St "*title*"
-Ss "*subtitle*"

The **-St** and **-Ss** options set the title and subtitle, respectively, for source listings. The quotation marks (" ") around the *title* or *subtitle* argument can be omitted if the title or subtitle does not contain space or tab characters. The space between **-St** or **-Ss** and its argument is optional.

The title appears in the upper left corner of each page of the source listing. The subtitle appears below the title.

The **-St** or **-Ss** option applies to the remainder of the command line c until the next occurrence of **-St** or **-Ss** on the command line. Thes options do not cause source listings to be created. They take effect onl when the **-Fs** option is also used to create a source listing.

Examples


```
cc -St "Income Tax" -Ss 4-14 -Fs tax*.c
```

This command compiles and links all source files beginning with *tax* an ending with the default extension (*.c*) in the current working directory Each page of the source listing contains the title *Income Tax* in the uppe left corner. The subtitle *4-14* appears below the title on each page.

```
cc -c -Fs -Fa -St"Calc Prog" -Ss"count" ct.c -Ss"sort" srt.c
```

In this command, **cc** compiles two source files and creates two source list ings. Each source listing has a unique subtitle, but both listings have th title *Calc Prog.*

Formats for Listings

The rest of this section describes and shows examples of the five types o listings available with the **cc** command. For information on how to creat these listings, see "Types of Listings" earlier in this section.

Source Listing

Source listings are helpful for debugging programs as they are being de veloped. These listings are also useful for documenting the structure of finished program.

The source listing contains the numbered source-code lines of each pro cedure in the source file, along with any diagnostic messages that wer generated. If the source file compiles with no errors more serious tha warning errors, the source listing also includes tables of local symbol global symbols, and parameter symbols for each function. If the compile is unable to finish compilation, it does not generate symbol tables.

At the end of the source listing is a summary of the segment sizes in you program. This summary is useful for analyzing the program's memor requirements.

Any error messages that occurred during compilation appear in the listing after the line that caused the error, as shown in the following example:

```
 1  char hexvalue[10];
 2
 3  main()
 4  {
 5    long htoi();
 6    printf("Please enter the hex value you want to convert:\n");
 7    scanf("%s", hexvalue);
 8    printf("The integer value of the hex value is %ld\n", htoi(hexvalue));
 9  }
10
11   long htoi(hexvalue)
12   char *hexvalue;
13   {
14       register char *ptr=hexvalue;
15       int i=0;
16       long n=0;
17       long exp16();
18       while (*ptr != '\0') {
19        if (*ptr >= 'a' && *ptr <= 'f')
20                *ptr -= 87;
21        else if (*ptr >= 'A' && *ptr <= 'F')
22                  *ptr -= 55;
23               else
24                     *ptr -= 48;
25        ptr+;
 bomb.c(25) : error C2059: syntax error : ';'
26       }
```

The line number given in the error message corresponds to the number of the source line immediately above the message in the source listing.

The following example shows the source listing for a simple C program:

```
Hex to ASCII                                                    PAGE  1
2/25/87                                                         02-25-87
                                                                10:44:23
 Line#  Source Line                C Optimizing Compiler Version 5.10
 1  char hexvalue[10];
 2
 3  main()
 4  {
 5    long htoi();
 6    printf("Please enter the hex value you want to convert:0);
 7    scanf("%s", hexvalue);
 8    printf("The integer value of the hex value is %ld0, htoi(hexvalue));
 9  }
10
11   long htoi(hexvalue)
12   char *hexvalue;
13   {
14       register char *ptr=hexvalue;
15       int i=0;
16       long n=0;
17       long exp16();
18       while (*ptr != ' ') {
19        if (*ptr >= 'a' && *ptr <= 'f')
20                    *ptr -= 87;
21        else if (*ptr >= 'A' && *ptr <= 'F')
22                     *ptr -= 55;
24                       *ptr -= 48;
25        ptr++;
26       }
27       ptr -= 1;
28       while (ptr>=hexvalue)
29          {
30     n+= (*ptr*exp16(i));
31           i++;
32           ptr--; 33          }
34       return(n);
35   }
 htoi  Local Symbols
Name     Class   Type      Size   Offset  Register
i . . . . . auto                          -0008
ptr . . . . . auto                        ***       si
n . . . . . auto                          -0004
hexvalue. . . . . param                    0004
 36
 37   long exp16(exp)
 38   int exp;
 39   {
 40           long result=1;
 41    int j;
 42    for (j=1; j<=exp; j++)
 43          result *= 16;
 44    return(result);
 45 }
```

```
Hex to A
2/25/87                                                    02-25-87
                                                           10:44:23

                              C Optimizing Compiler Version 5.10

exp16  Local Symbols

Name                    Class   Type        Size    Offset  Register

j . . . . . . . . . . . auto                        -0006
result. . . . . . . . . auto                        -0004
exp . . . . . . . . . . param                        0004


Global Symbols

Name                  Class   Type                Size    Offset

exp16 . . . . . . . . global  near function       ***      00ae
hexvalue. . . . . . . common  struct/array         10       ***
htoi. . . . . . . . . global  near function       ***      0038
main. . . . . . . . . global  near function       ***      0000
printf. . . . . . . . extern  near function       ***      ***
scanf . . . . . . . . extern  near function       ***      ***

Code size = 00e8 (232)
Data size = 005f (95)
Bss size  = 0000 (0)

No errors detected
```

At the end of each function, a table of local symbols is given, as shown in the following example for the function *htoi*:

```
htoi  Local Symbols

Name                    Class   Type        Size    Offset  Register

i . . . . . . . . . . . auto                        -0008
ptr . . . . . . . . . . auto                        ***       si
n . . . . . . . . . . . auto                        -0004
hexvalue. . . . . . . . param                        0004
```

The following list shows the contents of each column in the symbol table:

Column Contents

Name The name of each local symbol in the function.

Class Either *auto* if the symbol is a nonstatic local variable, or *param* if the symbol is a formal parameter.

Offset The symbol's offset address relative to the frame pointer (that is, the **BP** register). The *Offset* number is positive for *param* symbols and negative for *auto* symbols with **auto** storage class.

Register Blank unless the variable is stored in a register, in which case, this column indicates the register (**SI** or **DI**).

At the end of the source code, a table of global symbols is given, as shown in the following example:

```
Name                 Class   Type              Size   Offset

expl6 . . . . . . . global  near function      ***    00ae
hexvalue. . . . . . common  struct/array        10     ***
htoi. . . . . . . . global  near function      ***    0038
main. . . . . . . . global  near function      ***    0000
printf. . . . . . . extern  near function      ***     ***
scanf . . . . . . . extern  near function      ***     ***
```

The following list shows the contents of each column:

Column Contents

Name Each global symbol, external symbol, and statically allocated variable declared in the source file.

Class Either *global*, *common*, *extern*, or *static*, depending on how the symbol was defined in the source file.

Type A simplified version of the symbol's type as declared in the source file.

For functions, this entry is either *near function* or *far function*, depending on which memory model was used and how the function was declared. For a pointer, this entry is *near pointer*, *far pointer*, or *huge pointer*. For enumeration variables, this entry is *int*. For structures, unions, and arrays, this entry is *struct/array*.

Size Used only for variables. Specifies the number of bytes of storage allocated for the variable. Since the amount of storage allocated for an external array may not be known, its *Size* entry may be undefined.

Offset Used only for symbols with an entry of *global* or *static* in the *Class* column.

For variables, this entry gives the relative offset of the variable's storage in the logical data segment for the program file being compiled. Since the linker usually combines several logical data segments into a physical segment, this number is useful only for determining the relative position of storage of variables. For functions, this entry gives the relative offset of the start of the function in the logical code segment. For small-model programs, the linker combines logical code into a single physical segment, so this entry is useful for determining the relative positions of different functions defined in the same source file. However, for medium-, large-, and huge-model programs, each logical code segment becomes a unique physical segment. In these cases, this entry gives the actual offset of the function in its run-time code segment.

The last table in the source listing shows the segments used and their size, as in the following example:

```
Code size = 0103 (259)
Data size = 005f (95)
Bss size  = 0000 (0)
```

The number of bytes in each segment is given first in hexadecimal, and then in decimal (in parentheses).

Object Listing

The **-Fl** option produces an object listing. The object listing contains the instruction encoding and assembly code for your program. The line numbers are shown in the listing as comments. The instruction encoding is on the left and the assembly code on the right, as shown in the following example:

```
; Line 4
        PUBLIC _main
_main   PROC NEAR
        *** 000000   55                 push bp
        *** 000001   8b ec          mov  bp,sp
        *** 000003   33 c0          xor  ax,ax
        *** 000005   e8 00 00             call __chkstk
; Line 6
        *** 000008   b8 00 00             mov  ax,OFFSET DGROUP:$S G12
        *** 00000b   50                   push ax
        *** 00000c   e8 00 00             call _printf
        *** 00000f   83 c4 02             add  sp,2
```


Assembly Listing

The **-Fa** and **-S** options produce an assembly listing using directives suitable for assembly using the Macro Assembler, **masm**. It contains the assembly code corresponding to your C source file, as shown in the following example:

```
; Line 4
        PUBLIC _main
_main   PROC NEAR
        push   bp
        mov    bp,sp
        xor    ax,ax
        call   __chkstk
; Line 6
        mov    ax,OFFSET DGROUP:$SG12
        push   ax
        call   _printf
        add    sp,2
```

Note that the example shows the same code as in the object listing example, except that the instruction encoding is omitted.

The listing generated by the **-Fa** option in Versions 5.0 and later of the C Compiler can be used as input to **masm**.

Combined Source and Object Listing

The **-Fc** option produces a combined source and object listing. This shows each line of your source program followed by the corresponding line (or lines) of machine instructions, as shown in the following example:

```
_TEXT      SEGMENT
;|*** char hexvalue[10];
;|***
;|*** main()
;|*** {
; Line 4
      PUBLIC _main
_main PROC NEAR
      *** 000000   55                push bp
      *** 000001   8b ec        mov  bp,sp
      *** 000003   33 c0        xor  ax,ax
      *** 000005   e8 00 00           call __chkstk
;|***   long htoi();
;|***   printf("Please enter the hex value you want to convert:0);
; Line 6
      *** 000008   b8 00 00           mov  ax,OFFSET DGROUP:$SG12
      *** 00000b   50                 push ax
      *** 00000c   e8 00 00           call _printf
      *** 00000f   83 c4 02           add  sp,2
;|***   scanf("%s", hexvalue);
```

Note that this sample is like the object-listing sample, except that the source-program line is provided in addition to the line number.

When you examine a listing file, you will notice that the names of globally visible functions and variables begin with an underscore, as shown in the following example. This part of the listing is the same for all three kinds of listings:

```
EXTRN _printf:NEAR
EXTRN _scanf:NEAR
EXTRN __chkstk:NEAR
EXTRN __aNlmul:NEAR
EXTRN __aNNalshl:NEAR
EXTRN _hexvalue:TBYTE
```

The C Compiler automatically prefixes an underscore to all global names. If you write assembly-language routines to interface with your C program, this naming convention is important; see the section on "Controlling the Preprocessor" for more information.

The listing may also contain names that begin with more than one underscore (for example, *__chkstk*). Identifiers with more than one leading underscore are reserved for internal use by the compiler, and should not be used in your programs, except for those documented in the *C Library Guide*. Moreover, you should avoid creating global names that begin

with an underscore. Since the compiler automatically adds another leading underscore, these names will have two leading underscores and might conflict with the names reserved by the compiler.

Listing Pragmas

There are several pragmas that allow you to control the page formatting of the listings produced with the various list options. These pragmas are:

Pragma	Action
linesize	Sets the number of characters per line in the source listing.
page	Places a formfeed character(s) in the source listing.
pagesize	Sets the number of lines per page in the source listing.
skip	Skips the specified number of lines in the source listing.
subtitle	Specifies a subtitle for the source listing.
title	Specifies a title for the source listing.

The remainder of this section discusses each of the preceding pragmas.

The linesize Pragma

The **linesize** pragma sets the number of characters per line in the source listing. The syntax of this pragma is:

```
#pragma linesize([characters])
```

In this syntax, the optional parameter *characters* is an integer constant in the range 79-132 that specifies the number of characters you wish each line of the source listing to have. If *characters* is absent, the compiler uses the value specified in the **-Sl** option or, if that option is absent, the default value of 79 characters per line. Note that **linesize** takes effect in the line *after* the line in which the pragma itself appears.

The following example uses the pragma to produce a source listing with a 132-character line length:

```
#pragma linesize(132)
```

The page Pragma

The **page** pragma generates a formfeed (page eject) character in the source listing at the place where the pragma appears. The pragma has the following syntax:

```
#pragma page([pages])
```

The optional parameter *pages* is an integer constant in the range 1-127 that specifies the number of pages to eject. If *pages* is absent, the pragma uses a default value of 1, in which case the next line in the source file appears at the top of the next listing page.

The pagesize Pragma

The **pagesize** pragma sets the number of lines per page in the source listing. The pragma has the following syntax:

```
#pragma pagesize([lines])
```

The optional parameter *lines* is an integer constant in the range 15-255 that specifies the number of lines that you wish each page of the source listing to have. If this parameter is absent, the pragma sets the page size to the number of lines specified in the **-Sp** command-line option or, if that option is absent, to a default value of 63 lines.

The following example uses the pagesize pragma to set the number of lines per page of the source listing to 66 lines:

```
#pragma pagesize(66)
```

The skip Pragma

The **skip** pragma generates a newline (carriage return/line feed) in the source listing, at the point where the pragma appears. The pragma has the following syntax:

```
#pragma skip([lines])
```

The optional parameter *lines* is an integer constant in the range 1-127 that specifies the number of lines that you wish to skip. If this parameter is absent, **skip** defaults to one line.

The subtitle Pragma

The **subtitle** pragma sets a subtitle in the source listing. The pragma has the following syntax:


```
#pragma subtitle(subtitlename)
```

The required parameter *subtitlename* is a string literal containing the subtitle for subsequent pages in the source listing. The subtitle appears below the title on each page of the listing.

If you supply a null string ("") as the *subtitlename* parameter, **subtitle** removes any subtitle that was previously set. The **subtitlename** parameter can be a macro that expands to a string literal, and you can concatenate such macros with string literals in any combination.

The following statement sets the subtitle to *Error handler* for subsequent pages in the source listing:

```
#pragma subtitle("Error handler")
```

The title Pragma

The **title** pragma sets a title for the source listing. The pragma has the following syntax:

```
#pragma title(titlename)
```

The required parameter *titlename* is a string literal containing the title for the source listing. The title appears in the upper left corner of each page of the listing.

If you supply a null string ("") as the *titlename* parameter, **title** removes any title that was previously set. The **titlename** parameter can be a macro that expands to a string literal, and you can concatenate such macros with string literals in any combination.

The following statement sets the title to *File I/O Module* in the source listing:

```
#pragma subtitle("File I/O Module")
```

Map File

The **-Fm** option produces a map file. The map file contains a list of segments in order of their appearance within the load module. As an example, consider the following:

```
Start  Stop   Length Name                    Class
00000H 01E9FH 01EA0H _TEXT                   CODE
01EA0H 01EA0H 00000H C_ETEXT                 ENDCODE
.
.
.
```


The information in the *Start* and *Stop* columns shows the 20-bit address (in hexadecimal) of each segment, relative to the beginning of the load module. The load module begins at location zero. The *Length* column gives the length of the segment in bytes, the *Name* column gives the name of the segment, and the *Class* column gives information about the segment type.

The starting address and name of each group appear after the list of segments. An example of a group listing follows:

```
Origin   Group
01EA:0   DGROUP
```

In this example, **DGROUP** is the name of the data group. **DGROUP** is the only group used for data segments by programs compiled with the C Compiler, Version 5.1.

The following map file contains two lists of global symbols: the first list is sorted in ASCII-character order by symbol name and the second is by symbol address. A maximum of 2048 symbols can be sorted in each list. (To increase the number of sorted symbols, you must specify the **-MAP** linker option with the *number* argument to create the map file; see the "Linking with the cc Command" chapter of this guide for details.) The notation *Abs* appears next to the names of absolute symbols (symbols containing 16-bit constant values that are not associated with program addresses).

Many of the global symbols that appear in the map file are symbols used internally by the C Compiler. These usually begin with one or more leading underscores or end with *QQ*.

```
Address         Publics by Name

003F:0096       STKHQQ
0047:1D86       _brkctl
003F:04B0       _edata
0047:0910       _end
.
.
.
0047:00EC       __abrkp
0047:009C       __abrktb
0047:00EC       __abrktbe
003F:9876  Abs  __acrtmsg
0000:9876  Abs  __acrtused
.
.
.
0047:0240       ___argc
0047:0242       ___argv

Address         Publics by Value

003F:0010       _main
003F:0047       _htoi
003F:00DA       _expl6
003F:0113       __chkstk
003F:0129       __astart
003F:01C5       __cintDIV
.
.
.
```

The addresses of the external symbols are in the "*selector*:*offset*" format showing the location of the symbol relative to zero (the beginning of the load module).

Following the lists of symbols, the map file gives the program entry point as shown in the following example:

```
Program entry point at 003F:0129
```

Controlling the Preprocessor

The **cc** command provides several options that control the operation of the C preprocessor. You can define macros and manifest (symbolic) constants from the command line, change the search path for include files and stop compilation of a source file after the preprocessing stage to produce a preprocessed source-file listing.

The C preprocessor recognizes only preprocessor directives. It treats the source file as a text file, processing substitutions and definitions as directed. The preprocessor can be run on a file at any stage of development, whether or not the file is a complete C source file. In fact, the preprocessor is not restricted to processing C files; it can be run on any kind of file. However, input files to the preprocessor must follow the preprocessor rules; therefore, not all arbitrary text files may be suitable for use with the preprocessor. See the *C Language Reference* for a complete discussion of C preprocessor directives and the format expected for preprocessor input.

Defining Constants and Macros (-D)

Option

-D *identifier*[=[*string*]]

The **-D** option lets you define a constant or macro used in your source file. The *identifier* is the name of the constant or macro and *string* is its value or meaning. Note that spaces are permitted (but not required) between **-D** and the identifier.

If you leave out both the equal sign and *string*, the given constant or macro is assumed to be defined, and its value is set to 1. For example, *-DSET* is sufficient to define *SET*.

If you give the equal sign with an empty string, the given constant or macro is considered defined; its definition is the empty string. This definition effectively removes all occurrences of the identifier from the source file. For example, to remove all occurrences of *register*, use the following option:

-Dregister=

Note that the identifier *register* is still considered to be defined.

The effect of using the **-D** option is the same as using a preprocessor **#define** directive at the beginning of your source file. The identifier is defined in the source file being compiled either until an **#undef** directive removes the definition or until the end of the file is reached.

You can supply a command-line definition for an identifier that is also defined within the source file. However, you must use **#undef** to remove the source-file definition, unless the source-file definition is identical to the command-line definition. The command-line definition remains in effect until the identifier is removed with an **#undef** directive.

The **-D** option is especially useful with the **#if** and **#ifdef** directives because you can control conditional-compilation directives in the source file from the command line.

Examples

cc -D NEED=2 main.c

This example defines the manifest constant *NEED* in the source file *main.c*. This definition is equivalent to placing the directive at the top of the source file as shown in the following example:

```
#define NEED 2
```

For the next example, suppose a source file named *other.c* contains the following fragment:

```
#if defined(NEED)
.
.
.
#endif
```

Suppose further that *other.c* does not explicitly define *NEED* (that is, no **#define** directive for *NEED* is present). Then all statements between the **#if** and the **#endif** directives are compiled only if you supply a definition of *NEED* by using *-D*. For instance, the following command is sufficient to compile all statements following the **#if** directive:

```
cc -DNEED main.c
```

Note that *NEED* does not have to be set to a specific value to be considered defined. The following command, in contrast, causes the statements in the **#if** block to be ignored (not compiled):

```
cc main.c
```

Predefined Identifiers (Manifest Defines)

The compiler defines several identifiers that are useful in writing portable programs. These are known as "manifest defines." You can use these identifiers to compile code sections conditionally, depending on the processor and operating system being used. They begin with "M_" for "manifest." The predefined identifiers and their functions are as follows:

Identifier	Function
M_I86	This is an Intel processor.
M_SYS3	This is Unix System III compatible.
M_SYS5	This is Unix System V compatible.
M_BITFIELDS	This compiler supports bitfields.
M_WORDSWAP	The word-within-a-longword order is swapped with respect to the DEC PDP-11.
M_UNIX	Always defined, this identifies the target operating system as an implementation of UNIX System V.
M_I*n*86	Depending on **-M0**, **-M1**, **-M2**, or **-M3**, **M_I386** is defined with 386 compiler unless **-dos** is used.
M_I86*m***M**	Always defined, this identifies the memory model, where *m* is either **S** (small model), **C** (compact model), **M** (medium model), **L** (large model), or **H** (huge model). If huge model is used, both **M_I86LM** and **M_I86HM** are defined. Small model is the default. Memory models are discussed in the "Working with Memory Models" chapter.
_CHAR_UNSIGNED	This is defined only when the **-J** option is given to make the **char** type unsigned by default. For more information, see the section on "Changing the Default char Type."
M_SDATA or **M_LDATA** **M_STEXT** or **M_LTEXT**	Depending on **-M0**, **-M1**, or **-M2**.

Removing Definitions of Predefined Identifiers (-U, -u)

Options

-U *identifier*
-u

The **-U** (for "undefine") option turns off the definition of one of the predefined identifiers discussed in the previous section. One or more spaces may separate the **-U** and *identifier*. You can specify more than one **-U** option on the same command line. The **-u** option turns off all definitions.

Example

```
cc -UM_UNIX -UM_I86 work.c
```

This example removes the definitions of two predefined identifiers. Note that the **-U** option must be given for each removal.

Producing a Preprocessed Listing (-P, -E, -EP)

Options

-P	Writes preprocessed output to a file
-E	Writes preprocessed output to standard output; includes **#line** directives
-EP	Writes preprocessed output to a file and standard output

The **-P**, **-E**, and **-EP** options produce listings of preprocessed files. These options allow you to examine the output of the C preprocessor.

The preprocessed listing file is identical to the original source file except that all preprocessor directives are carried out, macro expansions are performed, and comments are removed. All three options suppress compilation. No object file or listing is produced, even if you specify the **-Fo** option or a listing-file option on the **cc** command line.

The **-P** option writes the preprocessed listing to a file with the same base name as the source file, but with a **.i** extension.

The **-E** option copies the preprocessed listing to the standard output (usually your terminal). It places a **#line** directive in the output at the

beginning and end of each included file and around lines removed by preprocessor commands that specify conditional compilation.

The **-E** option is useful when you want to resubmit the preprocessed listing for compilation. The **#line** directives renumber the lines of the preprocessed file, so that errors generated in later stages of processing refer to the original source file rather than to the preprocessed file.

The **-EP** option combines features of the **-E** and **-P** options; the file is preprocessed and copied both to a new file and to the standard output, but no **#line** directives are added.

Examples

```
cc -P main.c
```

This example creates the preprocessed file *main.i* from the source file *main.c*.

```
cc -E add.c > preadd.c
```

This command creates a preprocessed file with inserted **#line** directives from the source file *add.c*. The output is redirected to the file *preadd.c*.

```
cc -EP add.c
```

The command shown here produces the same preprocessed output as the second example, but without the **#line** directives. The output appears on the screen and is copied to a new file.

Preserving Comments (-C)

Option

-C

Normally, comments are stripped from a source file in the preprocessing stage, since they do not serve any purpose in later stages of compiling. The **-C** (for "comment") option preserves comments during preprocessing. The **-C** option is valid only when the **-E**, **-P**, or **-EP** option is also used.

Example

```
cc -P -C sample.c
```

The example produces a listing named *sample.i*. The listing file contains the original source file, including comments, with all preprocessor directives expanded or replaced.

Searching for Include Files (-I, -X)

Options

-I *directory*
-X

The **-I** and **-X** options temporarily override the default search paths for include files. (The default path is */usr/include*.)

You can add to the list of directories searched by using the **-I** (for "include") option. This option causes the compiler to search the directory or directories you specify before searching the default path */usr/include*. The space between **-I** and *directory* is optional. You can add more than one include directory by giving the **-I** option more than once in the **cc** command. The directories are searched in order of their appearance in the command line.

The directories are searched only until the specified include file is found. If the file is not found in the given directories or the standard places, the compiler prints an error message and stops processing. When this occurs, you must restart compilation with a corrected directory specification.

You can prevent the C compiler from searching the default paths for include files by using the **-X** (for "exclude") option. When **cc** sees the **-X** option, it considers the list of standard places to be empty. This option is often used with the **-I** option to define the location of include files that have the same names as include files found in other directories, but that contain different definitions.

Examples

```
cc -I /include -I/alt/include  main.c
```

In this example, **cc** looks for the include files requested by *main.c* in the following order: first in the directory */include*, then in the directory */alt/include*, and finally in the default directory */usr/include*.

```
cc -X -I /alt/include main.c
```

As shown in this example, the compiler looks for include files only in the directory */alt/include*. First the **-X** option tells **cc** to consider the list of standard places empty; then the **-I** option specifies one directory to be searched.

Checking for Program Errors

You may encounter several different kinds of error messages when you compile, link, and run a C program.

Several **cc** options are available to control the types of warnings generated at compile time, help with syntax checking, and verify compatibility between the actual arguments and formal parameters of a function during the early stages of program development. This section describes these options.

Understanding Error Messages

Error messages can appear at different stages of program development:

- In the compiling stage, the compiler generates a broad range of error and warning messages to help you locate errors and potential problems in your source files.
- During the linking stage, the linker is responsible for generating error messages.
- During program execution, any error messages you see are run-time error messages. This category includes messages about core dumps, segmentation violations, and floating-point exceptions, which are errors generated by an 8087, 80287, or 80387 coprocessor.

Other utilities included in this package, such as the UNIX System V Link Editor (**ld**), and the **make** program-maintenance utility, generate their own error messages.

When you are compiling and linking using the **cc** command, you may see both compiler and linker messages. Compiler messages have numbers preceded by the letter *C*, and linker messages have numbers preceded by the letter *L*.

You can also distinguish the type of a message by its format. See the "Error Messages and Exit Codes" appendix in this guide for a description of compiler error-message formats, a list of actual compiler error messages, and explanations of the circumstances that cause them.

Compiler error messages are sent to the standard output, which is usually your terminal. If you are using the C-shell, you can redirect the messages to a file by using the standard redirection symbols at the end of your command line:

If you are using the Bourne shell, you can redirect the messages to a file by using the standard redirection syntax:

cmd > *outputfile* **2>&1**

Example

Assume the following source file is named *rm.c*:

```
#include <stdio.h>

main(argc, argv)
     int argc;
     char argv[];

     {
     register int i;
     char *name;

     for (i = 1; i < arg; ++i)
          if (unlink(name = argv[i])) {
               printf("couldn't delete %s : ", name);
               perror("");
               }
     }
```

The following C-shell command line redirects error messages to a file named *rm.err*:

```
cc rm.c >& rm.err
```

In the previous command, only output that ordinarily goes to the console screen is redirected. The error-message file *rm.err* contains the following information:

```
rm.c(11): error C2065: 'arg' : undefined
rm.c(12): warning C4047: '=' : different levels of indirection
```

Based on the errors generated, you can correct *rm.c* as shown below:

```
#include <stdio.h>

main(argc, argv)
     int argc;
     char *argv[];              /* corrects warning C4047 */

     {
     register int i;
     char *name;

     for (i = 1; i < argc; ++i)  /* corrects error C2065 */
          if (unlink(name = argv[i])) {
               printf("couldn't delete %s : ", name);
               perror("");
               }
     }
```


Setting the Warning Level (-W, -w)

Option

-W{0|1|2|3}
-w

You can suppress warning messages produced by the compiler by using the **-W** (for "warning") option. Compiler warning messages are any messages beginning with *C4*; see the "Error Messages and Exit Codes," appendix for a full listing. Warnings indicate potential problems (rather than actual errors) with statements that may not be compiled as you intend. The **-W** options affect only source files given on the command line, they do not apply to object files.

The **-W0** option turns off warning messages. This option is useful when you compile programs that deliberately include questionable statements. The **-W0** option applies to the remainder of the command line or until the next **-W** option on the command line. The **-w** option has the same effect as the **-W0** option.

The **-W1** option (the default) causes the compiler to display most warning messages.

The **-W2** option causes the compiler to display an intermediate level of warning messages. Level 2 warnings may or may not indicate serious problems. They include the following:

- Use of functions with no declared return type
- Failure to put **return** statements in functions with non-**void** return types
- Data conversions that would cause loss of data or precision

The **-W3** option displays the highest level of warning messages, including warnings about the uses of non-ANSI features and extended keywords and about function calls before the appearance of function prototypes in the program.

Note that the warning messages in the "Error Messages and Exit Codes" appendix indicate the warning level that must be set (that is, the number for the appropriate **-W** option) for the message to appear.

Example

```
cc -W3 crunch.c print.c
```

This example enables all possible warning messages when the *crunch.c* and *print.c* source files are compiled.

Checking Syntax (-Zs)

Option

-Zs

The **-Zs** option causes the compiler to perform only a syntax check on the source files that follow the option on the command line. This option provides a quick way to find and correct syntax errors before you try to compile and link a source file.

When you give the **-Zs** option, the compiler does not generate code or produce object files, object listings, or executable files. However, the compiler does display error messages if the source file has syntax errors. You can specify the **-Fs** option on the same command line to generate a source listing that shows these error messages. For more information about the **-Fs** option, see the section on "Types of Listings."

Example

```
cc -Zs test*.c
```

This command causes the compiler to perform a syntax check on all source files in the current working directory that begin with *test* and end with the default extension (**.c**). The compiler displays messages for any errors found.

Generating Function Declarations (-Zg)

Option

-Zg

The **-Zg** option generates a function declaration for each function defined in the source file. You can use the -Zg option with multiple source files. The function declaration includes the function return type and an argument type list created from the types of the formal parameters of the function. Any function declarations already encountered are ignored.

The generated list of declarations is written to the standard output. It can be saved in a file using shell redirection.

When the **-Zg** option is used, the source file is not compiled. As a result, no object file or listing is produced.

The list of declarations is helpful for verifying that actual arguments and formal parameters of a function are compatible. You can save the list and include it in your source file to cause the compiler to perform type-checking. The presence of a declared argument-type list for a function "turns on" the compiler's type-checking between actual arguments to a function (given in the function call) and the formal parameters of a function.

This type-checking can be a helpful feature in writing and debugging C programs, especially when working with older C programs. Argument type-checking is a recent addition to the C language, so many existing C programs will not have argument-type lists. See the *C Language Reference* for more information about function declarations and argument-type lists.

You can use the **-Zg** option even if your source program already contain some function declarations. The compiler accepts more than one occur rence of a function declaration, as long as the declarations do not conflict No conflict occurs when one declaration has an argument-type list an another declaration of the same function does not, as long as the retur types are identical.

Note

If you use the **-Zg** option and your program contains formal parameters that have structure, enumeration, or union type (or pointers to such types), then the declaration for each structure, enumeration, or union type must have a tag. For example, use the following form:

```
struct tagA {
          .
          .
          .
     } A;
```

Example

```
cc -Zg file.c > filedecls.h
```

This command causes the compiler to generate argument-type lists fc functions defined in *file.c*. The list of declarations is redirected t *filedecls.h*.

Preparing for Debugging (-Zi, -Od)

Options

-Zi Creates object file for use with the source-level debugger, **sdb and CodeView**

-Od Disables code optimization to help with debugging

The **-Zi** option produces an object file containing full symbolic debugging information for use with the source-level debugger. Thi object file includes full symbol-table information and line numbers. If th **-Zi** option is given with no explicit **-O** options, all optimizations involv ing code motion and rearrangement are suppressed, although simpl optimizations are still performed. If any explicit **-O** options are given, *a* requested optimizations are performed.

The **-Od** option tells the compiler not to perform most optimizations. Some peephole optimizations and other simple optimizations are still performed. (Without the **-Od** option, the default is to optimize.) You may want to use this option when you plan to use a symbolic debugger with your object file, since optimization can involve rearrangement of instructions that make it difficult for you to recognize and correct your code when debugging. However, turning off optimizations may increase the size of the code generated to the point where it might not be possible to link your program.

Other optimization options are discussed in the section on "Optimizing."

Example

```
cc -Zi -Od test.c
```

This command produces an object file named *test.o* that contains line numbers corresponding to the line numbers of *test.c*. A source-listing file *test.lst* is also created. Limited optimization is performed.

Optimizing

The optimizing capabilities available with the C Compiler can reduce the storage space or execution time required for a program. This is achieved by eliminating unnecessary instructions and rearranging code. The compiler performs some optimizations by default. You can use the **-O** options, the **loop_opt** pragma (described in the section on "Loop Optimization"), the **intrinsic** pragma, and the **function** pragma (described in the section "Generating Intrinsic Functions") to exercise greater control over the optimizations performed. In addition, you can use the **-Gs** option or **check_stack** pragma to reduce program size and speed up execution.

Controlling Optimization (-O Options)

Option

-O*string*
#pragma loop_opt([on|off])
#pragma intrinsic(*function1***[,***function2***]...)**
#pragma function(*function1***[,***function2***]...)**

The **-O** options give you control over the optimization procedures that the compiler performs. One or more of the letters in *string* following the **-O** let you choose how the compiler performs optimization:

Letter	Optimizing Procedure
none	Performs optimization equivalent to **-Oct**
a	Relaxes alias-checking
c	Eliminates common expressions
d	Disables optimization
i	Expands certain intrinsic functions inline
l	Enables loop optimization
p	Improves consistency of floating-point results
s	Favors code size during optimization
t	Favors execution speed during optimization
x	Maximizes optimization (equivalent to **-Oatcli**)

The letters can appear in any order; for example, **-Oat** and **-Ota** have the same effect. More than one **-O** option can be given; the compiler uses the last **-O** option given if any conflict arises. Each option applies to all source files following that option on the command line.

The following sections discuss the various optimization options and their effects.

Relaxing Alias Checking (-Oa)

The **a** option letter can be used with the **l**, **s**, or **t** option letter to relax the assumptions the compiler makes about the use of "aliases" in the program. Aliases are multiple names (that is, symbolic references) for the same memory location in a program. Most commonly, aliases occur as a result of code similar to that shown in the following example:

```
func()
{
int  x, *p;

p = &x;    /* now "x" and "*p" refer to the same */
          /* memory location                    */
.
.
.
}
```


Use of the **-Oa** option can reduce the size of executable files and speed program execution. Its use is especially recommended when you also specify the **-Ol** option, since the compiler can detect a number of loop optimizations when the **-Oa** option is in effect that it cannot detect when **-Oa** is not in effect. However, before you specify **-Oa**, you must make sure that your program does not use aliases either directly or indirectly.

Note

Exercise caution when using the **-Od** option, because responsibility for alias checking is trasferred to the programmer from the compiler.

The use of aliases is important only if both names are actually used to reference the memory location. The following example illustrates the use of aliases:

```
func()
{
        int  x, *p;

        p = &x;

        .
        .
        .
/* ...expressions involving only *p */
        .
        .
        .
}
```

Since all access to the memory location labeled *x* is through the pointer *p*, *x* has no significance in the function. To illustrate, *func* could be rewritten as the following pair of functions:

```
func1()
{
        int  x;

        func2(&x);
}

func2(p)

int  *p;
{
        .
        .
        .
/*  ...expressions involving *p  */
          .
          .
          .
}
```

In this equivalent form, the alias created in *func1* is insignificant, since the memory location is not referenced at all and *func2* does not use aliases since *x* is not even in the scope of the function. The **-Oa** option can be safely specified in compiling either of these equivalent forms.

In addition to the obvious cases discussed above, aliases can be created through the use of pointers in other, more subtle ways. Two such cases involving the use of pointers as function arguments are illustrated in the following example:

```
int  x;

func(p)

int  *p;
{
       .
       .
       .
/*  ...expressions involving *p and x  */
       .
       .
       .
}
```


In this example, *x* is a communal variable, so the function can be called with *func(&x)*. The **-Oa** option can be used safely only if it is known that *func* is never invoked with the address of *x* as an argument.

```
func(p1, p2)

int *p1, *p2;
{
       .
       .
       .
/* ...expressions involving *p1 and *p2 */
       .
       .
       .
}
```

In this example, the function may be invoked with the same value for both arguments (that is, *func(p,p)* or *func(&x,&x)*). Thus, the **-Oa** option can be safely specified only if it is known that the function is always called with distinct values for the two arguments.

One use of aliases occurs so frequently that a special provision has been made for it. When the compiler encounters a call to a function with address-type arguments, it always assumes that all variables whose addresses are passed to the function are modified. If such function calls appear in a program, the **-Oa** option can be specified safely even though the function call results in an alias for each variable whose address is passed. The following example illustrates how the compiler handles this case:

```
func1()
{
        int  x, y, a, b;
        .
        .
        .
        x = a + b;

func2(&a);

        y = a + b;
}
```


As shown, when the compiler encounters the function call *func2(&a)*, it assumes that the function modifies *a*, even if the **-Oa** option has been specified. The compiler generates code to evaluate each instance of the expression *a + b*, rather than eliminating a common subexpression incorrectly.

Although you should convert programs that use aliases if you plan to compile them with the **-Oa** option, it is helpful to know the units of a program where the optimizations affected by the use of **-Oa** are applied. This information indicates where the uses of aliases are most likely to cause incorrect optimizations if **-Oa** is specified. The following list describes the program units where such optimizations are performed:

- All of the C optimizations, except for loop optimizations, that may be affected by the incorrect use of **-Oa** are applied at the level of basic blocks. In the C Compiler, the **-Oa** option can generally be used even if aliases are employed, provided no memory location is referenced by more than one name within any basic block. (A "basic block" is a contiguous sequence of statements, with a unique entry point and exit point and no branching in between. In C programs, basic blocks most often appear as the clauses of **if** statements, **switch** statements, loop bodies, or function bodies, although they may also occur as sequences of statements delimited by user labels.)

- Loop optimizations are applied at the level of whole loop bodies. Thus, if loop optimization is enabled, **-Oa** can generally be used even if aliases are employed, provided that no memory location is referenced by more than one name within any basic block or loop body.

Disabling Optimization (-Od)

The **-Od** option turns off most optimizations. This is useful in the early stages of program development to avoid optimizing code that will later be changed. Because optimization may involve rearrangement of instructions, you may also want to specify the **-Od** option when you use a debugger with your program or when you want to examine an object-file listing. If you optimize before debugging, it can be difficult to recognize and correct your code. However, note that turning off or restricting optimization of a program usually increases the size of the generated code. If your program contains a module that is close to the 64K limit on compiled code, turning off optimization may cause the module to exceed the limit.

Generating Intrinsic Functions (-Oi)

The **-Oi** option tells the compiler to generate intrinsic functions instead of function calls for certain functions. Intrinsic functions may be in-line functions, may use special argument-passing conventions, or (in some cases) may do nothing. Programs that use intrinsic functions are faster because they do not include the overhead associated with function calls. However, they may be larger because of the additional code that is generated.

The following functions have intrinsic forms:

- **memset**, **memcpy**, and **memcmp**
- **strset**, **strcpy**, **strcmp**, and **strcat**
- **outp**
- **_rotl**, **_rotr**, **_lrotl**, and **_lrotr**
- **min**, **max**, and **abs**

Note

Intrinsic versions of the **memset**, **memcpy**, and **memcmp** functions in compact- and large-model programs cannot handle huge arrays or huge pointers. To use huge arrays or huge pointers with these functions, you must compile your program with the huge memory model (that is, using the **-Mh** option on the command line).

You can use the **intrinsic** pragma to generate intrinsic functions only for selected functions. This pragma has the following format:

#pragma intrinsic (*function1* [,*function2*]...)

The **intrinsic** pragma affects the specified functions from the point where the pragma appears until either the end of the source file or the next **function** pragma specifying any of the same functions. The **function** pragma has the following format:

#pragma function (*function1* [,*function2*]...)

Note that you can also use the **function** pragma selectively to generate function calls instead of intrinsic functions when you compile a program with the **-Oi** option.

Loop Optimization (-Ol)

The **-Ol** option tells the compiler to perform loop optimizations. For best performance, the **-Ol** option should be specified along with the **a** option letter (**-Oal**), since the compiler can detect more loop optimizations when it relaxes its assumptions about the use of aliases.

You can use the **loop_opt** pragma to turn loop optimization on or off for selected functions. When you want to turn off loop optimization, put the following line before the code on which you don't want to perform loop optimization:

```
#pragma loop_opt (off)
```

Note that the preceding line disables loop optimization for all code that follows it in the source file, not just the routines on the same line. To reinstate loop optimization, insert the following line:

```
#pragma loop_opt (on)
```

If no argument is given to the **loop_opt** pragma, loop optimization reverts to the behavior specified on the command line: enabled if the **-Ox** or **-Ol** option is in effect, and disabled otherwise. The interaction of the **loop_opt** pragma with the **-Ol** and **-Ox** options is explained in greater detail in Table 2.5.

Table 2.5
Using the loop_opt Pragma

Syntax	Compiled with -Ox or -Ol?	Action
#pragma loop_opt()	no	Turns off optimization for loops that follow
#pragma loop_opt()	yes	Turns on optimization for loops that follow
#pragma loop_opt (on)	yes or no	Turns on optimization for loops that follow
#pragma loop_opt (off)	yes or no	Turns off optimization for loops that follow

Achieving Consistent Floating-Point Results (-Op)

The **-Op** option is useful when floating-point results must be consistent within a program. This option changes the way in which the program handles floating-point values.

Ordinarily the compiler stores each floating-point value in an 80-bit register. In subsequent references to that value, the compiler reads the value from the register. When the final value is written to memory, it is truncated, since floating-point types are allocated fewer than 80 bits of storage (32 bits for the **float** type and 64 bits for the **double** type). Thus, the value stored in the register may actually be more precise than the same value stored in a floating-point variable. Since the value is truncated each time it is written to memory, over the course of the program the value stored in the machine register may become quite different from the value that is written to memory.

If you use the **-Op** option, when floating-point values are referenced, the compiler reloads them from floating-point variables rather than from registers. Using **-Op** gives less precise results than using registers, and it may increase the size of the generated code. However, it gives you more control over the truncation (and hence the consistency) of floating-point values.

Optimizing for Speed and Code Size (-Ot, -Os)

When you do not give a **-O** option to the **cc** command, it automatically uses **-Ot**, meaning that program-execution speed is favored in the optimization. Wherever the compiler has a choice between producing smaller (but perhaps slower) and larger (but perhaps faster) code, the compiler generates faster code. For example, when the **-Ot** option is in effect, the compiler generates intrinsic functions to perform shift operations on long operands.

To cause the compiler to favor smaller code size instead, use the **-Os** option. For example, when the **-Os** option is in effect, the compiler uses function calls to perform shift operations on long operands.

Producing Maximum Optimization (-Ox)

The **-Ox** option is a shorthand way to combine optimizing options to produce the fastest possible program. Its effect is the same as using the following options on the same command line:

```
-Oatcli
```

That is, the **-Ox** option relaxes alias checking, generates all intrinsics for the functions listed in the section "Generating Intrinsic Functions," performs loop optimizations, favors execution time over code size, and removes stack probes. Note that the interactions between the **-Ox** option and the **loop_opt** pragma are the same as those described in Table 2.5. For more information about stack probes and ways of controlling their use, see the following section, "Removing Stack Probes."

Examples

```
cc -Oal file.c
```

This command tells the compiler to perform loop optimizations and relax alias-checking when it compiles *file.c*. The compiler favors program speed over program size, since the **-Ot** option is also specified by default.

```
cc -c -Os file.c
```

This command favors code size over execution speed when *file.c* is compiled.

```
cc -Od *.c
```

This command compiles and links all C source files with the default extension (**.c**) in the current directory and disables optimization. This command is most useful during the early stages of program development, since it improves compilation speed.

Removing Stack Probes (-Gs)

Options

-Gs
#pragma check_stack([on|off])

You can reduce the size of a program and speed up execution slightly by removing stack probes. You can do this either with the **-Gs** option or with the **check_stack** pragma.

A ''stack probe'' is a short routine called on entry to a function to verify that there is enough room in the program stack to allocate local variables required by the function. The stack probe routine is called at every function entry point. Ordinarily, the stack probe routine generates a stack overflow message when it determines that the required stack space is not available. When stack-checking is turned off, the stack probe routine is not called, and stack overflow can occur without being diagnosed (that is, no error message is printed).

Use the **-Gs** option when you want to turn off stack-checking for an entire module if you know that the program does not exceed the available stack space. For example, stack probes may not be needed for programs that make very few function calls, or that have only modest local variable requirements. In the absence of the **-Gs** option, stack-checking is on.

Use the **check_stack** pragma when you want to turn stack-checking on or off only for selected routines, leaving the default (as determined by the presence or absence of the **-Gs** option) for the rest. When you want to turn off stack-checking, put the following line before the definition of the function you don't want to check:

```
#pragma check_stack (off)
```

Note that the preceding line disables stack-checking for all routines that follow it in the source file, not just the routines on the same line. To reinstate stack-checking, insert the following line:

```
#pragma check_stack (on)
```

Note

For earlier versions of C, the **check_stack** pragma had a different format: **check_stack+** to enable stack-checking and **check_stack-** to disable stack-checking. Although the C Compiler still accepts this format, its use is discouraged, since it may not be supported in future versions.

If no argument is given for the **check_stack** pragma, stack-checking reverts to the behavior specified on the command line: disabled if the **-Gs** option is given, or enabled otherwise. The interaction of the **check_stack** pragma with the **-Gs** option is explained in greater detail in Table 2.6.

Table 2.6
Using the check_stack Pragma

Syntax	Compiled with -Gs Option?	Action
#pragma check_stack()	yes	Turns off stack-checking for routines that follow
#pragma check_stack()	no	Turns on stack-checking for routines that follow
#pragma check_stack(on)	yes or no	Turns on stack-checking for routines that follow
#pragma check_stack(off)	yes or no	Turns off stack-checking for routines that follow

Note

The **-Gs** option should be used with care. Although it can make programs smaller and faster, it may mean that the program will not be able to detect certain execution errors.

Example

```
cc -Oals -Gs file.c
```

This example optimizes the file *file.c* by removing stack probes with the **-Gs** option. The letters specified with the **-O** option tell the compiler to relax alias-checking (**a**), perform loop optimization (**l**), and favor code size over program speed (**s**). If you want stack-checking for only a few functions in *file.c*, you can use the **check_stack** pragma around the definitions of functions you want to check. Similarly, if you want to perform loop optimization on only a few functions in *file.c*, you can use the **loop_opt** pragma around the definitions of functions on which you want to perform loop optimization.

Enabling/Disabling Language Extensions (-Ze, -Za)

Option

-Ze Enables language extensions (default)
-Za Disables language extensions (strict ansi specifications)

The C Compiler is moving to support the ANSI C standard. In addition, it offers a number of features beyond those specified in the ANSI C standard. These additional features are enabled when the **-Ze** (default) option is in effect and disabled when the **-Za** option is in effect. They include the following:

- The **cdecl**, **far**, **fortran**, **huge**, **near**, and **pascal** keywords
- Use of casts to produce values, as in this example:

```
int *p;
((long *)p)++;
```

The preceding example could be rewritten to conform with ANSI C as shown here:

```
p = (int *)((char *)p + sizeof(long));
```

- Redefinitions of **extern** items as **static**, as follows:


```
extern int foo();
static int foo()
{}
```

- Use of trailing commas (,) without ellipses (,...) in function declarations to indicate variable-length argument lists, such as:

```
int printf(char *,);
```

- Benign **typedef** redefinitions within the same scope, like this:

```
typedef int INT;
typedef int INT;
```

- Use of mixed character and string constants in an initializer, for instance:

```
char arr[5] = {'a', 'b', "cde"};
```

- Use of bit fields with base types other than **unsigned int** or **signed int**

Use the **-Za** option if you will be porting your program to other environments. The **-Za** option tells the compiler to treat extended keywords as simple identifiers and disable the other extensions listed previously.

Packing Structure Members (-Zp)

Option

-Zp[{1|2|4}]
#pragma pack([{1|2|4}])

When storage is allocated for structures, structure members are ordinarily stored as follows:

- Items of type **char** or **unsigned char**, or arrays containing items of these types, are byte-aligned.

- Structures are word-aligned; structures of odd size are padded to an even number of bytes.

- All other types of structure members are word-aligned.

To conserve space, or to conform to existing data structures, you may want to store structures more or less compactly. The **-Zp** option and the **pack** pragma control how structure data are "packed" into memory.

Use the **-Zp** option when you want to specify the same packing for all structures in a module. When you give the **-Zp[***n***]** option, where *n* is 1, 2, or 4, each structure member after the first is stored on *n*-byte boundaries, depending on the option you choose. If you use the **-Zp** option without an argument, structure members are packed on 1-byte boundaries.

On some processors, the **-Zp** option may result in slower program execution because of the time required to unpack structure members when they are accessed. For example, on an 8086 processor, this option can reduce efficiency if members with **int** or **long** type are packed in such a way that they begin on odd-byte boundaries.

Use the **pack** pragma when you want to specify packing other than that specified on the command line for particular structures. Give the **pack(***n***)** pragma, where *n* is 1, 2, or 4, before structures that you want to pack differently. To reinstate the packing given on the command line, give the **pack()** pragma with no arguments.

Table 2.7 shows the interaction of the **-Zp** option with the **pack** pragma.

Table 2.7

Using the pack Pragma

Syntax	Compiled with -Zp Option?	Action
#pragma pack()	yes	Reverts to packing specified on the command line for structures that follow
#pragma pack()	no	Reverts to default packing for structures that follow

#pragma pack(*n*)	yes or no	Packs the following structures to the given byte boundary until changed or disabled

Example

```
cc -Zp prog.c
```

This command causes all structures in the program *prog.c* to be stored without extra space for alignment of members on **int** boundaries.

Setting the Stack Size (-F)

Option

-F *hexnum*

The **-F** option sets the size of the program stack. A space must separate the **-F** and *hexnum*. (This option applies only to the 286 compiler.)

The *hexnum* is a hexadecimal value representing the stack size in bytes. The value must be less than 0xFFFF hexadecimal (65,535 decimal).

If you do not specify this option, the start-up routine in the standard C library sets the default stack size to 2K.

If you get a stack-overflow message, you may need to increase the size of the stack. In contrast, if your program uses the stack very little, you may save some space by decreasing the stack size.

The **-F** option is a linking option that affects executable files only; it does not have any effect on source or object files.

Example

```
cc -F C00 *.o
```

This example sets the stack size to C00 hexadecimal (3K decimal) for the program created by linking all of the object files in the current working directory.

Restricting the Length of External Names (-nl)

Option

-nl *number*

The **cc** command allows you to restrict the length of external (public) names by using the **-nl** option. The *number* is an integer specifying the maximum number of significant characters in external names. The space between **-nl** and *number* is optional.

When you use the **-nl** option, the compiler considers only the first *number* characters of external names used in the program. The program may contain external names longer than *number* characters, but the extra characters are simply ignored.

The **-nl** option is typically used to conserve space or to aid in creating portable programs. The C Compiler imposes no restrictions on the length of external names (although it uses only the first 31 characters), but other compilers or linkers may produce errors when they encounter names longer than a predetermined limit.

Labeling the Object File (-V)

Option

-V *string*

Use the **-V** (for "version") option to embed a text string in an object file. The *string* must be enclosed in double quotation marks (" ") if it contains white-space characters or embedded double quotation marks. A backslash (\) must precede any embedded double quotation marks.

A typical use of the **-V** option is to label an object file with a version number or copyright notice.

Example

```
cc -V "C Compiler Version 5.1" main.c
```

This command places the following string in the object file *main.o*:

```
C Compiler Version 5.1
```

Changing the Default char Type (-J)

Option

-J

In C, the **char** type is signed by default, so if a **char** value is widened to **int** type, the result is sign-extended. You can change this default to **unsigned** with the **-J** option, causing the **char** type to be zero-extended when widened to **int** type. However, if a **char** value is explicitly declared **signed**, the **-J** option does not affect it, and the value is sign-extended when widened to **int** type.

When you specify **-J**, the compiler automatically defines the identifier **_CHAR_UNSIGNED**.

Controlling the Calling Convention (-Gc)

Options

-Gc
fortran
pascal
cdecl

The **-Gc** option and the **fortran**, **pascal**, and **cdecl** keywords allow you to control the function-calling and naming conventions so that your C programs can call and be called by functions that are written in FORTRAN and Pascal.

Because C, unlike other languages such as Pascal and FORTRAN, allows you to write functions that take variable numbers of arguments, it must handle function calls differently. Languages such as Pascal and FORTRAN normally push actual parameters to a function in left-to-right order, with the last argument in the list being the last one pushed on the stack. In contrast, C functions do not always know the number of actual parameters, so they must push their arguments from right to left, with the first argument in the list being the last one pushed.

Additionally, the calling function must remove the arguments from the stack in C (rather than having the called function do it, as in Pascal and FORTRAN). If the code for removing arguments is in the called function (as in Pascal and FORTRAN), it appears only once; if it is in the calling

function (as in C), it appears every time there is a function call. Since function calls are more numerous than individual functions, the Pascal/FORTRAN method is slightly smaller and more efficient.

The C Compiler has the ability to generate the Pascal/FORTRAN calling convention in one of several ways. The first is through the use of the **pascal** and **fortran** keywords. When these keywords are applied to functions, or to pointers to functions, they indicate a corresponding Pascal or FORTRAN function. Therefore, the correct calling convention must be used. In the following example, *sort* is declared as a function using the alternative calling convention:


```
short pascal sort(char *, char *);
```

The **pascal** and **fortran** keywords can be used interchangeably. Use them when you want to use the left-to-right calling sequence for selected functions only.

The second method for generating the Pascal/FORTRAN calling convention is to use the **-Gc** option. If you do this, the entire module is compiled using the alternative calling convention. You might use this method to make it possible to call all the functions in a C module from another language, or to gain the performance and size improvement provided by this calling convention. When you use **-Gc** to compile a module, the compiler assumes that all functions called from that module use the Pascal/FORTRAN calling convention, even if the functions are defined outside that module. Thus, using **-Gc** would normally mean that you cannot call or define functions that take variable numbers of parameters, and that you cannot call functions such as the C library functions that use the C calling sequence.

To overcome these restrictions, the **cdecl** keyword has been added to C. This keyword is the "inverse" of the **fortran** and **pascal** keywords. When applied to a function or function pointer, it indicates that the associated function is to be called using the normal C calling convention. This allows you to write C programs which take advantage of the more efficient calling convention while still having access to the entire C library, other C objects, and even user-defined functions that can take variable-length argument lists.

If you compile with the **-Gc** option, either you must declare the **main** function in the source program with the **cdecl** keyword, or you must change the start-up routine so that it uses the correct naming and calling conventions when calling **main**.

Run-time library functions all use the C calling convention. Therefore, care must be taken to declare them **cdecl** functions.

Use of the **pascal** and **fortran** keywords, and the **-Gc** option also affects the naming convention for the associated item or items; the name is converted to uppercase (capital letters), and the leading underscore that C normally prefixes is not added. The **pascal** and **fortran** keywords can be applied to data items and pointers, as well as functions. When applied to data items or pointers, these keywords force the naming convention described above for that item or pointer.

The **pascal**, **fortran**, and **cdecl** keywords, like the **near**, **far**, and **huge** keywords, are disabled by use of the **-Za** option. If this option is given, these names are treated as ordinary identifiers rather than keywords.

Examples

```
int cdecl var_print(char*,...);
```

In this example, *var_print* is allowed to have a variable number of arguments by declaring it as a function using the normal right-to-left C function calling convention and naming conventions. The *cdecl* keyword overrides the left-to-right calling sequence set by use of the **-Gc** option when compiling the source file in which this declaration appears. If this file is compiled without the **-Gc** option, *cdecl* has no effect since it is the same as the default C convention.

```
float *pascal nroot(number, root)
```

This instruction declares *nroot* to be a function returning a pointer to a value of type *float*. The function *nroot* uses the default calling sequence (left-to-right) and naming conventions for FORTRAN and Pascal programs.

```
long pascal index
```

This example simply changes the naming convention for the data item *index*: it is included in the object file in all capital letters and without a leading underscore.

Compiling Programs for DOS Environment (-dos, -FP)

The C compiler is capable of compiling programs that will execute in the DOS environment.

The **-dos** option instructs the compiler to use the set of libraries in */usr/lib/dos* and to use a different linker. Note that programs compiled with **-dos** will not run in the UNIX System V environment. Also note that many UNIX System V system calls are not supported in DOS.

There are a variety of **-FP** options that can be used along with **-dos** to control floating-point operations. For more information on **-FP** and on DOS cross-development in general, see "The DOS-OS/2 Development Guide" in the *Developer's Guide,* and the chapter "C Language Portability" in this guide.

Displaying Compiler Passes (-d, -z)

The **cc** command is actually a driver program which executes a series of compiler passes, perhaps an assembler pass, and a linker. It collects the various options and files on its command line and distributes them to the proper pass or to the linker. The C compiler is conceptually a four-pass compiler. The function of the various compiler passes is outlined below:

Pass 0
Pass zero of the compiler is comprised of the preprocessor and parser. The preprocessor handles file inclusion, macro expansion, and text substitution, and allows you to define constructs for conditional compilation. The parser performs two functions: (1) building a context-free grammar tree to pass to Pass 1; and (2) constructing a symbol table.

Pass 1
Pass two generates code. It walks the grammar tree constructed by pass 0, applies semantic rules to each syntactic construct, and produces the binary code indicated by the semantic rules.

Pass 2
The third pass provides post-generation optimization. It analyzes the code generated by pass 1 and applies optimization rules to alter the code for better performance (such as elimination of redundant code, rearrangement, etc.). It creates the object code and outputs listing files (if requested).

The **-d** option displays the various passes and their arguments before they are executed. The **-z** option shows the passes but does not execute them.

Producing OMF Object and Executable Files (-xenix)

By default, **cc** produces object and executable files using the COFF format, which is the same format used by the AT&T development system. The **-xenix** option causes **cc** to produce object and executable files that use the OMF format, which is compatible with the XENIX System V development system tools. When the **-xenix** option is used with any of the options that produce assembly-language output, the warning message normally issued (**masm** directives) is suppressed. Note that UNIX System V can execute programs that use *either* COFF or OMF formats.

Miscellaneous Pragmas

The following pragmas allow you to embed comments in the object or executable file or to send a string to the standard output:

Pragma	Action
comment	Places a comment record in the object file.
Message	Sends a message string to the standard output.

The comment pragma

The **comment** pragma allows you to place a comment record in an object file or executable file. The pragma has the following syntax:

```
#pragma comment (commenttype [,commentstring])
```

The required parameter *commenttype* specifies the type of comment record. The optional *commentstring* parameter is a string literal that provides additional information for some comment types. The following table lists and describes the types of comment records accepted by the **comment** pragma.

Record	Description
compiler	Places the name and version number of the compiler into the object file. This comment record is ignored by the linker. If you supply a *commentstring* parameter for this record type, the compiler generates a warning message.
exestr	Places the string specified in *commentstring* into the object file. At link time, this string is placed into the executable file. The string is not loaded into memory when the executable file is loaded; however, it can be found with a program that finds printable strings in files. One use for this comment-record type is to embed a version number or similar information in an executable file.
lib	Places a library-search record into the object file. This comment type must be accompanied by a *commentstring* containing the name (possibly including the path) of the library that you want the linker to search for. Since the library name precedes the default library-search records in the object file, the linker searches for this library just as if you had named it on the command line. You can place multiple library-search records in the same source file. Each record appears in the object file in the same order it is encountered in the source file.
user	Places a general comment into the object file. The *commentstring* parameter contains the text of the comment. This comment record is ignored by the linker.

The following examples illustrate some of the uses of the **comment** pragma. The following pragma causes the linker to search for the library **mylibry.a**. The linker searches first in the current working directory and then in the path specified in the **LIB** environment variable:

```
#pragma comment(lib,mylibry)
```

The following pragma causes the compiler to place the name and version number of the compiler in the object file:

```
#pragma comment(compiler)
```

For comments that take a *commentstring* parameter, you can use a macro in any place where you would use a string literal, provided that the macro expands to a string literal. You can also concatenate any combination of string literals and macros that expand to string literals. For example, the following statement is acceptable:


```
#pragma comment(user, "Compiled on " __DATE__ "at " __TIME__)
```

The message Pragma

The **message** pragma sends a string to the standard output. The pragma has the following syntax:

```
#pragma message(messagestring)
```

The *messagestring* parameter is a string literal that contains the message that you wish to send to the standard output. This pragma does not cause termination of the compilation. A typical use of **message** is to display informational messages at compile time.

The following code fragment uses **message** to display a message during compilation:

```
#if M_I86MM
      #pragma message("Medium memory model")
#endif
```

The *messagestring* parameter can be a macro that expands to a string literal, and you can concatenate such macros with string literals in any combination. For example, the following statement displays the name of the file being compiled and the date and time when the file was last modified:

```
#pragma message( "Compiling " __FILE__ ". Last modified: " __TIMESTAMP__)
```

Predefined Macro Names

The C Compiler supports all of the predefined macro names found in the ANSI proposed standard for the C language. These provide a convenient means for obtaining the date and time of the compilation and for indicating whether the compiler purports to conform fully to the proposed ANSI standard. The **__TIMESTAMP__** identifier offers a capability not found in the proposed ANSI standard. The following list explains each of these names:

Macro Name	Description
__DATE__	The date of compilation, expressed as a string literal in the form: Mmm [d]d yyyy.
__FILE__	The file name, expressed as a string literal.
__LINE__	The program line number where the __LINE__ macro was used.
__STDC__	The integer constant 0. If equal to 1, this macro indicates full conformity with the ANSI proposed standard for the C programming language.
__TIME__	The time of compilation, expressed as a string literal in the form: hh:mm:ss.
__TIMESTAMP__	The date and time of the last modification of the source file, expressed as a string literal in the form: Ddd Mmm [d]d hh:mm:ss yyyy

The **__TIMESTAMP__** macro name is not ANSI standard. Note that its time and date indicate the last modification of the source file, whereas **__DATE__** and **__TIME__** indicate the time of compilation. You can find additional information about the ANSI-compatible predefined identifiers **__DATE__** and **__TIME__** in the *C Language Reference*.

The following code fragment uses three predefined macros with the **#message pragma** to display informational messages at the time of compilation.

```
#pragma message("Compilation date: "__DATE__)
#pragma message("Compiling: "__FILE__)
#pragma message("Last modification: "__TIMESTAMP__)
```


Here is the output you might see from the preceding code fragment:

```
Compilation date: Dec  2 1987
Compiling: sample.c.
Last modification: Mon Dec  1 12:02:51 1987
```

Chapter 3

Linking with the cc Command

Introduction 3-1

The Default Linking Process 3-2

Passing Linker Information: The -link Option 3-3
Specifying Libraries 3-3
Specifying Linker Options 3-5

Introduction

Since the **cc** command controls linking as well as compiling, you can specify linker options and libraries other than the default combined library to be linked with your object files on the **cc** command line.

The Default Linking Process

When the **cc** command compiles a source file, it encodes the name of the appropriate library in the object file. The library name embedded in the library file is determined by the memory-model (**-M**) option you give on the **cc** command line.

If you use the default memory-model option (**-Ms**), **cc** encodes the name of the standard library that corresponds to the defaults.

When an object file is linked, the linker looks for libraries matching the names encoded in the object file.

The result is that you do not ordinarily need to give library names on the **cc** command line. For descriptions of the situations that require you to specify libraries on the **cc** command line, see the "Specifying Libraries" section in this chapter.

The linker used is /bin/ld, which by default produces object files in the COFF format. If the object file uses the OMF format, you have two choices:

1. Use **cvtomf** to convert the object file to COFF format. This occurs automatically if you do not use the **-xenix** option.

2. Direct the linker, **/bin/ld**, to link the file and produce an executable file using the *x.out* format. This occurs automatically if you use the **-xenix** option.

The remainder of this section applies only to the XENIX System V linker, **ld(CP)**. The AT&T linker is also described on the manual page, **ld(CP)**.

Passing Linker Information: The -link Option

To pass linker options or nondefault library names to the linker, give the following options on the **cc** command line after any source- and object-file names and **cc** options:

-link

Use the rest of the command line to specify linker options, libraries, and library search paths. Note that library names can also be specified with source- and object-file names before the **-link** option on the command line, as long as the library names have the **.a** extension. These library names are searched before library names specified after the **-link** option. Refer to the following sections for more information:

- "Specifying Libraries," to learn about specifying libraries and library search paths
- "Specifying Linker Options," for descriptions of the linker options that apply to C.

If you use the **-link** option with the **cc** command, it must be the last option on the command line.

Specifying Libraries

To link object files with libraries other than the default library, give the names of the nondefault libraries on the **cc** command line. Library names appearing before **-link** must have the **.a** extension; library names appearing after **-link** may have blank extensions or no extensions.

Since the object file already contains the names of the correct combined library, you do not need to specify libraries unless you want to do any of the following:

- Link with additional libraries
- Look for libraries in different locations
- Override the use of the default library

Linking with Additional Libraries

If you specify additional libraries to **cc**, the linker searches the libraries you specify *before* it searches the default library to resolve external references in the object files. It searches the libraries you specify in their order of appearance on the command line.

If a library name includes a path specification, the linker searches only that path for the library.

If you specify only a library name (without a path specification), the linker searches in the following locations to find the given library file:

- The current working directory
- Any path specifications that you give, in their order of appearance on the command line
- The default location */lib* or */lib/386*

If a library name without an extension appears after the **-link** option, the linker automatically supplies the **.a** extension. If you want to link a library file with an extension other than **.a**, you must specify the complete library name.

Looking in Different Locations for Libraries

You can tell the linker to look in different locations for libraries by giving a path specification on the **cc** command line.

The linker looks for the default libraries in the same order as it looks for libraries given on the command line.

Specifying Linker Options

When you use the **cc** command to invoke the linker, any linker options you specify (other than those supported by **cc** options such as **-F** and **-Fm**) must appear after the **-link** option on the command line. All options begin with the dash (-).

The following sections outline the rules for specifying linker options on the **cc** command line.

Abbreviations

Since linker options are named according to their functions, some of these options are quite long. You can abbreviate the options to save space and effort. Be sure that your abbreviation is unique, so that the linker can determine which option you want. The minimum legal abbreviation for each option is indicated in the syntax of the option.

Abbreviations must begin with the first letter of the option and must be continuous through the last letter typed. No gaps or transpositions are allowed.

Numerical Arguments

Some linker options take numerical arguments. A numerical argument can be any of the following:

- A decimal number from 0 to 65,535
- An octal number from 0 to 0177777. A number is interpreted as octal if it starts with 0. For example, the number *10* is a decimal number, but the number *010* is an octal number, equivalent to 8 in decimal
- A hexadecimal number from 0 to 0xFFFF. A number is interpreted as hexadecimal if it starts with 0x or 0X. For example, *0x10* is a hexadecimal number, equivalent to 16 in decimal

Linker Options

This section summarizes some of the linker options that can be used with C programs. Note that this section does not describe all available linker options. For a complete list, refer to the **ld**(CP) manual page in the *Programmer's Reference.*

The following linker option is most commonly used with C programs:

-SE[GMENTS]:*number*
Controls the number of segments that the linker allows a program to have. The default is 128, but you can set *number* to any value (decimal, octal, or hexadecimal) in the range 1-1024 (decimal).

For each segment, the linker must allocate some space to keep track of segment information. When you set the segment limit higher than 128, the linker allocates more space for segment information. For programs with fewer than 128 segments, you can keep the storage requirements of the linker at the lowest level possible by setting *number* to reflect the actual number of segments in the program. The linker displays an error message if the number of segments allocated is too high for the amount of memory the linker has available.

The following linker options can be used with C programs, but they perform the same actions as **cc** options. Therefore, you do not need to use them unless you are compiling and linking in separate steps.

-M[AP][:*number*]
Creates a map file. This option is equivalent to using the **-Fm** option with the **cc** command, except that you can give a *number* argument with the **-M** option. The *number* argument is any positive integer (decimal, octal, or hexadecimal) up to 65,535 (decimal) specifying how many symbols are sorted in the map listing. If no *number* argument is given, a maximum of 2048 symbols is sorted. (In practice, the number of sorted symbols is limited by the amount of free heap space.) If a *number* argument is given, the alphabetical list of symbols does not appear in the map file.

-LI[NENUMBERS]
Creates a map file and includes the line numbers and associated addresses of the source program. This option is equivalent to using the **-Zd** option with the **cc** command. For more information about the **-Zd** option, see the ''Compiling with the cc Command'' chapter of this guide.

-ST[ACK]:*number*
Specifies the size of the stack for your program, where *number* is any positive value (decimal, octal, or hexadecimal) up to 65,535 (decimal) representing the size, in bytes, of the stack. This option is equivalent to using the **-F** option of the **cc** command. For more information about the **-F** option, see the ''Compiling with the cc Command'' chapter of this guide.

Chapter 4

Running C Programs on System V

Introduction 4-1

Passing Command-Line Data to a Program 4-2

Introduction

After compiling and linking a program with the C Compiler and linking with the linker, you will have an executable file that can be run from the shell prompt.

System V uses the **PATH** environment variable to find executable files. You can execute your program from any directory, as long as the executable program file is in one of the directories on the path set in the **PATH** environment variable.

Your program can also be executed by other programs, and you can write it so that it will be capable of executing other programs. The **exec** and **system** routines provided in the run-time library allow your program to execute other programs. See the *C Library Guide* for a description of these routines.

System V has several other unique capabilities that your program can use if you write the program to take advantage of them. Among these capabilities are the following:

- Receiving arguments from the command line
- Reading information from the environment
- Sending a message to the shell by returning an exit code

This chapter explains how to write programs to take advantage of these features, and how to use them once your program is completed.

Passing Command-Line Data to a Program

Your C program can access data from a command line or from the environment. You can use the Bourne shell (or C-shell) commands to place data in the environment table. Command-line data are arguments that appear on the same line as the program name when you execute the program.

To pass data to your program on the command line, give one or more arguments after the program name when you execute the program. Each argument must be separated from the arguments around it by one or more spaces or tab characters, and may be enclosed in quotation marks (" "). If you want to give a single argument that includes spaces or tab characters, enclose the argument in quotation marks. For example, if your C program is called *try*, you might give it the following command line:


```
try 42 "de f" 16
```

In this case, the program will be executed and three arguments will be passed: *42*, *de f*, and *16*.

For a C program to read the data from the command line, the program should declare two variables as arguments to the **main** function. These variables and their contents are as follows:

Variable	Contents
argc	Number of arguments passed
argv	Array of strings containing arguments

By declaring these variables as arguments to **main**, you make them available as local variables in the **main** function. The following example illustrates how to declare these arguments:

```
main (argc, argv)
int argc;
char *argv[ ];
```

The number of arguments appearing on the command line is passed as the integer variable *argc*, and the command line is passed to the program as the array of strings indicated by *argv*.

The first argument of any command line is the name of the program to be executed. Therefore, the program name is the first string stored in *argv*, at *argv* **[0]**. Since a program name must be given to run the program, the integer value of *argc* is always at least 1. Therefore, if you pass two arguments to your program, *argc* will have a value of 3 (two arguments and the program name).

The first argument following the program name is stored at *argv* **[1]**, the second is stored at *argv* **[2]**, and so on, to the last argument. There is a third argument passed to the **main** function: *envp*, a pointer to the environment table. This argument is an extension provided by the C Compiler to support code ported from UNIX System V and other UNIX-like systems. When specified, it follows *argv* and is declared as follows:

```
char *envp[ ];
```

Although you can use this pointer to access the value of environment settings, this usage is nonstandard and not recommended. The **putenv** and **getenv** routines from the C run-time library accomplish the same task, and are easier and safer to use. Using the **putenv** routine may change the location of the environment table in memory, depending on memory requirements. Therefore, the value given to *envp* at the beginning of the program's execution may not be valid throughout. In contrast, the **putenv** and **getenv** routines access the environment table properly, even when its location changes. These routines use the global variable **environ** (described in the *C Library Guide*), which always points to the correct table location.

Example

```
myprog ABC "abc e" 3 8
```

This command line executes the program named *myprog* and passes the four command-line arguments to the **main** function. The arguments are stored as null-terminated strings, and the number of arguments is stored in *argc*. To access the last argument, for example, you would use an expression like the following:

```
argv[argc - 1]
```

Since the value of *argc* is 5 (counting the program name as an argument), this expression is equivalent to *argv[4]*, or the fifth string of the array.

Chapter 5

Working with Memory Models

Introduction 5-1
- Memory Model Considerations 5-2

Near, Far, and Huge Addressing 5-4

Using the Standard Memory Models 5-6
- Porting Considerations 5-7
- Creating Small-Model Programs 5-7
- Creating Medium-Model Programs 5-9
- Creating Compact-Model Programs 5-9
- Creating Large-Model Programs 5-10
- Creating Huge-Model Programs 5-11
- Segmentation Errors 5-12

Using the near, far, and huge Keywords 5-14
- Library Support for near, far, and huge 5-16
- Declaring Data with near, far, and huge 5-16
- Declaring Functions with the near and far Keywords 5-20
- Pointer Conversions 5-22

Creating Customized Memory Models 5-25
- Code Pointers 5-26
- Data Pointers 5-26
- Setting Up Segments 5-27
- Library Support for Customized Memory Models 5-29

Setting the Data Threshold 5-30

Naming Modules and Segments 5-31

Specifying Text and Data Segments 5-34

Introduction

Expanding the computing power of microcomputers often means giving the computer more "space" to work in. The Intel family of microprocessors (8080, 8086, 80286, and 80386) is a good example of such growth. Each new processor was capable of addressing more memory space than its predecessor.

The 8080 processor could address 64 kilobytes (64K) of memory, using 16-bit-wide address registers. For the 8086 processor, the address space was expanded to one-megabyte (1M). However, rather than expand the size of the address registers, a second set of "segment" registers was added. These registers select 64K blocks of memory, known as segments, within the one-megabyte address space. The 16-bit address registers then select an offset from the beginning of a segment through a hardware operation equivalent to shifting the segment register 4 bits (multiplying by 16) and adding that to the offset value. This allows the 8086 to have a larger address space, yet retain the 16-bit registers of the 8080 for backward compatibility.

The same architecture is used for the 80286 processor, except that in the processor's "protected mode" the 16-bit segment base values are shifted over 8 bits instead of 4 as in the 8086 or in the 80286's "real mode." The 80286 thus uses a 24-bit address, capable of addressing up to 16 megabytes of memory.

This segmented architecture can complicate the development of large programs under UNIX System V/86 and UNIX System V/286 Operating Systems. The 80386 processor with its 32-bit registers is not restricted by 64K segments; its segment size is 4096 Mbytes. It is therefore much more like non-segmented architectures such as the Motorola 68000.

However, a substantial amount of software development is done in the UNIX System V/86 and UNIX System V/286 environments. Understanding the potential stumbling blocks in the 80286 world is necessary to develop large programs effectively. Error messages such as "DGROUP allocation exceeds 64K," "Not enough core," and "Too big" can be incomprehensible without an understanding of segment usage under UNIX System V.

There are two types of segments under UNIX System V. Text segments (also called code segments) contain the actual machine instructions for the program. Data segments contain all of the program's data, such as

global variables and the stack. Under UNIX System V, the program's stack is included in the first data segment. A program's "memory model" determines how many text and data segments the program is allowed to have.

Memory Model Considerations

If you do not specify a memory model for 286 programs, **cc** uses the small memory model by default. This is sufficient for most programs.

You cannot use the small memory model if your program meets one or more of the following three conditions:

1. Your program has more than 64K of code.
2. Your program has more than 64K of data.
3. Your program contains individual arrays that need to be larger than 64K.

If you decide that the small memory model will not be adequate for your program, you have four options for larger memory models:

1. You can specify one of the other standard memory models (medium, compact, large, or huge) using one of the **-M** options.
2. You can create a mixed-model program using the **near**, **far**, and **huge** keywords.
3. You can create your own customized memory model using the **-M***string* option.
4. Method 2 can be combined with either method 1 or method 3.

Note

The only memory models supported for 80386 code are pure and impure small model. It is important to note that all other memory models apply to only 8086 and 80286 processors. Large and huge model programs will not run on an 8086, and any program for the 8086 or 80286, of any model, will run on an 80386, although the segment size is still limited to 64K.

When generating code specifically for the 80386 processor under System V, the C compiler supports only "small" model programs, but without the 64K limit, since 80386 registers are all 32 bits wide, and its segments are over four billion bytes long. All models are supported for 86/286 code.

Choosing a memory model for a program is a trade-off between size and speed. Programs of all memory models have one "near" data segment that is addressed through the processor's DS segment register. References to data in this segment require only a 16-bit address calculation. Large and huge model programs may have one or more additional segments. However, addressing data in these "far" segments requires loading a segment register in addition to calculating the offset within the segment.

Near, Far, and Huge Addressing

Understanding the terms "near," "far," and "huge" is crucial to understanding the concept of memory models. These terms indicate how data can be accessed in the pre-386 segmented architecture of the 80*x*86 family of microprocessors (8086, 80186, 80286).

System V loads the code and data allocated by your program into "segments" of physical memory. Each segment is up to 64K long. With the exception of impure small model programs, separate segments are always allocated for the program code and data. Impure small model programs fit all data and code into one segment. Except for this case, the minimum number of segments allocated for a program is two; these two segments, required for every program, are called "the default segments." The small memory model uses only the two default segments. The other memory models discussed in this chapter allow more than one code segment per program, more than one data segment per program, or both.

In the 80*x*86 family of microprocessors, all memory addresses consist of two parts:

1. A 16-bit number that represents the base address of a memory segment

2. Another 16-bit number that gives an offset within that segment

The architecture of the 80*x*86 microprocessor is such that code can be accessed within the default code or data segment using just the 16-bit offset value. This is possible because the segment addresses for the default segments are always known. This 16-bit offset value is called a "near" address, and can be accessed with a "near" pointer. Since only 16-bit arithmetic is required to access any near item, near references to code or data are smaller and more efficient.

When data or code lies outside the default segments, the address must use both the segment and offset values. Such addresses are called "far" addresses, and can be accessed by using "far" pointers in a C program. Accessing far data or code items is more expensive in terms of program speed and size, but using them allows your programs to address all memory, rather than just a 64K piece.

There is a third type of address in Microsoft C: the "huge" address. A huge address is similar to a far address in that each consists of a segment value and an offset value; but the two differ in the way address arithmetic is performed on pointers. Because items (both code and data) referenced

by far pointers are still assumed to lie completely within the segment in which they start, pointer arithmetic is done only on the offset portion of the address. This gain in pointer arithmetic efficiency is achieved, however, by limiting the size of any single item to 64K. Huge pointers overcome this size limitation by performing pointer arithmetic on all 32 bits of the data item's address, thus allowing data items referenced by huge pointers to span more than one segment, provided they conform to the rules outlined in the section on "Creating Huge-Model Programs."

The rest of this chapter deals with the various methods you can use to control whether your program makes far, near, or huge calls to access code or data.

Using the Standard Memory Models

The standard libraries provided with the UNIX System V Development System support five standard memory models. Using the standard memory models is the simplest way to control how your program accesses code and data in memory.

When you use the standard memory models, the compiler handles library support for you. The library corresponding to the memory model you specify is used automatically. Each memory model has its own library, except for the huge memory model, which uses the large-model library.

The advantage of using standard models for your programs is simplicity. In the standard models, memory management is specified by compiler options; since the standard models do not require the use of extended keywords, they are the best way to write code that can be ported to other systems (particularly systems that do not use segmented architectures).

The disadvantage of using standard memory models exclusively is that they may not produce the most efficient code. For example, if you have an otherwise small-model program containing a large array that pushes the total data size for your program over the 64K limit for small-model, it may be to your advantage to declare the one array with the **far** keyword, while keeping the rest of the program small model, as opposed to using the standard compact-memory model for the entire program. For maximum flexibility and control over how your program uses memory, you can combine the standard-memory-model method with the **near**, **far**, and **huge** keywords described in the "Using the near, far, and huge Keywords" section.

The **-M** option for **cc** is used to specify one of the five standard memory models (small, medium, compact, large, or huge) at compile time. These options are discussed in the next five sections.

Note

In the following sections, which describe in detail the different memory-model addressing conventions, it is important to keep in mind two common features of all five models:

1. No *single* source module can generate 64K or more of code.

2. No *single* data item can exceed 64K, unless it appears in a huge-model program or it has been declared with the **huge** keyword.

Porting Considerations

When porting software to UNIX System V on Intel processors from other operating systems or other processors, it is important to recognize the differences that arise from the Intel-segmented architecture. One common assumption is that an integer occupies the same number of bytes as a pointer. While this is true for small models, it is not true for middle and large models, and can cause many problems. Another common practice is to use the integer 0 to denote a null pointer. For large and huge model programs, 0 must be typecast to an appropriate pointer (typically a pointer to a **char**, such as **(char *)0** to assure that operations with pointers work correctly.

Creating Small-Model Programs

Option

-Ms

The small-model option tells the compiler to create a program that occupies one segment for both code and data. (Impure Small Model)

Impure small-model programs are typically C programs that are short or have a limited purpose. Since code and data for these programs are limited to 64K, the total size of a small-model program can never exceed 64K. Most programs fit easily into this model. Using the **-i** flag, you can create a pure small-model program. A pure small-model program has one segment of code and one segment of data for a total of 128K.

The default in small-model programs is that both code and data items are accessed with near addresses. You can override the default for data by using the **far** or **huge** keyword, and the default for code by using the **far** keyword. The **huge** keyword is relevant only to data items—specifically arrays and pointers to arrays.

The compiler creates small-model programs by default when you do not specify a memory model. The **-Ms** option is provided for completeness; you need never give it explicitly.

Impure Small Model

An ''impure'' program is one in which both text and data occupy the same physical segment. Impure programs can be created for the 8086, 80186, 80286, or 80386 processor. The maximum program size is 64K for all except the 80386. The **cc** program creates impure small-model programs by default on 8086/80286 systems. They can also be created using the **-Ms** option.

Pure Small Model

A ''pure'' program is one where text and data are in separate segments. The text is read-only and may be shared by several processes at once. On 8086/80186/80286 processors, the maximum program size is 128K (64K code + 64K data). On the 80386 processor, the maximum program size is 8 gigabytes (4G code plus 4G data). Pure small-model programs are created using the **-i** option. In this context, **-i** stands for ''instruction'' rather than ''impure''. This is the default on 80386 systems.

Creating Medium-Model Programs

Option

-Mm

The medium-model option provides a single segment for program data, and multiple segments for program code. Each source module is given its own code segment.

Medium-model programs are typically C programs that have a large number of program statements (more than 64K of code), but a relatively small amount of data (less than 64K). Program code can occupy any amount of space and is given as many segments as needed; total program data cannot be greater than 64K. The medium model provides a useful trade-off between speed and space, since most programs refer more frequently to data items than to code.

Creating Compact-Model Programs

Option

-Mc

The compact-model option directs the compiler to allow multiple segments for program data but only one segment for the program code.

Compact-model programs are typically C programs that have large amounts of data, but relatively small numbers of program statements. Program data can occupy any amount of space and are given as many segments as needed.

The default in compact-model programs is that code items are accessed with near addresses and data items are accessed with far addresses. You can override the default by using the **near** and **huge** keywords for data, and the **far** keyword for code.

Note

Note that in medium and compact models, **NULL** must be used carefully in certain situations. In memory models where code and data pointers are the same size, it can be used with either. **NULL** only represents a null data pointer in medium and compact models. Consider the following example:

```
void func1(char *dp)
{
.
.
.
}

void func2(char (*fp)(void))
{
.
.
.
}

main()
{
func1(NULL);
func2(NULL);
}
```

This example passes a 16-bit pointer to both *func1* and *func2* if compiled in medium model, and a 32-bit pointer to both *func1* and *func2* if compiled in compact model, unless prototypes are added to the beginning of the program to indicate the types, or an explicit cast is used on the argument to *func1* (compact model) or *func2* (medium model).

Creating Large-Model Programs

Option

-Ml

The large-model option allows the compiler to create multiple segments as needed for both code and data.

Large-model programs are typically very large C programs that use a large amount of data storage during normal processing.

The default in large-model programs is that both code and data items are accessed with far addresses. You can override the default by using the **near** and **huge** keywords for data, and the **near** keyword for code.

Creating Huge-Model Programs

Option

-Mh

The huge-model option is similar to the large-model option, except that the restriction on the size of individual data items is removed for arrays.

However, some size restrictions apply to elements of huge arrays where they are larger than 64K. To provide efficient addressing, array elements are not permitted to cross segment boundaries. This has the following implications:

1. No array element can be larger than 64K.

2. For any array larger than 128K, all elements must have a size in bytes equal to a power of 2 (that is, 2 bytes, 4 bytes, 8 bytes, 16 bytes, and so on). However, if the array is 128K or smaller, its elements may be any size, up to and including 64K.

In huge-model programs, care must be taken when using the **sizeof** operator or when subtracting pointers. The C language defines the value returned by the **sizeof** operator to be an **unsigned int** value, but the size in bytes of a huge array is an **unsigned long** value. To solve this discrepancy, the Microsoft C Compiler produces the correct size of a huge array when a type cast like the following is used:

```
(unsigned long)sizeof(huge_item)
```

Similarly, the C language defines the result of subtracting two pointers as an **int** value. When subtracting two huge pointers, however, the result may be a **long int** value. The Microsoft C Compiler gives the correct result when a type cast like the following is used:

```
(long)(huge_ptr1 - huge_ptr2)
```

Segmentation Errors

When compiling a small- or medium-model program, the compiler places all data in the data segment. However, the compiler cannot know how much total data is allocated in the segment. This is not determined until link time, when data from all the object modules are combined by the linker. If the linker finds that more than 64K have been allocated by the compiler, the linker will return the error message:

```
DGROUP allocation exceeds 64K
```

Errors with Small- and Medium-Model Programs

If this error occurs with a small- or medium-model program, there are three alternatives:

- Reduce the amount of data used by the program.
- Switch to the large-memory model.
- Create a hybrid-model program.

Hybrid models are created by declaring data using the **far** keyword and compiling with the **-Me** flag. The compiler then allocates additional segments for the far data. Care must be taken when referencing data declared in this manner. Since all the library functions will be expecting near data, far data must be transferred into a near data buffer before being passed to any library function, such as *printf*(). The hybrid model is best suited for programs with one or more large, seldom-used arrays or data structures where the rest of the program uses less than 64K of data.

Errors with Large-Model Programs

For large-model programs, the compiler divides different kinds of data into different segments. All initialized data is placed in DATA segments. Uninitialized data is placed in BSS (Blank Storage Space) segments. A large-model program may have as many DATA and BSS segments as needed, but only one near DATA segment (the segment addressed by the CPU **DS** register). For maximum efficiency, the compiler allocates as much data as possible to the first DATA segment. However, since the total amount of data is not known until all the object modules are linked together, more than 64K of data might be allocated for the first DATA segment. Thus, it is still possible to get the error DGROUP allocation error from the linker even with a large-model program.

One possible solution to this problem is to reduce the amount of initialized data in the program by declaring it uninitialized, then initializing at run time. Another possibility is to use the **-Mt** flag to force the compiler to move some data out of the DATA segment. Normally, the compiler places any initialized data item (single variable, array, or structure) in the first data segment if its size is less than 32767 bytes. The **-Mt** flag will lower this limit. For example, **-Mt1024** tells the compiler to place any data item larger than 1024 bytes in its own segment. The drawback to this solution is that, at run time, a segment register must be loaded for each access to that data. This may affect performance of the program. This method is most appropriate if the program contains a few large arrays or structures.

Another method of reducing the size of the first DATA segment is the use of the **-ND** compiler flag. (See "Setting Up Segments" in the "Creating Customized Memory Models" section in this chapter.) When a module is compiled with this flag, all the data in the module will be placed in its own data segment. Modules compiled using this flag should contain data only, or data and functions that do not use any data items declared in other modules.

80286 programs allocate their maximum stack size at run time; the default size is 4K. Since the stack must also fit in the first data segment, a problem will arise if there is not enough space in the first data segment to fit both the data and the stack. If the size of the data plus the size of the stack exceeds 64K, then, even if the linker will successfully link a program, the program's first data segment will be too large for the program to run. This problem will be reported by the C shell with the message "Not enough core." The Bourne shell will report the error with the message "too big." The two possible solutions to this problem are to reduce the stack size, or to reduce the amount of data in the first data segment. The latter method is recommended, since reducing the stack size may cause the program to run out of stack space.

Determining Segment Size

There are three utilities that are useful for finding and correcting problems related to program segmentation. The size utility **size**(CP) takes one or more executable or object file names as arguments, and prints the size in bytes of the text, DATA, and BSS segments. This information is helpful in determining exactly how much data is used by a program, and how it is divided between the DATA and BSS segments. The **hdr**(CP) utility prints other information about an executable file, such as its memory model and stack size. The **fixhdr**(CP) utility can be used (among other things) to alter the stack size of any executable. This is useful for experimenting with different stack sizes without the need to relink, or for cases where the source code is not available.

Using the near, far, and huge Keywords

One limitation of the predefined memory-model structure is that, whe you change memory models, all data and code address sizes are subject t change. However, the Microsoft C Compiler lets you override the defau addressing convention for a given memory model and access items with near, far, or huge pointer. This is done with the **near**, **far**, and **huge** ke words. These special type modifiers can be used with a standard memo model to overcome addressing limitations for particular data or coc items, or to optimize access to these items, without changing the addres ing conventions for the program as a whole. Table 5.1 explains how th use of these keywords affects the addressing of code or data, or pointers t code or data.

Note

The **near**, **far**, and **huge** keywords are not standard parts of the C language; they are meaningful only for systems that use a segmented architecture similar to that of the 80*x*86 microprocessors. Keep this in mind if you want your code to be ported to other systems.

Table 5.1

Addressing of Code and Data Declared with near, far, and huge

Keyword	Data	Pointer or Function	Arithmetic
near	Reside in default data segment; referenced with 16-bit addresses (Pointers to data are 16 bits)	Assumed to be in current code segment; referenced with 16-bit addresses (Pointers to functions are 16 bits)	Uses 16 bits
far	May be anywhere in memory, not assumed to reside in current data segment; referenced with 32-bit addresses (Pointers to data are 32 bits)	Not assumed to be in current code segment; referenced with 32-bit address (Pointers to functions are 32 bits)	Uses 16 bits
huge	May be anywhere in memory, not assumed to reside in current data segment; individual data items (arrays) can exceed 64K in size; referenced with 32-bit addresses (Pointers to data are 32 bits)	Not applicable to code	Uses 32 bits for data

In the Microsoft C Compiler, the **near**, **far**, and **huge** keywords are enabled by default. To treat these keywords as ordinary identifiers, you must give the **-Za** option at compile time. This option is useful if you are concerned with porting C programs from environments in which these are not keywords, especially if you are porting a program in which one of these words is used as a label. For further information about the use and effects of the **-Za** option, see the "Compiling with the cc Command" chapter of this guide.

Library Support for near, far, and huge

When using the **near**, **far**, and **huge** keywords to modify addressing conventions for particular items, you can usually use one of the standard libraries (small, compact, medium, or large) with your program. The large-model libraries are also appropriate for use with huge-model programs. However, you must use care when calling library routines. In general, you cannot pass far pointers, or the addresses of far data items, to a small-model library routine. Of course, you can always pass the *value* of a far item to a small-model library routine. For example:

```
long far time_val;

time(&time_val);       /* Illegal */
printf("%ld\0, time_val);  /* Legal */
```

If you use the **near**, **far**, or **huge** keyword, it is strongly recommended that you use function prototypes with argument-type lists to ensure that all pointer arguments are passed to functions correctly. See the section on "Pointer Conversions" for more information.

To learn more about library routines and memory models, see the *C Library Guide*.

Declaring Data with near, far, and huge

The **near**, **far**, and **huge** keywords modify either objects or pointers to objects. When using them to declare data or code (or pointers to data or code), keep the following rules in mind:

- The keyword always modifies the object or pointer immediately to its right. In complex declarations, think of the **far** keyword and the item to its right as being a single unit. For example, in the case of the declaration:

  ```
  char far* *p;
  ```

  p is a pointer (whose size depends on the specified memory model) to a far pointer to **char**. See the *C Language Reference* for complete rules governing the use of special keywords in complex declarations.

- If the item immediately to the right of the keyword is an identifier, the keyword determines whether the item will be allocated in the default data segment (**near**) or a separate data segment (**far** or **huge**). For example:

```
char far a;
```

allocates *a* as an item of type **char** with a far address.

- If the item immediately to the right of the keyword is a pointer, the keyword determines whether the pointer will hold a near address (16 bits), a far address (32 bits), or a huge address (also 32 bits). For example,

```
char far *p;
```

allocates *p* as a far pointer (32 bits) to an item of type **char**.

Examples

The examples in this section show data declarations using the **near**, **far**, and **huge** keywords.

```
char a[3000];           /* small-model program */
char far b[30000];
```

The first declaration in the example allocates the array *a* in the default data segment. By contrast, the array *b* in the second declaration may be allocated in any far data segment. Since these declarations appear in a small-model program, array *a* probably represents frequently used data that was deliberately placed in the default segment for fast access. Array *b* probably represents seldom used data that might make the default data segment exceed 64K and force the programmer to use a larger memory model if the array were not declared with the **far** keyword. The second declaration uses a large array, because it is more likely that a programmer would want to specify the address allocation size for items of substantial size.

```
char a[3000];           /* large-model program */
char near b[3000];
```

In this example, access speed would probably not be critical for array *a*. Even though it may or may not be allocated within the default data segment, it is always referenced with a 32-bit address. Array *b* is explicitly allocated **near** to improve speed of access in this memory model (large).

```
char huge a[70000];     /* small-model program */
char huge *pa;
```

In this small-model program, *a* must be declared as **huge** because it is larger than 64K. Using the **huge** keyword instead of the standard huge memory model means that the price for using huge data is only paid for this one large item. Other data can be accessed quickly within the default

segment. The pointer *pa* could be used to point to *a*. Any pointer arithmetic for *pa* (such as *pa*++) would be performed using 32-bit arithmetic.

```
char *pa;          /* small-model program */
char far *pb;
```

The pointer *pa* is declared as a near pointer to **char** in the example. The pointer is near by default since the example appears in a small-model program. By contrast, *pb* is allocated as a far pointer to **char**; *pb* could be used to point to, and step through, an array of characters stored in a segment other than the default data segment. For example, *pa* might be used to point to array *a* in the first example, while *pb* might be used to point to array *b*.

```
char far * *pa;          /* small-model program */
char far * *pa;          /* large-model program */
```

The pointer declarations in the example illustrate the interaction between the memory model chosen and the **near** and **far** keywords. Although the declarations for *pa* are identical, in a small-model program, *pa* is declared as a near pointer to an array of far pointers to type **char**, while in a large-model program, *pa* is declared as a far pointer to an array of far pointers to type **char**.


```
char far * near *pb;     /* any model */
char far * far *pb;
```

In the first declaration in the example, *pb* is declared as a near pointer to an array of far pointers to type **char**; in the second declaration, *pb* is declared as a far pointer to an array of far pointers to type **char**. Note that, in this example, the **far** and **near** keywords override the model-specific addressing conventions shown in the preceding example. The declarations for *pb* would have the same effect, regardless of the memory model. The examples in the following table illustrate the **far** and **near** keywords as used in declarations in a small-model program. It also gives the size in bits of the address and the value and the type of the value.

Table 5.2
Uses of 8086/80186/80286 near and far Keywords

Declaration	Size of Address	Size of Value	Type of Value
char c;	16	8	data
char far d;	32	8	data
char *p;	16	16	near pointer
char far *q;	16	32	far pointer
char * far r;	32	16	near pointer[1]
char far * far s;	32	32	far pointer[2]
int foo( );	16	16	integer function
int far foo( );	32	16	integer function[3]

Notes

1 This example of a near 16-bit pointer which may lie in a far data segment is unlikely to be useful; it is shown for syntactic completeness only.

2 This is similar to accessing data in a large-model program.

3 This example leads to trouble in most environments. The far call changes the CS register, and makes run time support unavailable.

The following example is from a middle-model compilation:

```
int near foo();
```

This allows a near call to the routine *foo* in a program where calls are normally **far**.

If you are using one of the keywords, it would be advisable to check the type of item in separate source files as the compiler does not do this.

If the **-M3e** option is used, the **near** keyword can address items in the program segment itself. The **near** keyword defines an item with a 32-bit address (relative to **DS**).

These keywords override the normal address length generated by the compiler for variables and functions. In pure small-model programs, **far** lets you access data and functions in segments outside the **TEXT** and **DATA** segments.

The examples in the table that follows show **near** and **far** keywords used in declarations of pure small- and mixed-model programs configured with the **-M3e** option:

Table 5.3

Uses of 80386 near and far Keywords

Declaration	Address Size	Allocation Size
char c;	near (32 bits)	8 bits (data)
char far d;	far (48 bits)	8 bits (data)
char *p;	near (32 bits)	32 bits (near pointer)
char far *q;	near (32 bits)	64 bits (far pointer)
char * far r;	far (48 bits)	32 bits (near pointer)[1]
char far * far s;	far (48 bits)	64 bits (far pointer)[2]
int foo( );	near (32 bits)	function returning 32 bits
int far foo( );	far (64/48 bits)	function returning 32 bits[3]

Notes

1 This example is shown for syntactic completeness only.

2 This resembles accessing data in a large-model program.

3 This example creates problems in most environments. The far call changes the CS register, and makes run-time support unavailable.

Declaring Functions with the near and far Keywords

The rules for using the **near** and **far** keywords for functions are similar to those for using them with data, as specified in the following list:

- The keyword always modifies the function or pointer immediately to its right. For more information about rules for evaluating complex declarations, see the *C Language Reference*.

- If the item immediately to the right of the keyword is a function, then the keyword determines whether the function will be allocated as near or far. For example:

```
char far fun( );
```

defines *fun* as a function called with a 32-bit address and returning type **char**.

- If the item immediately to the right of the keyword is a pointer to a function, then the keyword determines whether the function will be called using a near (16-bit) or far (32-bit) address. For example:

```
char (far * pfun)( );
```

defines *pfun* as a far pointer (32 bits) to a function returning type **char**.

- Function declarations must match function definitions.
- The **huge** keyword cannot be applied to functions.

Examples

```
void char far fun(void);                    /* small model */
void char far fun(void)
        {
        .
        .
        .
        }
```

In this example, *fun* is declared as a function returning type **char**. The **far** keyword in the declaration means that *fun* must be called with a 32-bit call.

```
static char far * near fun( );          /* large model */
static char far * near fun( )
        {
        .
        .
        .
        }
```

In the large-model example, *fun* is declared as a near function that returns a far pointer to type **char**. Such a function might be seen in a large-model program as a helper routine that is used frequently, but only by the routines in its own module. Since all routines in a given module share the same code segment, the function could always be accessed with a near

call. However, you could not pass a pointer to *fun* as an argument to another function outside the module in which *fun* was declared.

```
void far *fun(void);                    /* small model */
void (far * pfun)  ( ) = fun;
```

The small-model example declares *pfun* as a far pointer to a function that has a **void** return type, and then assigns the address of *fun* to *pfun*. In fact, *pfun* could be used to point to any function accessed with a far call. Note that if the function indicated by *pfun* has not been declared with the **far** keyword, or if it is not far by default, then calling that function through *pfun* would cause the program to fail.

```
double far * (far fun)( );          /* compact model */
double far * (far *pfun)( ) = fun;
```

In this final example, *pfun* is declared as a far pointer to a function that returns a far pointer to type **double**, and then assigns the address of *fun* to *pfun*. This might be used in a compact-model program for a function that is not used frequently and thus does not need to be in the default code segment. Both the function and the pointer to the function must be declared with the **far** keyword.

Pointer Conversions

Passing pointers as arguments to functions may cause automatic conversions in the size of the pointer argument, since passing a pointer to a function forces the pointer size to the larger of the following two sizes:

- The default pointer size for that type, as defined by the memory model used during compilation

  For example, in medium-model programs, data-pointer arguments are near by default, and code-pointer arguments are far by default.

- The size of the type of the argument

If a function prototype with argument types is given, the compiler performs type-checking and enforces the conversion of actual arguments to the declared type of the corresponding formal argument. However, if no declaration is present or the argument-type list is empty, the compiler will convert pointer arguments automatically to the default type or the type of the argument, whichever is larger. To avoid mismatched arguments, you should always use a prototype with the argument types.

Examples

```
/* This program produces unexpected results in compact-,
** large-, or huge-model programs.
*/

main( )

      {
      int near *x;
      char far *y;
      int z = 1;

      test_fun(x, y, z);   /* x will be coerced to far
                           ** pointer in compact, large,
                           ** or huge model
                           */
      }

int test_fun(ptr1, ptr2, a)
      int near *ptr1;
      char far *ptr2;
      int a;

      {
      printf("Value of a = %d\n", a);}
```


If the preceding example is compiled as a small-model program (with no memory-model options or the **-Ms** option on the **cc** command line) or medium-model program (**-Mm** option), then the size of pointer argument *x* is 16 bits, the size of pointer argument *y* is 32 bits, and the value printed for *a* is 1. However, if the preceding example is compiled with the **-Mc**, **-Ml**, or **-Mh** option, both *x* and *y* are automatically converted to far pointers when they are passed to *test_fun*. Since *ptr1*, the first parameter of *test_fun*, is defined as a near-pointer argument, it takes only 16 bits of the 32 bits passed to it. The next parameter, *ptr2*, takes the remaining 16 bits passed to *ptr1*, plus 16 bits of the 32 bits passed to it. Finally, the third parameter, *a*, takes the leftover 16 bits from *ptr2*, instead of the value of *z* in the *main* function. This shifting process does not generate an error message, since both the function call and the function definition are legal, but in this case the program does not work as intended, since the value assigned to *a* is not the value intended.

To pass *ptr1* as a near pointer, you should include a forward declaration that specifically declares this argument for *test_fun* as a near pointer, as shown in the following example:

```
/* First, declare test_fun so the compiler knows in advance
** about the near pointer argument:
*/
int test_fun(int near*, char far *, int);

main( )

      {
      int near *x;
      char far *y;
      int z = 1;

      test_fun(x, y, z);   /* now, x will not be coerced
                           ** to a far pointer; it will be
                           ** passed as a near pointer,
                           ** no matter what memory
                           ** model is used
                           */
      }

int test_fun(ptr1, ptr2, a)
      int near *ptr1;
      char far *ptr2;
      int a;

      {
      printf("Value of a = %d\n", a);
      }
```


Note that it would not be sufficient to reverse the definition order for *test_fun* and *main* in the first example to avoid pointer coercions; the pointer arguments must be declared in a forward declaration, as in the second example.

Creating Customized Memory Models

A third method of managing memory models is to combine features of the standard memory models to create your own customized memory model. You should have a thorough understanding of C memory models and the architecture of 8086 and 80286 processors before creating your own non-standard memory models, since there is no library support—other than the C start-up routines—for nonstandard memory models.

The **-M***string* option lets you change the attributes of the standard memory models to create your own memory models. The three letters in *string* correspond to the code-pointer size, the data-pointer size, and the stack- and data-segment setups. Because the letter allowed in each field is unique to that field, you can give the letters in any order after **-M**. All three letters must be present.

The standard-memory-model options (**-Ms**, **-Mm**, **-Mc**, **-Ml**, and **-Mh**) can be specified in the **-M***string* form. As an example of how to construct memory models, the standard-memory-model options are listed with their standard equivalents:

Standard	Custom Equivalent
-Ms	**-Msnd**
-Mm	**-Mlnd**
-Mc	**-Msfd**
-Ml	**-Mlfd**
-Mh	**-Mlhd**

As an example of the use of customized models, you might want to create a huge-compact model. This model would allow huge data items, but only one code segment. The option for specifying this model would be **-Mshd**.

An even more common use of customized models is to set up segments. (See the section on "Setting Up Segments," for more information.)

If you use a customized memory model for a program that includes both far and near functions, be aware of the following issues:

- The **chkstk** library function should be called only in functions that are compiled in the same model as the library being used. (For compatibility with UNIX System V, the **chkstk** function name cannot be model-encoded.)

- The interfaces to floating-point function calls are not model encoded, so functions containing floating-point calls must be compiled with the same model as the library being used.

Code Pointers

Options

-Ms*xx*	Near code pointers
-Ml*xx*	Far code pointers

Note

5

For the purposes of the descriptions that follow, the letters **l** (for "long") and **s** (for "short") are used as code pointers to distinguish them from the letters for data pointers in the memory-model string.

The letter **s** tells the compiler to generate near (16-bit) pointers and addresses for all code items. This is the default for small- and compact-model programs.

The letter **l** means that far (32-bit) pointers and addresses are used to address all code items. Far pointers are the default for medium-, large-, and huge-model programs.

Data Pointers

Options

-Mn*xx*	Near data pointers
-Mf*xx*	Far data pointers
-Mh*xx*	Huge data pointers

Three sizes are available for data pointers: near, far, and huge. The letter **n** tells the compiler to use near (16-bit) pointers and addresses for all data. This is the default for small- and medium-model programs.

The letter **f** specifies that all data pointers and addresses are far (32-bit). This is the default for compact- and large-model programs.

The letter **h** specifies that all data pointers and addresses are huge (32-bit). This is the default for huge-model programs.

When far data pointers are used, no single data item may be larger than a segment (64K) because address arithmetic is performed only on 16 bits (the offset portion) of the address. When huge data pointers are used, individual data items can be larger than a segment (64K) because address arithmetic is performed on the entire 32 bits of the address.

Setting Up Segments

Options

-Md*xx*	Sets **SS** = **DS**
-Mu[*xx*]	Sets **SS** != **DS**; **DS** reloaded on function entry
-Mw[*xx*]	Sets **SS** != **DS**; **DS** not reloaded on function entry

The letter **d** tells the compiler that the segment addresses stored in the **SS** and **DS** registers are equal; that is, the stack segment and the default data segment are combined into a single segment. This is the default for all programs. In small- and medium-model programs, the stack plus all data must occupy less than 64K; thus, any data item is accessed with only a 16-bit offset from the segment address in the **SS** and **DS** registers.

In compact-, large-, and huge-model programs, initialized global and static data are placed in the default data segment. The address of this segment is stored in the **DS** and **SS** registers. All pointers to data, including pointers to local data (the stack), are full 32-bit addresses. This is important to remember when passing pointers as arguments in large-model programs. Although you may have more than 64K of total data in these models, there can be no more than 64K of data in the default segment. The **-Gt** and **-ND** options can be used to control allocation of items in the default data segment if a program exceeds this limit. (For more information about these options, see the sections on "Setting the Data Threshold," and "Naming Modules and Segments.")

The letter **u** allocates different segments for the stack and the data segments. Each object file (module) is allocated its own segment for global and static data items. Note that the **-ND** option, described in "Naming

Modules and Segments,'' must be specified along with the letter **u** to allocate data segments other than the default. When the letter **u** and **-ND** are specified, the address in the **DS** register is saved upon entry to each function, and the new **DS** value for the module in which the function was defined is loaded into the register. The previous **DS** value is restored on exit from the function. Therefore, only one data segment is accessible at any given time. The **-ND** option can be used to combine these segments into a single segment.

If a standard memory-model option precedes it on the command line, the **-Mu** option can be specified without any letters indicating data- or code-pointer sizes. In this case, the program uses the specified memory model, but different segments are set up for the stack and data segments.

A single segment must be allocated for the stack, and its address must be stored in the **SS** register. The stack segment does not change during the execution of the program.

The letter w, like the letter **u**, sets up a separate stack segment, but does not automatically load the **DS** register at each module entry point. This option is typically used when writing application programs that interface with an operating system or with a program running at the operating-system level. The operating system or the program running under the operating system actually receives the data intended for the application program and places that data in a segment. Then the operating system or program must load the **DS** register with the segment address for the application program.

As with the **-Mu** option, the **-Mw** option can be specified without data- and code-pointer letters if a standard memory-model option precedes it on the command line. In this case, the program uses the specified memory model, but different segments are set up for the stack and data segments, and the **DS** register is not reloaded at each module entry point.

Even though **u** and **w** set up a separate segment for the stack, the stack's size is still fixed at the default unless this is overridden with the **-F** compiler option.

Library Support for Customized Memory Models

Most C programs make function calls to the routines in the C run-time library. Library support is provided for the five standard memory models (small, medium, compact, large, and huge) through four separate run-time libraries. (Huge and large models both use the large-model library.) When you write mixed-model programs, you are responsible for determining which library (if any) is suitable for your program and for ensuring that the appropriate library is used.

Library support is provided for customized memory models where the stack and default data segments are combined into a single segment (**-Md***xx*), but not for customized memory models where these segments are different (**-Mu***xx*, **-Mw***xx*, **-Mu**, and **-Mw**). In the latter cases, you probably need to create a customized library to be used with your customized memory model. Specify the library files and object files you want to use when linking. Be sure to use the start-up routine from the appropriate library for your memory model. Table 5.4 shows the libraries from which to extract the start-up routine for each customized memory model.

Table 5.4

Start-Up Routines for Customized Memory Models

Memory-Model Option	Use Start-Up from Library
-Msn*x*; **-MS** plus **-M***x*[1]	**/usr/lib/286/Sseg.o**
-Msf*x*; **-Msh***x*; **-MC**[1] plus **-M***x*	**/usr/lib/286/Cseg.o**
-Mln*x*; **-MM** plus **-M***x*[1]	**/usr/lib/286/Mseg.o**
-Mlf*x*; **-Mlh***x*; **-ML** plus **-M***x*; **-MH** plus **-M***x*[1]	**/usr/lib/286/Lseg.o**

"**l**" in the above table indicates a condition where *x* must be either **u** or **w**.

In general, library functions do not support customized memory models, since a particular run-time routine may in turn call another library routine that conflicts with your customized model.

Setting the Data Threshold

Option

-Gt[*number*]

By default, the compiler allocates all static and global data items within the default data segment in the small and medium memory models. In compact-, large-, and huge-model programs, only *initialized* static and global data items are assigned to the default data segment. The **-Gt** option causes all data items whose sizes are greater than or equal to *number* bytes to be allocated to a new data segment. When *number* is specified, it must follow the **-Gt** option immediately, with no intervening spaces. When *number* is omitted, the default threshold value is 256. When the **-Gt** option is omitted, the default threshold value is 32,767.

You can use the **-Gt** option only with compact-, large-, and huge-model programs, since small- and medium-model programs have only one data segment. The option is particularly useful with programs that have more than 64K of initialized static and global data in small data items.

Naming Modules and Segments

Options

-NM *modulename*
-NT *textsegment*
-ND *datasegment*

"Module" is another name for an object file created by the C compiler. Every module has a name. The compiler uses this name in error messages if problems are encountered during processing. The module name is usually the same as the source-file name. You can change this name using the **-NM** (for "name module") option. The new *modulename* can be any combination of letters and digits. The space between **-NM** and *modulename* is optional.

A "segment" is a contiguous block of binary information (code or data) produced by the C compiler. Every module except impure small has at least two segments: a text segment containing the program instructions, and a data segment containing the program data. Each segment in every module has a name. The linker uses this name to define the order in which the segments of the program appear in memory when loaded for execution. The segments in the group named **DGROUP** are an exception.

Text and data segment names are normally created by the C compiler. These default names depend on the memory model chosen for the program. For example, in small-model programs, the text segment is named **_TEXT** and the data segment is named **_DATA**. These names are the same for all small-model modules, so all text segments from all modules are loaded as one contiguous block, and all data segments from all modules form another contiguous block.

In medium-model programs, the text from each module is placed in a separate segment with a distinct name, formed by using the module base name along with the suffix **_TEXT**. The data segment is named **_DATA**, as in the small model.

In compact-model programs, the data from each module are placed in a separate segment with a distinct name, formed by using the module base name along with the suffix **_DATA**. The exception to this is initialized global and static data, which are put in the default data segment **_DATA**. The code segment is named **_TEXT**, as in the small model.

In large- and huge-model programs, the text and data from each module are loaded into separate segments with distinct names. Each text segment

is given the name of the module plus the suffix **_TEXT**. The data from each segment is placed in a private segment with a unique name (except for initialized global and static data placed in the default data segment). The naming conventions for text and data segments are summarized in Table 5.5.

Table 5.5
Segment-Naming Conventions

Model	Text	Data	Module
Small	**_TEXT**	**_DATA**	*filename*
Medium	*module*_**TEXT**	**_DATA**	*filename*
Compact	**_TEXT**	**_DATA**[1]	*filename*
Large	*module*_**TEXT**	**_DATA**[1]	*filename*
Huge	*module*_**TEXT**	**_DATA**[1]	*filename*

"**1**" in the above table indicates the name of default data segment; other data segments have unique private names.

You can override the default names used by the C compiler (thus overriding the default loading order) by using the **-NT** (for "name text") and **-ND** (for "name data") options. These options set the names of the text and data segments in each module being compiled to the given name. The *textsegment* argument used with the **-NT** option and the *datasegment* argument used with the **-ND** option can be any combination of letters and digits. The space between **-NT** and *textsegment*, like the space between **-ND** and *datasegment*, is optional.

If you use the **-ND** option to change the name of the default data segment, your program can no longer assume that the address contained in the stack segment register (**SS**) is the same as the address in the data segment register (**DS**). You must therefore compile your program either with the **-M***string* form of the memory-model option and the **u** option for the segment-setup letter, or with the **-M** option for a standard memory model followed by the **-Mu** option, as in the following example:

```
cc -Ms -Mu -ND DATA1 prog1.c
```

Use of the **-Mu** option forces the compiler to generate code to load **DS** with the correct data-segment value on entry to the code. See the section on "Creating Customized Memory Models," for more information on the

options. All modules whose data segments have the same name have these segments combined into a single segment named *DATA1* at link time.

Specifying Text and Data Segments

Pragmas

#pragma alloc_text (*textsegment*, *function1*[, *function2*]...)
#pragma same_seg (*variable1*[, *variable2*]...)
#pragma data_seg ([[*segmentname*]])

The **alloc_text** pragma gives you source-level control over the segment to which particular functions are allocated. The **same_seg** pragma provides information the compiler can use to generate better code. The **data_seg** pragma allows you to specify the name of the data segment that subsequent load-**DS** functions use.

If you use overlays or swapping techniques to handle large programs, **alloc_text** allows you to tune the contents of their text segments for maximum efficiency. The **alloc_text** pragma must appear before the definitions of any of the specified functions, but it may appear either before or after the functions are declared or called. Any functions specified in an **alloc_text** pragma must be either explicitly declared with the **far** keyword or assumed to be far because of the memory model used (medium, large, or huge).

The **same_seg** pragma tells the compiler to assume that the specified external variables are allocated in the same data segment. You are responsible for making sure that these variables are put in the same data segment; one way to do this is to specify the **-ND** option when you compile the program. The **same_seg** pragma must appear before any of the specified variables is used in executable code and after the variables are declared. Variables specified in a **same_seg** pragma must be explicitly declared with **extern** storage class, and they must either be explicitly declared with the **far** keyword or assumed to be far because of the memory model used (compact, large, or huge).

The **data_seg** pragma specifies the name of the data segment that subsequent **load-ds** functions should use. A "**load-ds**" function loads its own data segment upon entry. For more information about **load-ds** see Appendix A of this manual. In addition, **data_seg** causes the named segment to contain all data that would otherwise be allocated in the **DATA** segment (all subsequent initialized static and global data). If you omit the *segmentname* parameter, the compiler uses the segment name specified in the -ND option, or, if that option is absent, the default group **DGROUP**, since **DGROUP** is not a segment.

Chapter 6

Improving Program Speed

Introduction 6-1

Using Register Variables 6-2

Optimization Options and Pragmas 6-4
- Default Optimization 6-4
- Generating Intrinsic Functions 6-4
- Relaxing Alias-Checking 6-5
- Performing Loop Optimizations 6-5
- Removing Stack Probes 6-6
- Maximum Optimization 6-6

Choosing the Function-Calling Convention 6-7

Efficiency in Large Data Models 6-8
- Changing Addressing with near, far, and huge Keywords 6-8
- Setting the Data Threshold 6-9
- Controlling Segments Used for Allocation 6-9

Efficiency in Large Code Models 6-10

Introduction

This chapter describes a number of ways that you can improve the execution speed of programs compiled with the C Compiler. These techniques include:

- Using register variables
- Using optimization options and pragmas
- Choosing function-calling conventions
- Choosing and adjusting memory models

Where applicable, this chapter discusses the interactions between these techniques and the trade-offs involved in using them.

Using Register Variables

One common way to write a program for maximum speed is to declare selected local (**auto**) variables with **register** storage class. The declaration of a register variable requests the compiler to use machine registers when allocating space for the variable, if possible. The **register** storage class can be specified for any variable, but some classes of variables, such as structures, cannot be stored in registers.

Up to two register variables may be allocated per function. In lexical order, the 8086 and 80286 compilers take the first two variables with **register** storage class that meet the size criteria. The 80386 compiler takes the first three variables. Any later requests for **register** storage class are ignored, so be sure to declare the most important register variables first. The compiler deallocates the register when the variable is no longer being used. You may also want to declare register variables in parallel scope to achieve the effect of having more than two register variables per function.

The C Compiler automatically uses registers for variables within loops. Using register declarations for such variables may interfere with optimal loop code; you can experiment with various combinations of register and nonregister declarations to determine which combinations give the best results.

Register declarations can be used effectively for values, especially pointers, that appear outside of loops. Since a certain amount of code is required to save and restore registers, register declarations must be applied to values that are accessed at least three times within a function to cause any improvement in program speed.

Example

```
find_string(arr_of_chars, string)
char *string;
char *arr_of_chars[];
{
        int ix = 0;
        register char *q;
        while (*(q = string)) {      /* string is not null */
        {
           register int i = ix;

           /* search for entry whose first character
             * matches first character of string, if any
            */

           while (i < MAX_ARR_SIZE && *arr_of_chars[i] != *q)
                  i++;
           if (i == MAX_ARR_SIZE)
                  return(1); /* no matching entry */
           ix = i;
           }

           /* we've found an entry in arr_of_chars which
             * might match string */

           {
           register char *p = arr_of_chars[ix];
           while (*p && *q && *p++ == *q++)
                  ;
           if ((*p - *q) == 0)
                  return(0) /* they match, return 0 */
           /* otherwise continue checking for possible
            * matches
            */

           }
        }
}
```

In this example, the function named *find_string* actually has three register variables: *q*, *i*, and *p*. The function can use all three variables because *i* is through being used by the time *p* is needed. Introducing the *ix* variable to save the pointer from block-to-block speeds execution considerably because most work is being done in register variables.

Optimization Options and Pragmas

The **cc** compiler/linker driver provides a number of optimization options (**-O**, followed by one or more letters) that can improve program speed. In addition, the C Compiler includes several pragmas that allow you to control some of these optimizations on a local basis within a source program. The following sections outline these **cc** options and pragmas and their effects.

Default Optimization

If no **-O** option is given, the compiler uses the **-Ot** option, which optimizes programs for execution speed. However, this option does not enable loop optimizations or intrinsics. Some optimizations, such as long shifts, may be performed in line rather than using helper functions.

Generating Intrinsic Functions

The **-Oi** option generates intrinsic forms of the following functions:

- **memset, memcpy, memcmp**
- **strset, strcpy, strcmp, strcat**
- **inp, outp**
- **_rotl, _rotr, _lrotl, _lrotr,**
- **min, max, abs**

Intrinsics may be generated as in-line code or with different calling sequences. In general, using intrinsics increases program size but improves program speed. Note that the intrinsic forms of some functions may have slightly different semantics: for example, the intrinsic form of the **memcpy** function in compact- and large-model programs cannot handle huge arrays, but the function form can.

As with **-Ot**, this option may increase program size due to the additional code generated in line for each function. However, program execution is faster because no instructions for calling and returning from functions need to be performed.

The **intrinsic** pragma can be used to specify intrinsic functions on a local basis for any of the functions listed above. For information about the use of the **intrinsic** pragma, see the ''Compiling with the **cc** Command'' chapter of this guide.

Relaxing Alias-Checking

The **a** option letter can be used with the **l**, **s**, or **t** option letter to relax the assumptions the compiler makes about the use of ''aliases'' in the program. Use of the **-Oa** option can reduce the size of executable files and speed program execution. This is especially recommended when you also specify the **-Ol** option, since the compiler can detect a number of loop optimizations when the **-Oa** option is in effect that it cannot detect when **-Oa** is not in effect. However, before you specify **-Oa**, you must make sure that your program does not use multiple aliases to refer to the same memory location either directly or indirectly. For example, a program might do this indirectly in functions that operate on a communal variable and a pointer argument, or on multiple pointer arguments.

The **-Oa** option can be specified safely for programs that include calls to functions with address-type arguments. In this case, the compiler assumes that all variables whose addresses are passed to the function are modified, even if **-Oa** is specified.

In the cases noted above, the use of **-Oa** is most likely to cause incorrect optimizations within basic blocks (where most optimizations are applied) and within whole loop bodies (where loop optimizations are applied). In these cases, **-Oa** can still be specified safely even if aliases are used in the program, provided that no memory location is referenced by more than one name within any basic block or (if loop optimization is enabled) any loop body.

For more information and specific examples, see the ''Compiling with the **cc** Command'' chapter of this guide.

Performing Loop Optimizations

The **-Ol** option tells the compiler to perform loop optimizations. For best performance, use **-Ol** in conjunction with the **a** option letter (**-Oal**), which relaxes the assumptions the compiler makes about the use of aliases in the program. Using **-Oal** instead of just **-Ol** allows the compiler to detect many loop optimizations that it could not otherwise detect. For information about possible restrictions on the uses of the **-Oa** option, see the ''Compiling with the **cc** Command'' chapter of this guide.

You can control loop optimization on a local basis by specifying the **loop_opt** pragma. Loop optimization is turned off for any functions following **#pragma loop_opt(off)** and turned on for any functions following **#pragma loop_opt(on)** in a source program. This pragma overrides any loop optimization specified on the **cc** command line.

Removing Stack Probes

The **-Gs** option, described in the "Compiling with the **cc** Command" chapter of this guide, speeds program execution slightly by removing calls to stack-checking routines known as "stack probes." Stack probes verify that a program has enough stack space to allocate required local variables. The potential disadvantage in removing stack probes is that stack-overflow errors may occur without generating a diagnostic message. However, this technique can be useful for programs that are known not to exceed the available stack space.

You can also control stack checking on a local basis by specifying the **check_stack** pragma. Stack checking is turned off for any functions following a **#pragma check_stack(off)** pragma and turned on for any functions following a **#pragma check_stack(on)** pragma in the source program. This pragma overrides the removal of stack checking specified on the **cc** command line.

Maximum Optimization

The **-Ox** option combines the **-Ot**, **-Oi**, **-Oa** and **-Ol** optimization options described in this section. Provided that the restrictions outlined for each optimization option do not apply, you can use the **-Ox** option to create the fastest possible program.

Choosing the Function-Calling Convention

Because C functions can accept variable numbers of arguments, arguments passed to these functions must be pushed on the stack from right to left, with the first argument in the list being the last one pushed. In addition, the calling function, rather than the called function, is responsible for removing arguments from the stack.

This convention results in somewhat slower programs than the alternative convention used by FORTRAN and Pascal. In the FORTRAN/Pascal convention, arguments are pushed on the stack from left to right, in the order in which they are passed to the function, and the called function removes arguments from the stack. Since the code for removing arguments appears only once (in the called function) for the FORTRAN/Pascal convention, rather than multiple times (every time a function is called) as in the C convention, and since most programs have fewer functions than function calls in a program, the FORTRAN/Pascal calling convention usually results in smaller, faster programs.

You can specify the FORTRAN/Pascal calling convention for all functions in a module by compiling with the **-Gc** option. The trade-off for improved program speed is that you cannot call functions that use the C calling convention or take variable numbers of arguments unless you declare these functions, or pointers to these functions, with the **cdecl** keyword, which specifies the normal C calling conventions for these functions.

If you do not want to specify the FORTRAN/Pascal convention for a whole module, you can declare individual functions or pointers to functions with the **pascal** or **fortran** keyword. Either of these keywords tells the compiler that the function uses the FORTRAN/Pascal calling conventions.

Efficiency in Large Data Models

Programs are most efficient when their data reside in the default data segment, that is, when the data can be accessed with 16-bit (near) addresses. The C Compiler provides two standard memory models in which all data reside in the default data segment: the small (default) model and the medium model. The customized memory models that use near data pointers (**-Mn***xx*) also restrict program data to the default data segment. Programs compiled with these models are restricted to 64K of total data.

For programs compiled with the compact, large, and huge memory models, the compiler creates a default data segment containing all initialized global and static data and creates an additional data segment for each program module. Since accessing data outside the default data segment is slower than accessing data within the default data segment, programs will run faster if as many of their variables as possible are declared in such a way that they are allocated in the default data segment. One way to accomplish this is to initialize variables at the time you declare them. This section discusses other ways of controlling the allocation of data for large data models.

Changing Addressing with near, far, and huge Keywords

The **near**, **far**, and **huge** keywords allow you to specify explicitly the addressing used for particular data items and functions. These keywords override the default addressing conventions specified by the program's memory model. Thus, you can use them to improve the speed of access to program data. For example, you can tell the compiler to allocate data items in the default data segment for a compact-, large-, or huge-model program by declaring the items (or pointers to the items) with the **near** keyword. Alternatively, if a program has a small amount of code and data except for one particularly large array, you could compile the program with the small or medium memory model and declare the array with the **far** or **huge** keyword.

The disadvantage of using these keywords is that they are specific to the MS-DOS/UNIX implementation of C and, thus, are not portable to other operating environments.

For more information about **near**, **far**, and **huge** and for examples of their use, see the "Working with Memory Models" chapter in this guide.

Setting the Data Threshold

Another way to control allocation in large data models is to set a data threshold by compiling with the **-Gt** option. This option is especially useful if your program uses more than 64K of initialized static and global data and does not fit in the default data segment. Any data items larger than the value you specify are allocated to their own data segments.

Controlling Segments Used for Allocation

If programs compiled with large data models use external far data items, you can tell the compiler which items reside in the same far data segment by using the **same_seg** pragma. The variables you specify in this pragma help the optimizer recognize common subexpressions involving data loads. Note that you must also compile your program with the **-ND** option to ensure that the variables you specify are allocated in the same segment.

For a description of the **-ND** option and the **same_seg** pragma, see the "Working with Memory Models" chapter of this guide.

Efficiency in Large Code Models

One linker option, **-T**, can result in smaller and faster executable files and improved program-load times for programs that explicitly or implicitly use far function calls.

The **-T** option tells the linker to optimize far calls to procedures that lie in the same segment as the caller. When you specify the **-T** option, the linker optimizes 32-bit calls to procedures in the same segment as the calling procedure. Since the segment addresses of the calling and called procedures are the same, only a 16-bit call is required. If the **-T** option is given, the linker removes the far call and replaces it with code that first places **CS** on the stack, then makes a near call. The called procedure still returns with a far (32-bit) return instruction. However, because both the code segment (stored in **CS**) and the near address are on the stack, the far return is done correctly. The linker also adds a **NOP** instruction so that the five-byte far call is replaced by exactly five bytes of instructions.

Note

You may not want to use the **-T** option if your program includes system-level assembly language routines or if you are linking object files that were compiled with a different C compiler.

Chapter 7

Object and Executable File Formats

Introduction 7-1

iAPX-286 and -386 System Architecture 7-2
- Memory Management 7-2
- Logical Address Space 7-2
- Logical-to-Physical Address Translation 7-2

The Intel Object Module Format 7-4

Definition of Terms 7-6

Module Identification and Attributes 7-9

Segment Definition 7-10

Segment Addressing 7-11

Symbol Definition 7-12

Indices 7-13

Conceptual Framework for Fixups 7-14
- LOCATION Types 7-15

Self-Relative Fixups 7-19

Segment-Relative Fixups 7-20

Record Order 7-22

Introduction to the Record Formats 7-24
- Title and Official Abbreviation 7-24
- The Boxes 7-24
- Rectyp 7-24
- Record Length 7-25
- Name 7-25

Number 7-25
Repeated or Conditional Fields 7-25
Chksum 7-25
Bit Fields 7-26
T-Module Name 7-26
Name 7-27
Seg Attr 7-27
Segment Length 7-29
Segment Name Index 7-30
Class Name Index 7-30
Overlay Name Index 7-30
Group Name Index 7-31
Group Component Descriptor 7-31
Name 7-32
Eight-Leaf Descriptor 7-32
Public Base 7-34
Public Name 7-35
Public Offset 7-35
Type Index 7-36
External Name 7-36
Type Index 7-37
Line-Number Base 7-38
Line-Number 7-38
Line Number Offset 7-38
Segment Index 7-39
Enumerated Data Offset 7-39
Data 7-39
Segment Index 7-39
Iterated Data Offset 7-40
Iterated Data Block 7-40
Repeat Count 7-40
Block Count 7-40
Content 7-41
Thread 7-42
Fixup 7-43
Mod Type 7-46
Comment Type 7-48
Comment 7-49

Numeric List of Record Types 7-50

Type Representations for Communal Variables 7-51

The Segmented x.out Format 7-54
General Description of x.out 7-54
Example of File Layout 7-56

Iterated Segments 7-56
Non-Iterated Segments and Implicit bss 7-57
Large Model 7-58
Special Header Fields 7-58
Symbol Table 7-58
UNIX System V Executable Format 7-59
Selected Portions of Include Files 7-60

ntroduction

his chapter describes the object and executable file formats used by NIX System V/386 release 3.2.

/hen the **-xenix** option is used with **cc**, the file format used is the Intel)bject Module Format, or OMF. When **cc** is used without the **-xenix** ɔtion, the file format used is the AT&T Common Object File Format, or OFF.

his chapter is divided into four sections. The first provides you with a ɪief introduction to the architecture of the iAPX-286 and -386 pro-ɛssors.

he second section discusses OMF which is used by all Microsoft lan-ıage tools. The implementation of this format makes it possible to com-ile programs that run in the UNIX System V, XENIX and MS-DOS ıvironments.

he third section provides a brief description of our implementation of ıe **x.out** format in a segmented environment. For detailed information, ɛe the **x.out** header file (/usr/include/x.out.h).

he fourth section describes the Common Object Module Format (COFF) ɜed by the AT&T development system. You can find additional informa-ɔn in the **a.out** header file (/usr/include/a.out.h).

7

iAPX-286 and -386 System Architecture

UNIX System V runs on the 80386 processor in protected mode. This s tion provides a general introduction to the architecture of protected-mo operation. It does not discuss the various 80386 paging mechanisms. I an in-depth discussion of the iAPX-286 and iAPX-386, refer to the app priate programmer's reference manual published by Intel.

Memory Management

Memory management provides a mapping from the logical addresses us within a program to physical machine addresses. This serves two p poses:

- Programs are not tied to any particular physical address.
- Access permissions to particular areas of memory can be co trolled.

Logical Address Space

The mapping of virtual addresses to physical addresses is achieved means of descriptor tables which are themselves resident in memory. any given moment, there are two alternate descriptor tables available: t Global Descriptor Table (GDT) and the Local Descriptor Table (LDT).

7

The UNIX System V kernel uses the GDT to map the kernel's virtu address space. Each user process has its own LDT as part of its per-p cess data which maps the logical address space of the process.

Each entry in a descriptor table specifies the base address, length, a access permissions of a particular segment of physical memory.

Logical-to-Physical Address Translation

Logical addresses consist of two parts: a segment selector used to selec particular descriptor table entry, and an offset added to the base addr found in the descriptor table to give a physical memory address.

The segment selector is a 16-bit number containing three pieces of information:

1. The Request Privilege Level (RPL) is encoded as the low-order two bits of the selector. The RPL is a feature of the system architecture protection scheme. Segment selectors in user processes always have both of these bits set to indicate RPL 3, the lowest privilege level.
2. The Table Indicator (TI) is encoded as the next most significant bit (bit 2). The TI indicates whether address translation will use the GDT (TI = 0) or the LDT (TI = 1). User processes can only access the LDT; therefore the TI for a segment selector in a user process is always 1.
3. The Index field is encoded as the high-order 13 bits of the selector. This is used to index into the appropriate descriptor table and select a particular entry.

When a descriptor table entry has been selected, the offset is added to the base address in physical memory to form a physical address.

Depending on the characteristics of the segment, as defined in the descriptor table, the offset may be a 16- or 32-bit number. The offset will be 16 bits on an 80286 processor or in a 16-bit segment on an 80386 processor. The 32-bit offsets apply only to the 80386.

The Intel Object Module Format

This section presents the object record formats that define the relocatable object language for the iAPX-86 family of microprocessors. The 8086 object language is the output of all language translators that have the 8086 as their target processor and are linked by the link editor. The 8086 object language is input and output for object language processors such as linkers and librarians.

Note

Except where otherwise noted, references to the 8086 in this document refer to the 8086/80286/80386 processors. In general, the 8086/80286 references are made to 16-bit offsets and 64K segment offsets, which do not apply to the 80386.

The 8086 object module formats permit you to specify relocatable memory images that may be linked together. The formats allow efficient use of the memory-mapping facilities of the 8086 microprocessor.

The following record formats, as described in this chapter, are supported. Those formats preceded by an asterisk (*) deviate from the Intel specification.

Object Module Record Formats

T-Module Header Record
List of Names Record
*Segment Definition Record
*Group Definition Record
*Type Definition Record
*Public Names Definition Record
*External Names Definition Record
*Line Numbers Record
Logical Enumerated Data Record
Logical Iterated Data Record
Fixup Record
*Module End Record
Comment Record

Definition of Terms

The following terms are fundamental to the 8086 relocation and linkage.

OMF
Object Module Formats

MAS
Memory Address Space. Note that the MAS is distinguished from actual memory, which may occupy only a portion of the MAS.

MODULE
An "inseparable" collection of object code and other information.

T-MODULE
A module created by a translator, such as C, Pascal, or FORTRAN.

The following restrictions apply to object modules:

- Every module needs a name. Translators provide names for T-Modules, giving a default name (possibly the filename or a null name) if neither source code nor user specifies otherwise.
- Every T-Module in a collection of linked modules must have a different name so that symbolic debugging systems can distinguish the various line numbers and local symbols. This restriction is not required by **ld**.

FRAME
A contiguous region of MAS that can be addressed using a single segment register. This concept is useful because the content of the four 8086 segment registers defines four (possibly overlapping) FRAMEs. No 16-bit address in the 8086 code can access a memory location outside of the current four FRAMEs. On an 8086, a FRAME must begin on a paragraph boundary (that is, a multiple of 16 bytes). On 80286 and 80386 processors, this restriction does not apply. On an 80386, a FRAME is a region of up to (2**32) bytes addressed by a single segment register.

LSEG
Logical Segment. A contiguous region of memory whose contents are determined at translation time (except for address-binding). Neither size nor location in MAS is necessarily determined at translation time. Size, although partially fixed, may not be final because the LSEG may be combined at LINK time with other

LSEGs, forming a single LSEG. On 8086/80286 processors, an LSEG must not be larger than 64K, so that it can fit in a FRAME. This means that any byte in an LSEG may be addressed by a 16-bit offset from the base of a FRAME covering the LSEG. An 80386 LSEG may be as much as (2**32) bytes in size and any byte in it may be addressed by a 32-bit offset from the base of the FRAME containing the LSEG.

PSEG

Physical Segment. This term is equivalent to FRAME. Some people prefer PSEG to FRAME because the terms PSEG and LSEG reflect the physical and logical nature of the underlying segments.

FRAME NUMBER

This term is only used in reference to 8086 processors, or 80286/80386 processors operating in real address mode. Every FRAME begins on a paragraph boundary. The paragraphs in MAS can be numbered from 0 through 65535. These numbers, each of which defines a FRAME, are called FRAME NUMBERS.

PARAGRAPH NUMBER

This term is equivalent to FRAME NUMBER.

PSEG NUMBER

This term is equivalent to FRAME NUMBER.

GROUP

A collection of LSEGs defined at translation time, whose final locations in MAS are constrained such that there is at least one FRAME that covers (contains) every LSEG in the collection.

The notation Gr A(X,Y,Z) means that LSEGs X, Y, and Z form a group whose name is A. The fact that X, Y, and Z are all LSEGs in the same group does not imply any ordering of X, Y, and Z in MAS, nor does it imply any contiguity between X, Y, and Z.

The link editor does not currently allow an LSEG to be a member of more than one group. The link editor ignores all attempts to place an LSEG in more than one group.

CANONIC

Any location in the 8086 MAS is contained in exactly 4096 distinct FRAMEs, but one of these FRAMEs can be distinguished because it has a higher FRAME NUMBER. This distinguished FRAME is called "the canonic FRAME" of the location. The canonic FRAME of a given byte is the FRAME so chosen that the byte's offset from that FRAME lies in the range 0 to 15 (decimal). Thus, if FOO is a symbol defining a memory location, one may speak of the "canonic FRAME of FOO," or of "FOO's canonic

FRAME.'' By extension, if S is any set of memory locations, then there exists a unique FRAME that has the lowest FRAME NUMBER in the set of canonic FRAMEs of the locations in S. This unique FRAME is called the canonic FRAME of the set S. Thus, we may speak of the canonic FRAME of an LSEG, or of a group of LSEGs.

SEGMENT NAME

LSEGs are assigned segment names at translation time. These names serve two purposes:

- They play a role at LINK time in determining which LSEGs are combined with other LSEGs.
- They are used in assembly source code to specify groups.

CLASS NAME

LSEGs may optionally be assigned class names at translation time. Classes define a partition on LSEGs: two LSEGs are in the same class if they have the same class name.

The link editor applies the following semantics to class names. The class name ''CODE'' or any class name whose suffix is ''CODE'' implies that all segments of that class contain only code and may be considered read-only. Such segments may be overlaid if the user specifies the module containing the segment as part of an overlay.

OVERLAY NAME

LSEGs may optionally be assigned overlay names. The overlay name of an LSEG is ignored by **ld** (version 2.40 and later versions), but it is used by Intel relocation and linkage products.

COMPLETE NAME

The complete name of an LSEG consists of the segment name, class name, and overlay name. LSEGs from different modules are combined if their complete names are identical.

Module Identification and Attributes

A module header record is always the first record in a module and provides the module name.

In addition to a name, a module may have the attribute of being a main program and may have a specified starting address. When you are linking multiple modules together, only one module with the main attribute should be given.

In summary, modules may or may not be main and may or may not have a starting address.

Segment Definition

A module is a collection of object code defined by a sequence of records produced by a translator. The object code represents contiguous regions of memory whose contents are determined at translation time. These regions are called LOGICAL SEGMENTS (LSEGs). A module defines the attributes of each LSEG. The SEGMENT DEFINITION RECORD (SEGDEF) is the vehicle by which all LSEG information (name, length, memory alignment, and so on) is maintained. The LSEG information is required when multiple LSEGs are combined and when segment addressability is established. (See "Segment Addressing".) The SEGDEF records must follow the first header record.

Segment Addressing

The 8086/80286 addressing mechanism provides segment base registers from which a 64-Kbyte region of memory, called a FRAME, may be addressed. There are one code-segment base register (CS), two data-segment base registers (DS, ES), and one stack-segment base register (SS). The 80386 has two additional segment registers: FS and GS, and can address up to (2**32) bytes of memory from each segment register.

The greatest possible number of LSEGs that may make up a memory image far exceeds the number of available base registers. Thus, base registers may require frequent loading. This would occur in a modular program with many small data and/or code LSEGs.

Since such frequent loading of base registers is undesirable, it is a good strategy to collect many small LSEGs together into a single unit that fits in one memory frame so that all the LSEGs may be addressed using the same base register value. This addressable unit is a GROUP. See the section "Definition of Terms" in this chapter.

To have addressability of objects within a GROUP, each GROUP must be explicitly defined in the module. The GROUP DEFINITION RECORD (GRPDEF) provides a list of constituent segments either by segment name or by segment attribute such as "the segment defining symbol FOO" or "the segments with class name ROM."

The GRPDEF records within a module must follow all SEGDEF records because GRPDEF records can reference SEGDEF records when defining a GROUP. The GRPDEF records must also precede all other records except header records, as the linker must process them first.

Symbol Definition

The **ld** command supports three different types of records that fall into the class of symbol definition records. The two most important types are PUBLIC NAMES DEFINITION RECORDs (PUBDEFs) and EXTERNAL NAMES DEFINITION RECORDS (EXTDEFs). These types are used to define globally visible procedures and data items and to resolve external references. In addition, TYPDEF records are used by **ld** for the allocation of communal variables. (See the section "Type Representations for Communal Variables" later in this chapter.)

Indices

"Index" fields appear throughout this document. An index is an integer that selects some particular item from a collection of such items. Some examples are NAME INDEX, SEGMENT INDEX, GROUP INDEX, EXTERNAL INDEX, and TYPE INDEX.

In general, indices must assume values quite large (that is, much larger than 255). Nevertheless, a great number of object files will contain no indices with values greater than 50 or 100. Therefore, indices will be encoded in one or two bytes, as required.

The high-order (left-most) bit of the first, and possibly the only, byte determines whether the index occupies one byte or two. If the bit is 0, then the index is a number between 0 and 127, occupying one byte. If the bit is 1, then the index is a number between 0 and 32K-1, occupying two bytes, and is determined as follows: the low-order 8 bits are in the second byte, and the high-order 7 bits are in the first byte.

Conceptual Framework for Fixups

A "fixup" is some modification to object code, requested by a translator, performed by **ld**, achieving address-binding.

Note

This definition of "fixup" accurately represents the viewpoint maintained by **ld**. Nevertheless, the link editor can be used to achieve modifications of object code (that is, "fixups") that do not conform to this definition. For example, the binding of code to either hardware floating-point or software floating-point subroutines is a modification to an operation code, where the operation code is treated as if it were an address. The previous definition of "fixup" is not intended to disallow or disparage object code modifications.

8086 translators specify a fixup with four data items:

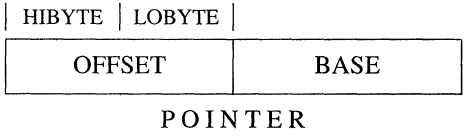
- The place and type of a LOCATION to be fixed up.
- One of two possible fixup MODES.
- A TARGET, which is a memory address to which LOCATION must refer.
- A FRAME defining a context within which the reference takes place.

There are 5 types of LOCATION: a POINTER, a BASE, an OFFSET, a HIBYTE, and a LOBYTE.

The vertical alignment of the following figure illustrates four points. (Remember that the high-order byte of a word in 8086 memory is the byte with the higher address.) The **ld** command does not require the presence of the high- or low-order complement of these items. (For instance, in the case of HIBYTE, a high-order word, it doesn't matter if the low-order word is present.)

- A BASE is the high-order word of a pointer.
- An OFFSET is the low-order word of a pointer.

- A HIBYTE is the high-order half of an OFFSET.
- A LOBYTE is the low-order half of an OFFSET.



LOCATION Types

A LOCATION is specified by two data: (1) the LOCATION type, and (2) where the LOCATION is. The first is specified by the LOC subfield of the LOCAT field of the FIXUP record; the second is specified by the DATA RECORD OFFSET subfield of the LOCAT field of the FIXUP record.

The link editor supports two fixup MODEs: "self-relative" and "segment-relative."

Self-Relative fixups support the 8- and 16-bit offsets that are used in the CALL, JUMP and SHORT-JUMP instructions. Segment-Relative fixups support all other addressing modes of the 8086.

The TARGET is the location in MAS being referenced. (More explicitly, the TARGET may be considered the lowest byte in the object being referenced.) A TARGET is specified in one of eight ways. There are four "primary" ways, and four "secondary" ways. Each primary way of specifying a TARGET uses two kinds of data: an INDEX-or-FRAME-NUMBER 'X', and a displacement 'D'.

- (T0) X is a SEGMENT INDEX. The TARGET is the Dth byte in the LSEG identified by the INDEX.
- (T1) X is a GROUP INDEX. The TARGET is the Dth byte in the LSEG identified by the INDEX.
- (T2) X is an EXTERNAL INDEX. The TARGET is the Dth byte following the byte whose address is (eventually) given by the External Name identified by the INDEX.
- (T3) X is a FRAME NUMBER. The TARGET is the Dth byte in the FRAME identified by the FRAME NUMBER (that is, the address of TARGET is (X*16)+D).

Each secondary way of specifying a TARGET uses only one data item: the INDEX-or-FRAME-NUMBER X. An implicit displacement equal to zero is assumed.

- (T4) X is a SEGMENT INDEX. The TARGET is the 0th (first) byte in the LSEG identified by the INDEX.
- (T5) X is a GROUP INDEX. The TARGET is the 0th (first) byte in the LSEG in the specified group that is eventually LOCATEd lowest in MAS.
- (T6) X is an EXTERNAL INDEX. The TARGET is the byte whose address is the External Name identified by the INDEX.
- (T7) X is a FRAME NUMBER. The TARGET is the byte whose 20-bit address is (X*16).

Note

The link editor does not support methods T3 and T7.

The following nomenclature is used to describe a TARGET:

TARGET:	SI (<segment name>), <displacement>	[T0]
TARGET:	GI (<group name>), <displacement>	[T1]
TARGET:	EI (<symbol name>), <displacement>	[T2]
TARGET:	SI (<segment name>)	[T4]
TARGET:	GI (<group name>)	[T5]
TARGET:	EI (<symbol name>)	[T6]

The following examples illustrate how this notation is used:

TARGET: SI(CODE), 1024	The 1025th byte in the segment "CODE".
TARGET: GI(DATAAREA)	The location in MAS of a group called "DATAAREA".
TARGET: EI(SIN)	The address of the external subroutine "SIN".

TARGET: EI(PAYSCHEDULE), 24 — The 24th byte following the location of an EXTERNAL data structure called "PAYSCHEDULE".

Every 8086 memory reference is to a location contained within some FRAME, where the FRAME is designated by the content of some segment register. For **ld** to form a correct, usable memory reference, it must know what the TARGET is, and to which FRAME the reference is being made. Thus, every fixup specifies such a FRAME in one of six ways. Some use data X, which is in INDEX-or-FRAME-NUMBER, as above. Others require no data.

The six methods of specifying frames are:

1. (F0) X is a SEGMENT INDEX. The FRAME is the canonic FRAME of the LSEG defined by the INDEX.

2. (F1) X is a GROUP INDEX. The FRAME is the canonic FRAME defined by the group (that is, the canonic FRAME defined by the LSEG in the group that is eventually LOCATEd lowest in MAS).

3. (F2) X is an EXTERNAL INDEX. The FRAME is determined when the External Name's public definition is found. There are three cases:

   - (F2a) The symbol is defined relative to some LSEG, and there is no associated GROUP. The LSEGs canonic FRAME is specified.
   - (F2b) The symbol is defined absolutely, without reference to an LSEG, and there is no associated GROUP. The FRAME is specified by the FRAME NUMBER subfield of the PUBDEF record that gives the symbol's definition.
   - (F2c) Regardless of how the symbol is defined, there is an associated GROUP. The canonic FRAME of the GROUP is specified. (The group is specified by the GROUP INDEX subfield of the PUBDEF Record.)

4. (F3) X is a FRAME NUMBER (specifying the obvious FRAME).

5. (F4) No X. The FRAME is the canonic FRAME of the LSEG containing LOCATION.

6. (F5) No X. The FRAME is determined by the TARGET. There are four cases:

- (F5a) The TARGET specifies a SEGMENT INDEX: in this case, the FRAME is determined as in (F0).
- (F5b) The TARGET specifies a GROUP INDEX: in this case, the FRAME is determined as in (F1).
- (F5c) The TARGET specifies an EXTERNAL INDEX: in this case, the FRAME is determined as in (F2).
- (F5d) The TARGET is specified with an explicit FRAME NUMBER: in this case the FRAME is determined as in (F3).

Note

The link editor does not support frame methods F2b, F3, or F5d.

Nomenclature describing FRAMEs is similar to the above nomenclature for TARGETs.

FRAME:	SI (<segment name>)	[F0]
FRAME:	GI (<group name>)	[F1]
FRAME:	EI (<symbol name>)	[F2]
FRAME:	LOCATION	[F4]
FRAME:	TARGET	[F5]
FRAME:	NONE	[F6]

For an 8086 memory reference, the FRAME specified by a self-relative reference is usually the canonic FRAME of the LSEG containing the LOCATION, and the FRAME specified by a segment relative reference is the canonic FRAME of the LSEG containing the TARGET.

Self-Relative Fixups

Self-relative fixups can be applied to LOCATIONS which are either 16- or 32-bit OFFSETS or they are LOBYTES. The result of applying a self-relative fixup to any other type of LOCATION is undefined.

Both the LOCATION and the TARGET must lie within the FRAME specified for the fixup.

The value to be used in the fixup is defined as the displacement from the byte in memory following the LOCATION to the TARGET.

If the LOCATION to be fixed-up is a LOBYTE, the fixup value must lie in the range -128 to 127.

If the LOCATION to be fixed up is a 16-bit OFFSET, the fixup value must lie in the range -32768 to 32767.

The fixup value is added to the existing contents of the LOCATION, ignoring any overflow.

Self-relative fixups are typically applied to the relative displacement values used in instructions such as conditional jumps.

Segment-Relative Fixups

Segment-relative fixups can be applied to any type of LOCATION.

The way in which a LOCATION containing a BASE component (that is, a BASE or a POINTER) is fixed up depends on whether the code is to run in real or virtual address mode. The contents of the BASE portion of a LOCATION must ultimately be capable of being loaded into a segment register; therefore, in real address mode this will be a paragraph number and in virtual address mode this will be a selector value.

Fixup values for the BASE and OFFSET components of a LOCATION are calculated as follows:

1. In real address mode:

   The base fixup value (FBVAL) is defined as the FRAME NUMBER of the FRAME specified in the fixup.

   The offset fixup value (FOVAL) is defined as the offset of the TARGET from the start of the FRAME specified in the fixup. This offset must be ≥ 0 and ≤ FFFF.

2. In protected mode:

   The base fixup value (FBVAL) is defined as the segment selector of the FRAME specified in the fixup.

   The offset fixup value (FOVAL) is defined as the offset of the TARGET from the start of the FRAME specified in the fixup. This offset must be ≥ 0 and ≤ the maximum segment size implied by the segment selector for the FRAME; that is, (2**16)-1 for 80286 segments and 16-bit 80386 segments, or (2**32)-1 for 32-bit 80386 segments.

The fixup values for BASE and OFFSET are applied to the LOCATION as follows:

1. If the LOCATION is a BASE or a POINTER, then FBVAL is stored in the BASE component of the LOCATION.

2. If the LOCATION is a POINTER, or a 16- or 32-bit OFFSET, or a LOBYTE, then the offset fixup value (FOVAL) is added to the existing contents of the OFFSET component of the LOCATION ignoring any overflow.

3. If the LOCATION is a HIBYTE, then FOVAL is divided by 256 and the result is added to the LOCATION, ignoring overflow.

Record Order

An object code file must contain a sequence of one or more modules or a library containing zero or more modules. A module is defined as a collection of object code defined by a sequence of object records. The following syntax shows the valid orderings of records to form a module. In addition, the given semantic rules provide information about how to interpret the record sequence.

Note

The syntactic description language used below is defined in WIRTH: CACM, November 1977, vol.#20, no.#11, pp.#822-823. The character strings represented by capital letters above are not literals, but are identifiers that are further defined in the section describing the record formats.

```
object file   = tmodule
tmodule       = THEADR seg-grp  {component}  modtail
seg_grp       = {LNAMES} {SEGDEF} {TYPDEF | EXTDEF | GRPDEF}
component     = data | debug_record
data          = content_def | thread_def | TYPDEF | PUBDEF | EXTDEF
debug_record  = LINNUM
content_def   = data_record {FIXUPP}
thread_def    = FIXUPP (containing only thread fields)
data_record   = LIDATA | LEDATA
modtail       = MODEND
```

The following rules apply:

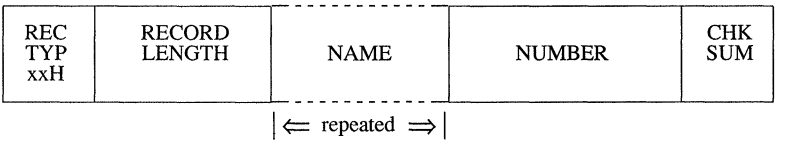
- A FIXUPP record always refers to the previous DATA record.
- All LNAMES, SEGDEF, GRPDEF, TYPDEF, and EXTDEF records must precede all records that refer to them.
- COMENT records may appear anywhere in a file, except as the first or last record in a file or module, or within a content_def.

Introduction to the Record Formats

The following pages present diagrams of record formats in schematic form. Here is a sample record format, to illustrate the various conventions.

SAMPLE RECORD FORMAT

(SAMREC)



Title and Official Abbreviation

At the top is the name of the record format described, with an official abbreviation. To promote uniformity among various programs, including translators and debuggers, the abbreviation should be used in both code and documentation. The record format abbreviation is always six letters.

The Boxes

Each format is drawn with boxes of two sizes. The narrow boxes represent single bytes. The wide boxes represent two bytes each. The wide dashed boxes represent a variable number of bytes, one or more, depending upon content. The wide solid boxes represent 4-byte fields.

Rectyp

The first byte in each record contains a value between 0 and 255, indicating the record type. For records that have both 16- and 32-bit versions, the low-order bit of the record type indicates the type: 0=16-bit, 1=32 bit.

Record Length

The second field in each record contains the number of bytes in the record, exclusive of the first two fields.

Name

Any field that indicates a "NAME" has the following internal structure: the first byte contains a number between 0 and 127, inclusive, that indicates the number of remaining bytes in the field. The remaining bytes are interpreted as a byte string.

Most translators constrain the character set to be a subset of the ASCII character set.

Number

A 4-byte NUMBER field represents a 32-bit unsigned integer, where the first 8 bits (least-significant) are stored in the first byte (lowest address), the next 8 bits are stored in the second byte, and so on.

Repeated or Conditional Fields

Some portions of a record format contain a field or a series of fields that may be repeated one or more times. Such portions are indicated by the "repeated" or "rpt" brackets below the boxes.

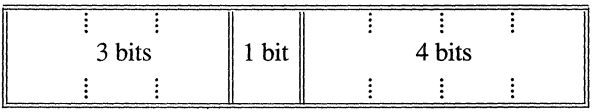
Similarly, some portions of a record format are present only if some given condition is true; these fields are indicated by similar "conditional" or "cond" brackets below the boxes.

Chksum

The last field in each record is a check sum, which contains the 2's complement of the sum (modulo 256) of all other bytes in the record. Therefore, the sum (modulo 256) of all bytes in the record equals 0.

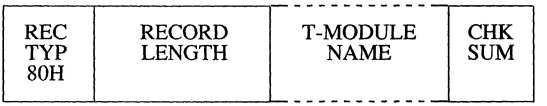
Bit Fields

Descriptions of contents of fields will sometimes be at the bit level. Boxes with complete vertical lines drawn through them represent bytes or words; the partial vertical lines indicate bit boundaries; thus the byte represented below, has three bit-fields of 3-, 1-, and 4-bits.



T-MODULE HEADER RECORD

(THEADR)



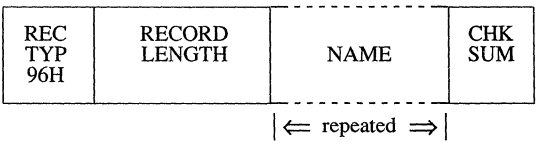
Every module output from a translator must have a T-MODULE HEADER RECORD.

T-Module Name

The T-MODULE NAME provides a name for the T-MODULE.

LIST OF NAMES RECORD

(LNAMES)



This record provides a list of names that may be used in following SEG-DEF and GRPDEF records as the names of Segments, Classes, and/or Groups.

The ordering of LNAMES records within a module, together with the ordering of names within each LNAMES Record, induces an ordering on the names. Thus, these names are considered to be numbered: 1, 2, 3, 4, ... These numbers are used as ''Name Indices'' in the Segment Name Index, Class Name Index, and Group Name Index fields of the SEGDEF and GRPDEF Records.

Name

NAME is a repeatable field which provides a name and which may have zero length.

SEGMENT DEFINITION RECORD

(SEGDEF)

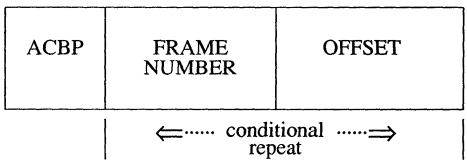
REC TYP 98H 99H	RECORD LENGTH	SEG ATTR	SEGMENT LENGTH	SEGMENT NAME INDEX	CLASS NAME INDEX	OVER-LAY NAME INDEX	CHK SUM

SEGMENT INDEX values 1 through 32767, which are used in other record types to refer to specific LSEGs, are defined implicitly by the sequence in which SEGDEF Records appear in the object file.

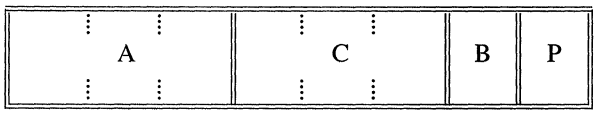
In the REC TYP field, 98H and 99H describe 16- and 32-bit segments, respectively.

Seg Attr

The SEG ATTR field provides information on various attributes of a segment, and has the following format:



The ACBP byte contains four numbers which are the A, C, B, and P attribute specifications. This byte has the following format:



"A" (Alignment) is a 3-bit subfield that specifies the alignment attribute of the LSEG. The semantics are defined as follows:

A=0 SEGDEF describes an absolute LSEG.

A=1 SEGDEF describes a relocatable, byte-aligned LSEG.

A=2 SEGDEF describes a relocatable, word-aligned LSEG.

A=3 SEGDEF describes a relocatable, paragraph-aligned LSEG.

A=4 SEGDEF describes a relocatable, page-aligned LSEG.

A=5 SEGDEF describes a relocatable, double-word-aligned LSEG. (386 OMF only)

If A=0, the FRAME NUMBER and OFFSET fields will be present. Using **ld**, absolute segments may be used for addressing purposes only. For example, the starting address of a ROM and the symbolic names for addresses within the ROM may be defined in this way. **ld** will ignore any data specified as belonging to an absolute LSEG.

''C'' (Combination) is a 3-bit subfield that specifies the combination attribute of the LSEG. Absolute segments (A=0) must have combination zero (C=0). For relocatable segments, the C field encodes a number (0,1,2,4,5,6 or 7) that indicates how the segment can be combined. The interpretation of this attribute is best given by considering how two LSEGs are combined:

- Let X,Y be LSEGs, and let Z be the LSEG resulting from the combination of X,Y.
- Let LX and LY be the lengths of X and Y, and let MXY denote the maximum of LX, LY.
- Let G be the length of any gap required between the X- and Y-components of Z to accommodate the alignment attribute of Y.
- Let LZ denote the length of the (combined) LSEG Z; let dx (0<=dx<LX) be the offset in X of the (combined) LSEG Z; let dx (0<=dx<LX) be the offset in X of a byte, and let dy similarly be the offset in Y of a byte.

The following table gives the length LZ of the combined LSEG Z, and the offsets dx' and dy' in Z for the bytes corresponding to dx in X and dy in Y. Intel additionally defines alignment types 5 and 6 and also processes code and data placed in segment with align-type.

Combination Attribute Example

C	LZ	dx'	dy'	
2	LX+LY+G	dx	dy+LX+G	Public
5	LX+LY+G	dx	dy+LX+G	Stack
6	MXY	dx	dy	Common

The table has no lines for C=0, C=1, C=3, C=4, and C=7. C=0 indicates that the relocatable LSEG may not be combined; C=1 and C=3 are undefined. C=4 and C=7 are treated like C=2. C1, C4, and C7 all have different meanings according to the Intel standard.

''B'' (Big) is a 1-bit subfield which, if 1, indicates that the Segment Length is exactly 2**16 (2**32 in the case of 32-bit segments). In this case the SEGMENT LENGTH field must contain zero.

The ''P'' field must always be zero. The ''P'' field is the ''Page resident'' field according to the Intel standard.

The FRAME NUMBER and OFFSET fields (present only for absolute segments, A=0) specify the placement in MAS of the absolute segment. The range of OFFSET is constrained to be between 0 and 15 inclusive. If a value larger than 15 is desired for OFFSET, then an adjustment of the FRAME NUMBER should be done.

Segment Length

The SEGMENT LENGTH field gives the length of the segment in bytes. The length may be zero; if so, **ld** will *not* delete the segment from the module. The SEGMENT LENGTH field is two bytes for a 16-bit segment (Rectyp 98) and four bytes for a 32-bit segment (Rectyp 99). This is large enough for numbers up to (2**16)-1 and (2**32)-1, respectively. The B attribute bit in the ACBP field (see SEG ATTR section) must be used to indicate a length of (2**16) or (2**32).

Segment Name Index

The Segment Name is a name the programmer or translator assigns to the segment. Examples: CODE, DATA, STACK, TAXDATA, MODULENAME_CODE. This field provides the Segment Name, by indexing into the list of names provided by the LNAMES Record(s).

Class Name Index

The Class Name is a name the programmer or translator can assign to a segment. If none is assigned, the name is null, and has length 0. The purpose of Class Names is to allow the programmer to define a "handle" used in the ordering of the LSEGs in MAS. Examples: RED, WHITE, BLUE; ROM FASTRAM, DISPLAYRAM. This field provides the Class Name, by indexing into the list of names provided by the LNAMES Record(s).

Overlay Name Index

Note

This is ignored in **ld** versions 2.40 and later, but supported in all earlier versions. However, semantics differ from Intel semantics.

The Overlay Name is a name the translator and/or **ld**, at the programmer's request, applies to a segment. The Overlay Name, like the Class Name, may be null. This field provides the Overlay Name, by indexing into the list of names provided by the LNAMES Record(s).

Note

The "Complete Name" of a segment is a 3-component entity comprising a Segment Name, a Class Name, and an Overlay Name. (The latter two components may be null.)

GROUP DEFINITION RECORD

(GRPDEF)

Group Name Index

The Group Name is a name by which a collection of LSEGs may be referenced. The important property of such a group is that, when the LSEGs are eventually fixed in MAS, there must exist some FRAME which "covers" every LSEG of the group.

The GROUP NAME INDEX field provides the Group Name, by indexing into the list of names provided by the LNAMES Record(s).

Group Component Descriptor

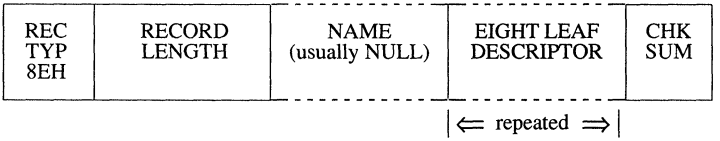
Each GROUP COMPONENT DESCRIPTOR has the following format:

The first byte of the DESCRIPTOR contains 0FFH; the DESCRIPTOR contains one field, which is a SEGMENT INDEX that selects the LSEG described by a preceding SEGDEF record.

Intel defines 4 other group descriptor types, each with its own meaning. They are 0FEH, 0FDH, 0fBH, and 0fAH. The link editor will treat all of these values the same as 0FFH (i.e., it always expects 0FFH followed by a segment index, and it does not check to see if the value is actually 0FF).

TYPE DEFINITION RECORD

(TYPDEF)



The link editor uses TYPDEF records only for communal variable allocation. This is *not* Intel's intended purpose. See "Type Representations for Communal Variables."

As many "EIGHT LEAF DESCRIPTOR" fields as necessary are used to describe a branch. (Every such field except the last in the record describes eight leaves; the last such field describes from one to eight leaves.)

TYPE INDEX values 1 through 32767, which are contained in other record types to associate object types with object names, are defined implicitly by the sequence in which TYPDEF records appear in the object file.

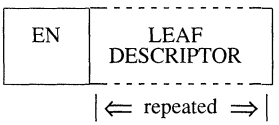
Name

Use of this field is reserved. Translators should place a single byte containing 0 in it (the representation of a name of length zero).

7

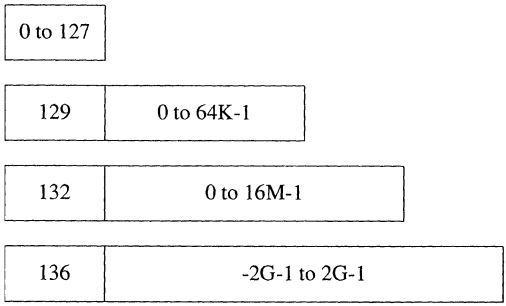
Eight-Leaf Descriptor

This field can describe up to eight Leaves.



The EN field is a byte: the 8 bits, left to right, indicate if the following 8 Leaves (left to right) are Easy (bit=0) or Nice (bit=1).

The LEAF DESCRIPTOR field, which occurs between 1 and 8 times, has one of the following formats:



The first format (single byte), containing a value between 0 and 127, represents a Numeric Leaf whose value is the number given.

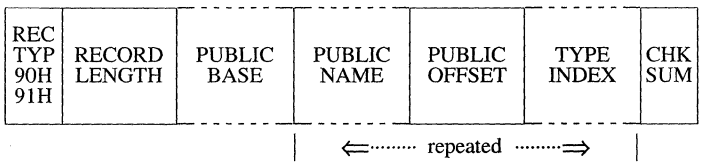
The second format, with a leading byte containing 129, represents a Numeric Leaf. The number is contained in the following two bytes.

The third format, with a leading byte containing 132, represents a Numeric Leaf. The number is contained in the following three bytes.

The fourth format, with a leading byte containing 136, represents a Signed Numeric Leaf. The number is contained in the following four bytes, sign extended if necessary.

PUBLIC NAMES DEFINITION RECORD

(PUBDEF)



This record provides a list of one or more PUBLIC NAMEs; for each one, three data are provided: (1) a base value for the name, (2) the offset value of the name, and (3) the type of entity represented by the name.

In the RECORD TYPE field, 90H and 91H describe 16- and 32-bit publi definition records, respectively.

Public Base

The PUBLIC BASE has the following format:

The GROUP INDEX field has a format given earlier, and provides number between 0 and 32767 inclusive. A non-zero GROUP INDE associates a group with the public symbol, and is used as described in th section of this chapter titled "Conceptual Framework for Fixups," cas (F2c). A zero GROUP INDEX indicates that there is no associated grou

The SEGMENT INDEX field has a format given earlier, and provides number between 0 and 32767, inclusive.

A non-zero SEGMENT INDEX selects an LSEG. In this case, the loca tion of each public symbol defined in the record is taken as a nor negative displacement (given by a PUBLIC OFFSET field) from the firs byte of the selected LSEG, and the FRAME NUMBER field must b absent.

A SEGMENT INDEX of 0 (legal only if GROUP INDEX is also 0) mean that the location of each public symbol defined in the record is taken as displacement from the base of the FRAME defined by the value in th FRAME NUMBER field.

The FRAME NUMBER is present if both the SEGMENT INDEX an GROUP INDEX are zero.

A non-zero GROUP INDEX selects some group; this group is taken as th "frame of reference" for references to all public symbols defined in thi record; that is, **ld** will perform the following:

1. Any fixup of the form:

   TARGET: EI(P)
   FRAME: TARGET

(where "P" is a public symbol in this PUBDEF record) will be converted by **ld** to a fixup of the form:

TARGET: SI(L),d
FRAME: GI(G)

where "SI(L)" and "d" are provided by the SEGMENT INDEX and PUBLIC OFFSET fields. (The "normal" action would have the frame specifier in the new fixup be the same as in the old fixup: FRAME: TARGET.)

2. When the value of a public symbol, as defined by the SEGMENT INDEX, PUBLIC OFFSET, and (optional) FRAME NUMBER fields, is converted to a {base,offset} pair, the base part will be taken as the base of the indicated group. If a non-negative 16-bit offset cannot then complete the definition of the public symbol's value, an error occurs.

A GROUP INDEX of zero selects no group. **ld** will not alter the FRAME pecification of fixups referencing the symbol, and will take, as the base art of the absolute value of the public symbol, the canonic frame of the egment (either LSEG or PSEG) determined by the SEGMENT INDEX ield.

ublic Name

he PUBLIC NAME field gives the name of the object whose location in AS is made available to other modules. The name must contain one or ore characters.

ublic Offset

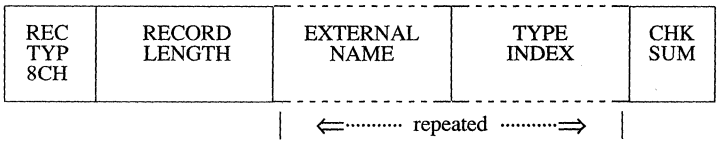
he PUBLIC OFFSET field is a 16-bit value (Rectyp=90H), or a 32-bit alue (Rectyp=91H), which is either the offset of the Public Symbol with espect to an LSEG (if SEGMENT INDEX > 0), or the offset of the Public ymbol with respect to the specified FRAME (if SEGMENT INDEX = 0).

Type Index

The TYPE INDEX field identifies a single preceding TYPDEF (Ty Definition) Record containing a descriptor for the type of enti represented by the Public Symbol. This field is ignored by **ld**.

EXTERNAL NAMES DEFINITION RECORD

(EXTDEF)



This record provides a list of external names, and for each name, the ty of object it represents. **ld** will assign to each External Name the val provided by an identical Public Name (if such a name is found).

External Name

This field provides the name, which must have non-zero length, of external object.

Inclusion of a Name in an External Names Record is an implicit reque that the object file be linked to a module containing the same nar declared as a Public Symbol. This request obtains whether or not t External Name is referenced within some FIXUPP Record in the modul

7

The ordering of EXTDEF Records within a module, together with the or ering of External Names within each EXTDEF Record, induces an orde ing on the set of all External Names requested by the module. Thu External Names are considered to be numbered 1, 2, 3, 4, ... The numbers are used as "External Indices" in the TARGET DATUM and/ FRAME DATUM fields of FIXUPP Records to refer to a particular Exte nal Name.

Note

8086 External Names are numbered positively: 1,2,3,... This is a change from 8080 External Names, which were numbered starting from zero: 0,1,2,... This conforms with other 8086 Indices (Segment Index, Type Index, etc.) which use 0 as a default value with special meaning.

External indices may not reference forward. For example, an external definition record defining the kth object must precede any record referring to that object with index k.

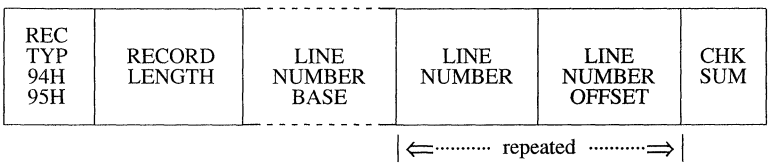
Type Index

This field identifies a single preceding TYPDEF (Type Definition) record containing a descriptor for the type of object named by the External Symbol.

The TYPE INDEX is used only in communal variable allocation by the link editor.

LINE NUMBERS RECORD

(LINNUM)

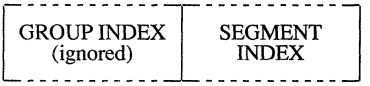


This record provides the means by which a translator may pass the correspondence between a line number in source code and the corresponding translated code.

In the RECORD TYPE field, 94H and 95H describe 16- and 32-bit line number records, respectively.

Line-Number Base

The LINE-NUMBER BASE has the following format:



The SEGMENT INDEX determines the location of the first byte of code corresponding to some source line number.

Line-Number

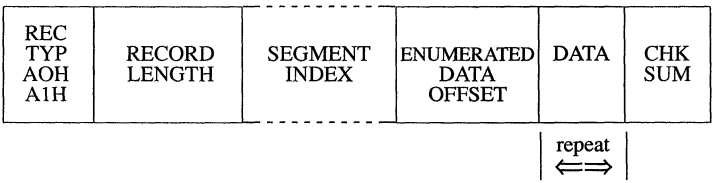
A line number between 0 and 32767, inclusive, is provided in binary by this field. The high-order bit is reserved for future use and must be zero.

Line Number Offset

The LINE-NUMBER OFFSET field is either a 16-bit value (Rectyp=94H) or a 32-bit value (Rectyp=95H) that is the offset of the line number with respect to an LSEG (if SEGMENT INDEX > 0).

LOGICAL ENUMERATED DATA RECORD

(LEDATA)



This record provides contiguous data from which a portion of an 8086 memory image may be constructed.

In the RECORD TYPE field, A0H and A1H describe 16- and 32-bit LEDATA records, respectively.

Segment Index

This field must be non-zero and specifies an index relative to the SEGMENT DEFINITION RECORDS found previous to the LEDATA RECORD.

Enumerated Data Offset

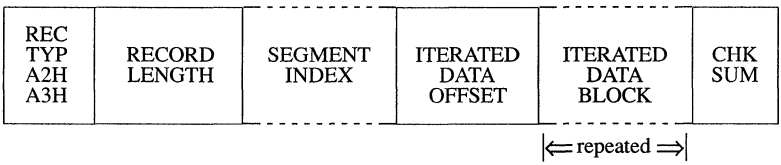
This field specifies either a 16-bit offset (Rectype=A0H) or a 32-bit offset (Rectyp=A1H) that is relative to the base of the LSEG specified by the SEGMENT INDEX and defines the relative location of the first byte of the DAT field. Successive data bytes in the DAT field occupy successively higher locations of memory.

Data

This field provides up to 1024 consecutive bytes of relocatable or absolute data.

LOGICAL ITERATED DATA RECORD

(LIDATA)



This record provides contiguous data from which a portion of an 8086 memory image may be constructed.

In the RECORD TYPE field, A2H and A3H describe 16- and 32-bit LIDATA records, respectively.

Segment Index

This field must be non-zero and specifies an index relative to the SEGDEF records found previous to the LIDATA RECORD.

Iterated Data Offset

This field specifies either a 16-bit offset (Rectype=A2H) or a 32-bit offset (Rectyp=A3H) that is relative to the base of the LSEG specified by the SEGMENT INDEX and defines the relative location of the first byte in the ITERATED DATA BLOCK. Successive data bytes in the ITERATED DATA BLOCK occupy successively higher locations of memory.

Iterated Data Block

This repeated field is a structure specifying the repeated data bytes. The structure has the following format:

Note

The link editor cannot handle LIDATA records whose ITERATED DATA BLOCK is larger than 512 bytes.

Repeat Count

This field specifies the number of times that the CONTENT portion of this ITERATED DATA BLOCK is to be repeated. REPEAT COUNT must be non-zero.

Block Count

This field specifies the number of ITERATED DATA BLOCKS that are to be found in the CONTENT portion of this ITERATED DATA BLOCK. If this field has value zero, then the CONTENT portion of this ITERATED DATA BLOCK is interpreted as data bytes. If non-zero, then the CONTENT portion is interpreted as that number of ITERATED DATA BLOCKs.

Content

This field may be interpreted in one of two ways, depending on the value of the previous BLOCK COUNT field.

If BLOCK COUNT is zero, then this field is a 1-byte count followed by the indicated number of data bytes.

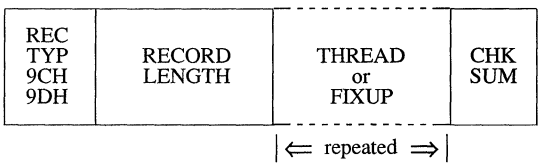
If BLOCK COUNT is non-zero, then this field is interpreted as the first byte of another ITERATED DATA BLOCK.

Note

From the outermost level, the number of nested ITERATED DATA BLOCKS is limited to 17, i.e., the number of levels of recursion is limited to 17.

FIXUP RECORD

(FIXUPP)



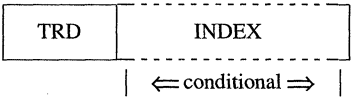
This record specifies 0 or more fixups. Each fixup requests a modification (fixup) to a LOCATION within the previous DATA record. A data record may be followed by more than one fixup record that refers back to it. Each fixup is specified by a FIXUP field that specifies four data: a location, a mode, a target, and a frame. The frame and the target may be specified totally within the FIXUP field, or may be specified by reference to a preceding THREAD field.

A THREAD field specifies a default target or frame that may subsequently be referred to in identifying a target or a frame. Eight threads are provided: four for frame specification and four for target specification. Once a target or frame has been specified by a THREAD, it may be referred to by following FIXUP fields (in the same or following FIXUPP records), until another THREAD field with the same type (TARGET or FRAME) and Thread Number (0 - 3) appears (in the same or another FIXUPP record).

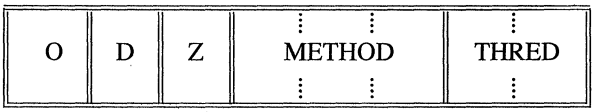
In the RECORD TYPE field, 9CH and 9DH describe 16- and 32-bit FIX-UPP records, respectively.

Thread

THREAD is a field with the following format:



The TRD DAT (ThReaD DATa) subfield is a byte with this internal structure:



The "Z" is a 1-bit subfield, currently without any defined function, that is required to contain 0.

The "D" subfield is one bit that identifies what type of thread is being specified. If D=0, then a target thread is being defined; if D=1, then a frame thread is being defined.

METHOD is a 3-bit subfield containing a number between 0 and 3 (D=0) or a number between 0 and 6 (D=1).

7

If D=0, then METHOD = (0, 1, 2, 3, 4, 5, 6, 7) mod 4, where the 0, ..., 7 indicate methods T0, ..., T7 of specifying a target. Thus, METHOD indicates what kind of INDEX or FRAME NUMBER is required to specify the target, without indicating if the target will be specified in a primary or secondary way. Note that methods 2b, 3, and 7 are not supported by **ld**.

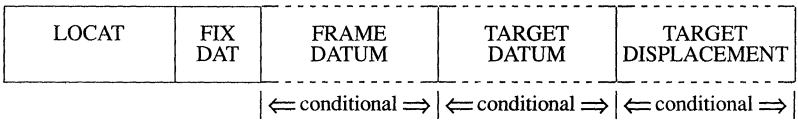
If D=1, then METHOD = 0, 1, 2, 4, 5, corresponding to methods F0, ..., of specifying a frame. Here, METHOD indicates what kind (if any) of Index is required to specify the frame. Note that methods 3 and 5d are not supported by **ld**.

THRED is a number between 0 and 3, and associates a Thread Number to the frame or target defined by the THREAD field.

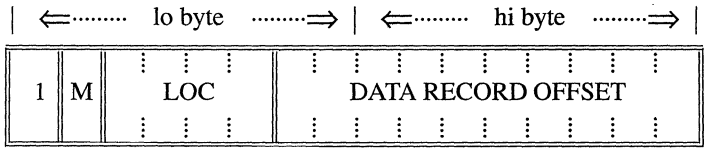
INDEX contains a Segment Index, Group Index, or External Index depending on the specification in the METHOD subfield of the TRD field. This subfield will not be present if F4 or F5 are specified by METHOD.

Fixup

FIXUP is a field with the following format:



LOCAT is a byte pair with the following format:



M is a 1-bit subfield that specifies the mode of the fixups: self-relative (M=0) or segment-relative (M=1).

Note

Self-Relative fixups may not be applied to LIDATA records.

LOC is a four-bit subfield indicating the type of location that is to be fixed up:

0	-	8 bit lobyte
1	-	16 bit offset
2	-	16 bit base
3	-	32 bit pointer
4	-	8 bit hibyte
5	-	16 bit offset (linker resolved)
9	-	32 bit offset
11	-	48 bit pointer
13	-	32 bit offset (linker resolved)

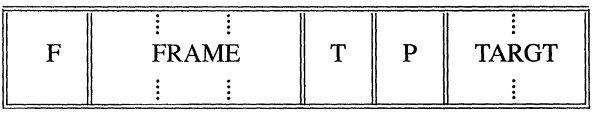
LOC values 9, 11, and 13 are only valid in 32-bit FIXUPP records (record type 9D). All values not mentioned are invalid.

The DATA RECORD OFFSET is a number between 0 and 1023, inclusive, that gives the relative position of the lowest order byte of LOCATION (the actual bytes being fixed up) within the preceding DATA record. The DATA RECORD OFFSET is relative to the first byte in the data fields in the DATA RECORDs.

Note

It is possible for the value of DATA RECORD OFFSET to designate a "location" within a REPEAT COUNT subfield or a BLOCK COUNT subfield of the ITERATED DATA field. Such a reference is an error. The action of **ld** on such a malformed record is undefined.

FIX DAT is a byte with the following format:



Note

Frame method 2b, F3, and F5d are not supported. Target method T3 and T7 are not supported.

F is a 1-bit subfield that specifies whether the frame for this FIXUP is specified by a thread (F=1) or explicitly (F=0).

FRAME is a number interpreted in one of two ways as indicated by the F bit. If F is zero, FRAME is a number between 0 and 5 and corresponds to methods F0, ..., F5 of specifying a FRAME. If F=1, then FRAME is a thread number (0-3). It specifies the frame most recently defined by a THREAD field that defined a frame thread with the same thread number. (Note that the THREAD field may appear in the same, or in an earlier FIXUPP record.)

''T'' is a 1-bit subfield that specifies whether the target specified for this fixup is defined by reference to a thread (T=1), or is given explicitly in the FIXUP field (T=0).

''P'' is a 1-bit subfield that indicates whether the target is specified in a primary way (requires a TARGET DISPLACEMENT, P=0) or specified in a secondary way (requires no TARGET DISPLACEMENT, P=1). Since a target thread does not have a primary/secondary attribute, the P bit is the only field that specifies the primary/secondary attribute of the target specification.

TARGT is interpreted as a 2-bit subfield. When T=0, it provides a number between 0 and 3, corresponding to methods T0, ..., T3 or T4, ..., T7, depending on the value of P (P can be interpreted as the high-order bit of T0, ..., T7). When the target is specified by a thread (T=1), then TARGT specifies a thread number (0-3).

FRAME DATUM is the ''referent'' portion of a frame specification, and is a Segment Index, a Group Index, or an External Index. The FRAME DATUM subfield is present only when the frame is specified neither by a thread (F=0) nor explicitly by methods F4 or F5 or F6.

TARGET DATUM is the ''referent'' portion of a target specification, and is a Segment Index, a Group Index, an External Index, or a Frame Number. The TARGET DATUM subfield is present only when the target is not specified by a thread (T=0).

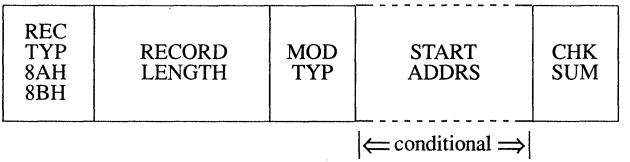
TARGET DISPLACEMENT is the displacement required by ''primary'' methods of specifying TARGETs. This field is 2 bytes long in 16-bit FIXUPP records (Rectyp=9CH) and 4 bytes long in 32-bit FIXUPP records (Rectyp=9DH). This subfield is present if P=0.

Note

All these methods are described in the section of this chapter titled "Conceptual Framework for Fixups."

MODULE END RECORD

(MODEND)

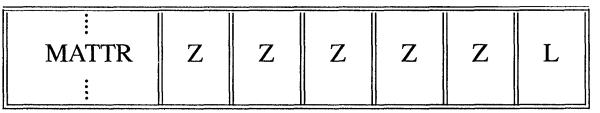


This record serves two purposes. It denotes the end of a module and indicates whether the module just terminated has a specified entry point for initiation of execution. If the latter is true, the execution address is specified.

In the RECORD TYPE field, 8AH and 8BH describe 16- and 32-bit MODEND records, respectively.

Mod Type

This field specifies the attributes of the module. The bit allocation and associated meanings are as follows:



MATTR is a 2-bit subfield that specifies the following module attributes:

MATTR	MODULE ATTRIBUTE
0	Non-main module with no START ADDRS
1	Non-main module with START ADDRS
2	Main module with no START ADDRS
3	Main module with START ADDRS

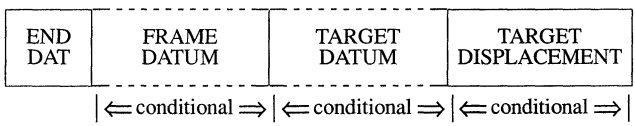
"L" indicates whether the START ADDRS field is interpreted as a logical address that requires fixing up by **ld** (L=1). Note that with **ld**, L must always equal 1.

"Z" indicates that this bit has not currently been assigned a function. These bits are required to be zero.

Physical start addresses (L=0) are not supported.

The START ADDRS field (present only if MATTR is 1 or 3) has the following format:

START ADDRS



The starting address of a module has all the attributes of any other logical reference found in a module. The mapping of a logical starting address to a physical starting address is done in exactly the same manner as mapping any other logical address to a physical address as specified in the discussion of fixups and the FIXUPP record. The above subfields of the START ADDRS field have the same semantics as the FIX DAT, FRAME DATUM, TARGET DATUM, and TARGET DISPLACEMENT fields in the FIXUPP record. Only "primary" fixups are allowed. Frame method F4 is not allowed.

The TARGET DISPLACEMENT field is 2 bytes in a 16-bit MODEND record (Rectyp=8AH) and 4 bytes in a 32-bit MODEND record (Rectyp=8BH).

COMMENT RECORD

(COMENT)

REC TYP 88H	RECORD LENGTH	COMMENT TYPE	COMMENT	CHK SUM

This record allows translators to include comments in object text.

Comment Type

This field indicates the type of comment carried by this record. This allows comments to be structured for those processes that wish to selectively act on comments. The format of this field is as follows:

NP	NL	Z	Z	Z	Z	Z	Z	COMMENT CLASS

The NP (NOPURGE) bit, if 1, indicates that it is not able to be purged by object file utility programs which implement the capability of deleting COMENT record.

The NL (NOLIST) bit, if 1, indicates that the text in the COMMENT field is not to be listed in the listing file of object file utility programs which implement the capability of listing object COMMENT records. In the above diagram, "Z" indicates no value and must equal zero.

The COMMENT CLASS field is defined as follows:

0	Language translator comment.
1	Intel copyright comment. The NP bit must be set.
2-155	Reserved for Intel use. (See Note 1 below.)
156-255	Reserved for users. Intel products will apply no semantics to these values. (See Note 2 below.)

NOTES:

1. Class value 159 is used to specify a library to add to the link editor's library search list. The comment field will contain the name of the library. Note that unlike all other name specifications, the library name is not prefixed with its length. Its length is determined by the record length.

2. Class value 156 is used to specify a DOS level number. When the class value is 156, the comment field will contain a two-byte integer specifying a DOS level number.

3. Class value 161 is used to indicate that the module contains UNIX System V extensions to OMF, such as the various 32-bit record types.

Comment

This field provides the commentary information.

Numeric List of Record Types

*6E	RHEADR	*92	LOCSYM
*70	REGINT	*93	MLOC386
*72	REDATA	94	LINNUM
*74	RIDATA	95	MLIN386
*76	OVLDEF	96	LNAMES
*78	ENDREC	98	SEGDEF
*7A	BLKDEF	99	MSEG386
*7C	BLKEND	9A	GRPDEF
*7E	DEBSYM	9C	FIXUPP
80	THEADR	9D	MFIX386
*82	LHEADR	*9E	(none)
*84	PEDATA	A0	LEDATA
*86	PIDATA	A1	MLED386
88	COMENT	A2	LIDATA
8A	MODEND	A3	MLID386
8B	H386END	*A4	LIBHED
8C	EXTDEF	*A6	LIBNAM
8E	TYPDEF	*A8	LIBLOC
90	PUBDEF	*AA	LIBDIC
91	MPUB386		

Note

The record types marked with an asterisk are not supported by the link editor. They will be ignored if they are found in an object module.

Type Representations for Communal Variables

This section defines the UNIX System V standard for communal variable allocation on the 8086 and 80286.

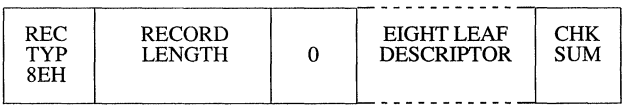
A communal variable is an uninitialized public variable whose final size and location are not fixed at compile time. Communal variables are similar to FORTRAN common blocks in that if a communal variable is declared in more than one object module being linked together, then its actual size will be the largest size specified in the several declarations. In the C language, all uninitialized public variables are communal. The following example shows three different declarations of the same C communal variable:

```
char  foo[4];          /* In file a.c */
char  foo[1];          /* In file b.c */
char  foo[1024];       /* In file c.c */
```

If the objects produced from a.c, b.c, and c.c are linked together, then the linker will allocate 1024 bytes for the char array "foo."

A communal variable is defined in the object text by an external definition record (EXTDEF) and the type definition record (TYPDEF) to which it refers.

The TYPDEF for a communal variable has the following format:

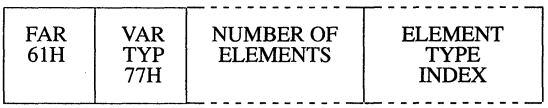


The EIGHT LEAF DESCRIPTOR field has the following format:

The EN field specifies whether the next 8 leaves in the LEAF DESCRIPTOR field are EASY (bit = 0) or NICE (bit = 1). This byte is always zero for TYPDEFS for communal variables.

The LEAF DESCRIPTOR field has one of the following two formats. The format for communal variables in the default data segment (near variables) is as follows:

The VAR TYP field may be either SCALAR (7BH), STRUCT (79H), or ARRAY (77H). The VAR SUBTYP field (if any) is ignored by **ld**. The format for communal variables not in the default data segment (far variables) is as follows:



The VARiable TYPe field must be ARRAY (77H). The length field specifies the NUMBER OF ELEMENTS, and the ELEMENT TYPE INDEX is an index to a previously defined TYPDEF whose format is that of a near communal variable.

The format for the LENGTH IN BITS or NUMBER OF ELEMENTS fields is the same as the format for the LEAF DESCRIPTOR field, described in the TYPDEF record format section of this chapter.

Link Time Semantics

All EXTDEFs referencing a TYPDEF of the previously described formats are treated as communal variables. All others are treated as externally defined symbols for which a matching public symbol definition (PUBDEF) is expected. A PUBDEF matching a communal variable definition will override the communal variable definition. Two communal variable definitions are said to match if the names given in the definitions match. If two matching definitions disagree as to whether a communal variable is near or far, the linker will assume the variable is near.

If the variable is near, then its size is the largest specified for it. If the variable is far, then the link editor issues a warning if there are conflicting array element size specifications; if there are no such conflicts, then the variable's size is the element size times the largest number of elements specified. The sum of the sizes of all near variables must not exceed 64K bytes. The sum of the sizes of all far variables must not exceed the size of the machine's addressable memory space.

"Huge" Communal Variables

A far communal variable whose size is larger than 64K bytes will reside in segments that are contiguous (8086) or have consecutive selectors (80286). No other data items will reside in the segments occupied by a huge communal variable.

If the linker finds matching huge and near communal variable definitions, it issues a warning message, since it is impossible for a near variable to be larger than 64K bytes.

The Segmented x.out Format

This section describes the executable object file format used in XENIX System V and in UNIX System V when the **-xenix** option is used. The format used is an extension to the existing *x.out* format, specifically enhanced for the segmented architecture of the 286 CPU. Note that *x.out* is a name for the format of the file, the actual executable file will be called a.out by default.

The UNIX System V linker (*/bin/ld*, see the "Linking with the cc Command" chapter) will link the Intel 86 Relocatable Object Module Format into the executable format described in this section.

The UNIX System V product supports a subset of segmented OMF. Other parts are specified here for use by other vendors, and to reserve their meaning for possible future use. Those parts supported in this release of UNIX System V are:

- The x.out header
- The x.out extended header
- The file segment table
- Multiple non-iterated text segments
- Multiple non-iterated data segments
- Symbol table segments in the format described herein

Note specifically that the machine-dependent table is *not* supported. The iterated text/data feature is supported by the kernel, but the UNIX System V linker will expand iterated records.

General Description of x.out

The following is a general description of the *x.out* object file format, extended to handle segmentation. It implements iterated text and data segments, huge, large, middle, and small model, as well as block alignment to improve the efficiency of loading executable files.

Note

The default file name produced by the linker is *a.out* regardless of the actual file format used. Any mention of x.out in this guide is referring only to the *format* of OMF executable files.

The extensions to the existing format consist of adding a file segment table that describes and points to various (possibly block-aligned) file segments. A file segment may contain a memory image, may indicate how to construct a memory image (iterated text or data), or may contain symbols or other non-executable information. In addition to the file segment table, there is an optional machine-dependent table.

The header must be first item in the object file, and the extended header must immediately follow the header. The extended header indicates the segment and (optional) machine-dependent tables' sizes and positions. Although the segment table is not block aligned, individual entries will line up on a multiple of 32 bytes (the size of a segment table entry). The segment table indicates the sizes and positions of the remaining file segments. The file segments may be aligned on a boundary that is a multiple of 512 bytes, with that multiple stored in the extended header, or at location zero if the file segments are not block aligned.

The segment table is an array of records describing the file segments, each containing:

- A segment type: text, data, symbols, etc.
- Segment attributes, specific to the type of segment.
- A file pointer to the (possibly iterated) text/data for this segment.
- A physical size, the size of the segment in the file.
- A virtual size, the size the segment will occupy in memory.
- A location counter, this segment's current base address, usually 0.

A sample of a segment table entry is shown below. The *xs* fields in this data structure are referred to throughout the remaining discussion in this section.

Segment table entry

```
struct xseg {                                   /* x.out segment table entry */
        unsigned shortxs_type;          /* segment type */
        unsigned short  xs_attr;        /* segment attributes */
        unsigned short  xs_seg;         /* segment number */
        unsigned short  xs_sres;        /* unused */
        long            xs_filpos;              /* file position */
        long            xs_psize;               /* physical size (in file) */
        long            xs_vsize;               /* virtual size (in core) */
        long            xs_rbase;               /* relocation base address */
        long            xs_lres;                /* unused */
        long            xs_lres2;               /* unused */
};
```

The segment table is a contiguous array of the above structures. Each file segment has a corresponding segment table entry that describes the segment's position *xs_filpos* and physical size *xs_psize* in the file. If there is no associated file segment, both fields must be set to zero.

The kernel's local descriptor table (LDT) can be built from the virtual size, the segment type, and segment attribute fields.

Example of File Layout

This section provides an example of the layout of an *x.out* file where:

- The segment table has two entries (segments).
- The file page size is 512 bytes.
- Both file segments are smaller than 512 bytes.
- The second file segment contains iterated data.

Accessing the machine-dependent table and the file segment table must always be done through the absolute file pointers in the extended header. The ordering of the two tables and file segments shown above is not required to be consistent with the *x.out* UNIX System V specification.

Iterated Segments

The data structure for an iterated segment is shown below:

```
struct xiter {
        long            xi_size;        /* byte count */
        long            xi_rep;/* replication count */
        long            xi_offset;      /* destination offset in segment */
};
```

If the segment contains iterated text/data (indicated by a bit in the *xs_attr* field), the *xs_filpos* field is the file position of some number of iteration records mixed with the text/data to be iterated. If any part of a segment is iterated, then all of that segment is represented as iterated; non-iterated portions may be represented by an iteration record with a replication count of one.

The format of the text/data to be iterated is:

<iteration record> <text/data> <iteration record> <text/data> ...

where each <iteration record> is of the above "struct xiter" data structure. Each iteration record is followed by *xi_size* bytes of text/data that are to be placed in the current segment at the specified offset *xi_offset* *xi_rep* times. When *xs_psize* bytes of iteration records and text/data have been expanded, the iteration is complete.

Under UNIX System V, areas of memory that are initialized by more than one iteration record will have the contents of those memory areas undefined. Areas of memory that are not initialized by any iteration records will be zeroed out. An iteration byte count *xi_size* of zero will not result in any iteration. Portions of a segment that are to be **bss** sections should use an iteration record with a non-zero byte count and replicate one or more zeroed data bytes. For more information on **bss** sections, see the chapter on the Common Object File Format in this book.

This representation of iterated text/data will handle iterations that contain very large replication counts and/or very large non-iterated sizes.

Non-Iterated Segments and Implicit bss

If the iteration bit in *xs_attr* is **not** set, no iterations are required to initialize the segment. If the implicit bss bit in the *xs_attr* field is set and the virtual size is greater than the physical size, then the rest of the segment (up to *xs_vsize* bytes) is filled with zeros by the kernel loader. This implicit bss definition means that small and middle model executables' single data segments may still contain unexpanded bss without the use of explicit iteration records.

Segments made up entirely of implicit "C" bss need only set the physical size to zero, and set the implicit bss bit. This eliminates the need for any file segment containing data or iteration records. If there are no iterations and no implicit bss, the virtual size of the segment *xs_vsize* must be the same as the physical size *xs_psize*, and a single copy of the text/data located at *xs_filpos* is all that is required to initialize the segment.

Large Model

With *x.out* format, large model is supported by allowing multiple logical text and/or data segments. Middle and small models are simpler cases, with perhaps single logical segments for data (or both text and data). Iterated segments are independent of memory model.

Special Header Fields

The model bits in the *x_renv* field of the main header, XE_LDATA and XE_LTEXT, usually indicate the default size of data and text pointers used in the executable code. The kernel depends on these two bits to indicate the size of data and text pointers passed in system calls. However, since multiple segments are allowed in small and middle model, there can be little other meaning attached to these bits. Passing near data and/or text pointers implies use of the first data and text segments, respectively.

Also in the *x_renv* field, the absolute bit, XE_ABS, identifies a standalone executable file. When this bit is set, the extended header stack size field is used as the default physical load address. The UNIX System V kernel loader will not load a binary if the XE_ABS bit is set. The UNIX System V boot loader will not load a binary unless the XE_ABS bit is set. See the manual page on **ld(CP)** for information about how to set the XE_ABS bit and the physical load address.

Symbol Table

The data structure for the *x.out* symbol table is shown below:

```
struct sym {                        /* x.out symbol table entry */
        unsigned short s_type;
        unsigned short s_seg;
        long                s_value;
};
```

The symbol table differs from the previous *x.out* format only in that the *s_seg* field now holds the selector of the segment that defines the symbol. If the symbol is absolute, the value field holds the symbol's value; otherwise, it holds the offset in the indicated segment to which the symbol refers.

The symbol name trails the above "struct sym" data structure in the form of a null terminated string. The type field values are defined in */usr/include/sys/relsym.h*.

The use of the *xs_seg* field in the segment table is undefined for symbol table segments. Its use may be defined by the particular symbol table format used.

UNIX System V Executable Format

UNIX System V does not execute binaries that make use of selectors below 0x3f or selectors that do not have the low 3 bits set (LDT, ring 3). UNIX System V also requires that the first data selector be after the last text selector. Binaries are allowed to have zero length segments or "holes" (unused selectors) in text or data, but holes in text may not contain data selectors, and holes in data may not contain text selectors.

The fields, *xext.xe_eseg:xexec.x_entry*, must contain the initial **cs:ip** addresses of the user process. **cs:ip** are the addresses of the starting segments of the program to be run.

Small-model impure binaries (text and data combined into a single segment) must have a single file segment, of type data, with a selector of at least 0x47. It must contain all text, followed by all data, followed by bss. The sizes of each must be stored in the *x_text*, *x_data*, and *x_bss* fields of the main header. UNIX System V uses the value stored in the *xext.xe_eseg* field as the text selector, which must be at least 0x3f and less than the data selector. All text/data/bss binaries are executable through the text selector, and all text/data/bss binaries are readable and writable through the data selector. UNIX System V maps the text selector to the same memory as the data selector.

In addition to the above, the linker, **ld**, generates binaries that conform to the following:

- Text selectors start at 0x3f.
- Data selectors start at the first free selector past text.
- All text selectors are contiguous.
- All data selectors are contiguous.
- Small-model impure binaries conform to the above specification, with 0x47 as the data selector. In the symbol table, the selector 0x47 is associated with data symbols, and the selector 0x3f is associated with text symbols, to allow **adb** and **nm** to present consistent data to the user.

Selected Portions of Include Files

The following are selected portions of the *usr/include/sys/x.out.h* and *usr/include/sys/relsym.h* include files:

```
struct xexec {
        /* x.out header */
        unsigned short x_magic;
                /* magic number */
        unsigned short x_ext;
                /* size of header extension */
        long            x_text;
                /* size of text segment */
        long            x_data;
                /* size of initialized data */
        long            x_bss;
                /* size of uninitialized data */
        long            x_syms;
                /* size of symbol table */
        long            x_reloc;
                /* relocation table length */
        long            x_entry;
                /* entry offset, see xe_eseg */
        char            x_cpu;
                /* cpu type & byte/word order */
        char            x_relsym;
                /* relocation & symbol format */
        unsigned short x_renv;
                /* run-time environment */
};
```

```
struct xext {
        /* x.out header extension */
        long            xe_trsize;
                /* size of text relocation */
        long            xe_drsize;
                /* size of data relocation */
        long            xe_drsize;
                        /* size of data relocation */
        long            xe_dbase;
                /* data relocation base */
        long            xe_stksize;
                /* stack size (if XE_FS set) */
        long            xe_segpos;
                /* segment table position */
        long            xe_segsize;
                /* segment table size */
        long            xe_mdtpos;
                /* machine dependent table position */
        long            xe_mdtsize;
                /* machine dependent table size */
        char            xe_mdttype;
                /* machine dependent table type */
        char            xe_pagesize;
                /* file pagesize, in multiples of 512 */
        char            xe_ostype;
                /* operating system type */
        char            xe_osvers;
                /* operating system version */
        unsigned short xe_eseg;
                /* entry segment (hardware dependent) */
        unsigned short xe_sres;
                /* reserved */
};

/*
 *      Definitions for xexec.x_renv (short).
 *
 *      vv      version compiled for
 *      xx      extra (zero)
 *      s       set if segmented x.out
 *      a       set if absolute (set up for physical address)
 *      i       set if segment table contains iterated text/data
 *      h       set if huge model data
 *      f       set if floating point hardware required
 *      t       set if large model text
 *      d       set if large model data
 *      o       set if text overlay
 *      f       set if fixed stack
 *      p       set if text pure
 *      s       set if separate I & D
 *      e       set if executable
 */
```

```
#define XE_V2          0x4000
        /* up to and including 2.3 */
#define XE_V3          0x8000
        /* after version 2.3 */
#define XE_VERS        0xc000
        /* version mask */

#define XE_SEG 0x0800
        /* segment table present */
#define XE_ABS 0x0400
        /* absolute memory image (standalone) */
#define XE_ITER        0x0200
        /* iterated text/data present */
#define XE_HDATA       0x0100
        /* huge model data */
#define XE_FPH 0x0080
        /* floating point hardware required */
#define XE_LTEXT       0x0040
        /* large model text */
#define XE_LDATA       0x0020
        /* large model data */
#define XE_OVER        0x0010
        /* text overlay */
#define XE_FS          0x0008
        /* fixed stack */
#define XE_PURE        0x0004
        /* pure text */
#define XE_SEP 0x0002
        /* separate I & D */
#define XE_EXEC        0x0001
        /* executable */


struct xseg {
        /* x.out segment table entry */
        unsigned short xs_type;
                /* segment type */
        unsigned short xs_attr;
                /* segment attributes */
        unsigned short xs_seg;
                /* segment number */
        unsigned short xs_sres;
                /* unused */
        long           xs_filpos;
                /* file position */
        long           xs_psize;
                /* physical size (in file) */
        long           xs_vsize;
                /* virtual size (in core) */
        long           xs_rbase;
                /* relocation base address */
        long           xs_lres;
                /* unused */
        long           xs_lres2;
                /* unused */
};
```

```
struct xiter {
        /* x.out iteration record */
        long            xi_size;
                /* byte count */
        long            xi_rep;
                /* # of repetitions */
        long            xi_offset;
                /* destination offset in segment */
};


struct sym {
        /* x.out symbol table entry */
        unsigned short s_type;
        unsigned short s_seg;
        long            s_value;
};


/*
 *      Definitions for xe_mdttype
 */
#define XE_MDTNONE      0
        /* no machine dependent table */
#define XE_MDT286               1
        /* iAPX286 LDT */

/*
 *      Definitions for xe_ostype
 */
#define XE_OSNONE       0
#define XE_OSUNIX System V      1
        /* UNIX System V */
#define XE_OSRMX        2
        /* iRMX */

/*
 *      Definitions for xe_osvers
 */
#define XE_OSXV3        1
        /* UNIX System V */


/*
 *      Definitions for xs_type:
 *        Values from 64 to 127 are reserved.
 */
#define XS_TNULL        0       /* unused segment */
#define XS_TTEXT        1       /* text segment */
#define XS_TDATA        2       /* data segment */
#define XS_TSYMS        3       /* symbol table segment */
#define XS_TREL4                /* relocation segment */
```

```
/*
 *     Definitions for xs_attr:
 *         The top bit is set if the file segment represents
 *         a memory image. The other 15 bits' definitions
 *         depend on the type of file segment.
 */
#define XS_AMEM       0x8000
       /* segment represents a memory image */
#define XS_AMASK      0x7fff
       /* type specific field mask */

/*
 *     Definitions for xs_attr, built by or'ing the following
 *     bit patterns:  these values are valid for XS_TTEXT and
 *     XS_TDATA file segments only.
 */
#define XS_AITER      0x0001
       /* contains iteration records */
#define XS_AHUGE      0x0002
       /* contains huge element */
#define XS_ABSS       0x0004
       /* contains implicit bss */
#define XS_APURE      0x0008
       /* is read-only, may be shared */
#define XS_AEDOWN     0x0010
       /* segment expands downward */

/*
 *     Definitions for xs_attr.
 *     These values are valid for XS_TSYMS file segments only.
 */
#define XS_SXSEG      0x0001
       /* x.out segmented format */
```

When using the *xs_seg* field, note that if the XS_AMEM bit is set in the *xs_attr* field, the file segment represents a memory image, and the value placed in this field should be the segment number as used by the hardware to reference the segment. This is the actual value placed in the segment register. For the 286, it is simply an LDT selector (under UNIX System V, if the privilege level is not 3, the file will not be executed). Otherwise the segment is not a memory image, and the contents of the field are not defined. File segments other than memory images may define and use this field as needed.

There are two bits in the *xexec.x_cpu* field that are used to indicate the CURRENT byte and word ordering of the non-character data fields of the header, extended header, segment table, and symbol table. These bits, XC_BSWAP and XC_WSWAP, do not indicate the byte and word ordering of the target CPU, XC_CPU.

The segment table is not block aligned. No individual segment table entry may straddle a block boundary.

Chapter 8

C Language Compatibility with Assembly Language

Introduction 8-1

C Calling Sequence for 8086/80286 8-2

Entering an 8086/80286 Assembly Routine 8-3

8086/80286 Return Values 8-4

Exiting an 8086/80286 Routine 8-5

8086/80286 Program Example 8-6

80386 C-Language Calling Sequence 8-7

Entering an 80386 Assembly-Language Routine 8-8

80386 Return Values 8-9

Exiting an 80386 Routine 8-11

80386 Program Example 8-12

Introduction

This chapter explains how to use 8086/286/386 assembly-language routines with C-language programs and functions. In particular, it explains how to call assembly-language routines from C-language programs and how to call C-language functions from an assembly-language routine.

This assembly-language interface is especially useful for those assembly-language programmers who wish to use the functions of the standard C library and other C libraries.

Note

Two different calling conventions are available. The 8086/80286 calling convention is established by configuring C-language programs with the **-M0**, **-M1**, or **-M2** option. The 80386 calling convention is established by configuring C-language programs with the **-M3** option.

C Calling Sequence for 8086/80286

To receive values from C-language function calls or to pass values to C functions, assembly-language routines must follow the C argument passing conventions. C-language function calls pass their arguments to the given functions by pushing the value of each argument onto the stack. The call pushes the value of the last argument first and the first argument last. If an argument is an expression, the call computes the expression's value before pushing it onto the stack.

Arguments with **char**, **int**, or **unsigned** type occupy a single word (16 bits) on the stack. Arguments with **long** type occupy a double word (32 bits) with the value's high-order word occupying the first word pushed onto the stack. Arguments with **float** type are converted to **double** type (64 bits). Note that **char** type arguments are zero-extended to **int** type before being pushed on the stack.

If an argument is a structure, the function call pushes the last word of the structure first and each successive word in turn until the first word is pushed.

After a function returns control to a routine, the calling routine is responsible for removing arguments from the stack.

Entering an 8086/80286 Assembly Routine

Assembly-language routines that receive control from C function calls should preserve the contents of the **BP**, **SI**, and **DI** registers and set the **BP** register to the current **SP** register value before proceeding with their tasks. The following example illustrates the recommended instruction sequence for entry to an assembly-language routine:

```
entry:
        push    bp
        mov     bp,sp
        push    di
        push    si
```

This is the same sequence used by the C compiler.

If this sequence is used, the last argument passed by the function call (which is also the first argument given in the call's argument list) is at address ''[bp+4]''. Subsequent arguments begin at address ''[bp+6]'' or ''[bp+8]'' depending on the size of the first argument.

This sequence is strongly recommended even if the **SI** and **DI** registers are not modified, since it allows backtracing with the **adb** program during program debugging.

8086/80286 Return Values

Assembly-language routines that wish to return values to a C-language program or receive return values from C functions must follow the C return value conventions. C functions place return values that have **int**, **char**, or **unsigned** type in the **AX** register. They place values with **long** type in the **AX** and **DX** registers, with the high order word in **DX**.

To return a structure or a floating point value, C functions place the address of the given value in the **AX** register. The structure or floating point value must be in a static area in memory. Long addresses are returned in the **AX** and **DX** registers with the segment selector in **DX**.

Exiting an 8086/80286 Routine

Assembly-language routines that return control to C programs should restore the values of the **BP**, **SI**, and **DI** registers before returning control. The following example illustrates the recommended instruction sequence for exiting a routine:

```
pop   si
pop   di
mov   sp, bp
pop   bp
ret
```

This sequence does not change the **AX, BX, CX,** or **DX** registers or any of the segment registers. It also does not remove arguments from the stack. This is the responsibility of the calling routine.

8086/80286 Program Example

To illustrate the assembly-language interface, consider the following example of a C function:

```
add(i,j)
int i,j;
{
      return(i+j);
}
```

If written as an assembly-language routine, this function must save the proper registers, retrieve the arguments from the stack, add the arguments, place the return value in the **AX** register, then restore registers and return control. The following is a example of how the routine can be written:

```
_add:
      push  bp
      mov   bp,sp
      push  di
      push  si

      mov   ax,[bp+4]
      add   ax,[bp+6]

      pop   si
      pop   di
      mov   sp, bp
      pop   bp
      ret
```

If, on the other hand, the C function is to be called by an assembly-language routine, the routine must contain instructions that push the arguments on the stack in the proper order, call the function, and clear the stack. It may then use the return value in the **AX** register. The following is an example of the instructions that can do this:

```
push  <j value>
push  <i value>
call  _add
add   sp,*4
```

Note that the C compiler does not preserve **ES** over calls. Assembly-language routines need not preserve **ES** and should not assume that it will be preserved if they make calls to routines written in C.

80386 C-Language Calling Sequence

To receive values from 80386 C-language function calls, or to pass values to 80386 C-language functions, assembly-language routines must follow the 80386 C-language argument-passing conventions.

C-language function calls pass arguments to the function by pushing each argument onto the stack. The call pushes the last function argument first and the first function argument last onto the stack. If an argument is an expression, the call computes the expression's value before pushing it onto the stack.

Arguments with **char**, **int**, **unsigned**, **short**, or **long** type occupy a doubleword (32 bits or 4 bytes) on the stack. Arguments with **float** type are converted to **double** type (64 bits or 8 bytes). Note that **char**, **unsigned char**, **short**, and **unsigned short** type arguments are sign extended or zero extended, respectively, to **int** type before being pushed onto the stack.

If an argument is a structure, the function call pushes the last word of the structure first and each successive word in turn until the first word of the structure is pushed onto the stack.

After a function returns control to the calling routine, the calling routine is responsible for removing all function arguments from the stack.

Entering an 80386 Assembly-Language Routine

Assembly-language routines that receive control from 80386 C function calls should preserve the contents of the **EBP**, **ESI**, **EDI**, and **EBX** registers. In addition, the routines should set the **EBP** register to the current **ESP** register value before proceeding with their tasks. The following example illustrates a recommended instruction sequence for entry to an assembly-language routine:

```
entry:
      push    ebp
      mov     ebp,esp
      push    edi
      push    esi
      push  ebx
```

Note that this is the same routine that the compiler uses after pushing the function arguments onto the stack.

If this sequence is used, the last function argument pushed by the function call (which is also the first argument in the function's argument list) is at address "[ebp+8]". Subsequent arguments are at address "[ebp+12]" or "[ebp+16]", depending on the size of the argument pushed onto the stack at "8[ebp]".

80386 Return Values

Assembly-language routines that return values to an 80386 C-language program or receive return values from 80386 C-language functions must follow the 80386 C-language return-value conventions. C-language functions place return values that have **int**, **char**, **unsigned**, **short**, and **long** types in the **EAX** register.

Floating-point values are returned to the top of the ndp 80287 stack. The following example shows the recommended instruction sequence for passing floating-point values:

```
float func(),f;
f = func(f)
      fld   DWORD PTR f
      sub   esp,8
      fstp  QWORD PTR [esp]
      call  func        ; result in ST(0)
      add   esp,8
      fstp  DWORD PTR f
```

The following example shows the recommended instruction sequence for returning floating-point values:

```
float fvalue;
return (fvalue);
      fld   fvalue            ; result in ST(0)
      pop   edx
      pop   esi
      pop   edi
      leave
      ret
```

C-language structure returns are returned to a buffer whose address is passed as a hidden first parameter.

The following example shows the recommended instruction:

```
struct shape
{
        int stuff, to, fill, it, with;
} in, out, them();
out = them(in);

        sub     esp,20
        mov     edi,esp
        lea     edi,in          ; structure copy input
        mov     ecx,5           ; struct onto stack
        rep     movsd
        lea     eax,out         ; pass address of
        push    eax             ; assignment as extra "hidden"
        call    them              ;parameter
        add     esp,24
```

The following example shows the recommended instruction sequence for returning C-language structure returns:

```
struct shape source;
return shape;
        mov     edi,[ebp+8]
        mov     esi,source
        mov     ecx,5
        rep     movsd
        pop     ebx
        pop     esi
        pop     edi
        leave
        ret
```

Exiting an 80386 Routine

Before returning control from an assembly-language routine to an 80386 C-language program, restore the **EBP**, **ESI**, **EDI**, and **EBX** registers. The following example illustrates the recommended instruction sequence for exiting a routine:

```
pop   ebx
pop   esi
pop   edi
leave
ret
```

This sequence does not save the **EAX**, **ECX**, or **EDX** register. These registers are scratch registers for use by the compiler. If the routine modifies segment register **ES**, **SS**, or **DS**, the routine must preserve the modified segment registers. The sequence does not remove arguments from the stack. This is the responsibility of the calling routine.

80386 Program Example

The following example illustrates an 80386 C-language function that can be written as an assembly-language routine. The function takes two integer arguments and adds them together, returning the resultant value.

```
int add(i, j)
int i, j;
{
return(i + j);
}
```

If written as an assembly-language routine, this function must save the proper registers, retrieve the arguments from the stack, add the arguments, place the return value in the **EAX** register, then restore the proper registers and return control to the calling routine. The following is an example of how the routine can be written:

```
_add:
     push  ebp
     mov   ebp,esp
     push  edi
     push  esi
     push  ebx

     mov   eax,[ebp+8]
     add   eax,[ebp+12]

     pop   ebx
     pop   esi
     pop   edi
     mov   esp, ebp
     pop   ebp
     ret
```

Note

In the above assembly-language routine, it is not necessary to save the contents of the **ESI**, **EDI**, and **EBX** registers because the routine does not modify their contents. If the **ESI**, **EDI**, or **EBX** register was modified by the routine, its contents must be saved.

If the C-language function is to be called by an assembly-language routine, the routine must contain instructions that push the arguments onto the stack in the proper order, call the function, and clear the stack. It can then use the return value in the **EAX** register. The following is an example of the instructions that perform this task:

```
push <j value>
push <i value>
call _add
add     esp,8
```

Chapter 9

Error Processing

ıtroduction 9-1

'sing the Standard Error File 9-2

'sing the errno Variable 9-3

rinting Error Messages 9-4

'sing Error Signals 9-5

ncountering System Errors 9-6

Introduction

System V automatically detects and reports errors that occur when using standard C library functions. Errors range from problems with accessing files to allocating memory. In most cases, the system simply reports the error and lets the program decide how to respond. System V terminates a program only if a serious error has occurred, such as a violation of memory space.

This chapter explains how to process errors, and describes the functions and variables a program may use to respond to errors.

Using the Standard Error File

The standard error file is a special output file that can be used by a program to display error messages. The standard error file is one of three standard files (standard input, output, and error) automatically created for the program when it is invoked. Note that this feature is only available under the Bourne shell (*/bin/sh*).

The standard error file, like the standard output, is normally assigned to the user's terminal screen. Thus, error messages written to the file are displayed on the screen. The file can also be redirected by using the shell's redirection symbol (>). For example, the following command redirects the standard error file to the file *errorlist* under Bourne shell:

```
dc  2>errorlist
```

The standard error file, like the standard input and standard output, has predefined file pointer and file descriptor values. The file pointer **stderr** may be used in stream functions to copy data to the error file. The file descriptor **2** may be used in low-level functions to copy data to the file. For example, in the following program fragment, **stderr** is used to write the message "Unexpected end of file." to the standard error file.

```
if ( (c=getchar()) == EOF)
     fprintf(stderr, "Unexpected end of file.\n");
```

The standard error file is not affected by the shell's pipe symbol (|). This means that even if the standard output of a program is piped to another program, errors generated by the original program will still appear at the terminal screen (or in the appropriate file if the standard error is redirected).

Using the errno Variable

The **errno** variable is a predefined external variable which contains the error number of the most recent System V system function error. Errors detected by system functions, such as access permission errors and lack of space, cause the system to set the **errno** variable to a number and return control to the program. The error number identifies the error condition. The variable may be used in subsequent statements to process the error.

The file *errno.h* contains manifest constant definitions for each error number, and the external declaration of **errno.** These constants may be used in any program in which the line:

#include <errno.h>

is placed at the beginning of the program. The meaning of each manifest constant is described in the manual page, **intro(S).**

The **errno** variable is typically used immediately after a system function has returned an error. In the following program fragment, **errno** is used to determine the course of action after an unsuccessful call to the **open** function:

```
if ( (fd=open("accounts", O_RDONLY)) == -1 )
   switch (errno) {
      case(EACCES):
         fd = open("/usr/tmp/accounts",O_RDONLY);
         break;
      default:
         exit(errno);
   }
```

In this example, if **errno** is equal to EACCES (a manifest constant), permission to open the file *accounts* in the current directory is denied, so the file is opened in the directory */usr/tmp* instead. If the variable is any other value, the program terminates.

Printing Error Messages

The **perror** function copies a short error message describing the most recent system function error to the standard error file. The function call has the form:

perror (*s*);

where *s* is a pointer to a string containing additional information about the error.

The **perror** function places the given string before the error message and separates the two with a colon (:). Each error message corresponds to the current value of the **errno** variable. For example, in the following program fragment, **perror** displays the message:

```
accounts: Permission denied.
```

if **errno** is equal to the constant **EACCES**:

```
if ( errno == EACCES ) {
     perror("accounts");
     fd = open ("/usr/tmp/accounts", O_RDONLY);
}
```

All error messages displayed by **perror** are stored in an array named **sys_errno**, an external array of character strings. The **perror** function uses the variable **errno** as the index to the array element containing the desired message. For more information on the **perror** function, see the **perror**(S) manual page.

Using Error Signals

Some program errors cause System V to generate error signals. These signals are passed back to the program that caused the error and normally terminate the program. The most common error signals are SIGBUS, the bus error signal; SIGFPE, the floating point exception signal; SIGSEGV, the segment violation signal; SIGSYS, the system call error signal; and SIGPIPE, the pipe error signal. Other signals are described in the **signal**(S) manual page.

A program can, if necessary, catch an error signal and perform its own error processing by using the **signal** function. This function, as described in the "Using Signals" chapter of the *Programmer's Guide*, can set the action of a signal to a user-defined action. For example, the function call:

```
signal(SIGBUS, fixbus);
```

sets the action of the bus error signal to the action defined by the user-supplied function *fixbus*. Such a function usually attempts to remedy the problem, or at least display detailed information about the problem before terminating the program.

For details about how to catch, redefine, and restore these signals, see "Signals and Interrupts" in the *Programmer's Guide*.

Encountering System Errors

Programs that encounter serious errors, such as hardware failures or internal errors, generally do not receive detailed reports on the cause of the errors. Instead, UNIX operating systems treat these errors as "system errors," and report them by displaying a system error message on the system console. This section briefly describes some aspects of System V system errors and how they relate to user programs.

Most system errors occur during calls to system functions. If the system error is recoverable, the system will return an error value to the program and set the **errno** variable to an appropriate value. No other information about the error is available.

Although the system lets two or more programs share a given resource, it does not keep close track of which program is using the resource at any given time. When an error occurs, the system returns an error value to all programs regardless of which caused the error. No information about which program caused the error is available.

System errors that occur during routine I/O operations initiated by the System V system itself generally do not affect user programs. Such errors cause the system to display appropriate system error messages on the system console.

Some system errors are not detected by the system until after the corresponding function has returned successfully. Such errors occur when data written to a file by a program has been queued for writing to disk at a more convenient time, or when a portion of data to be read from disk is found to already be in memory and the remaining portion is not read until later. In such cases, the system assumes that the subsequent read or write operation will be carried out successfully and passes control back to the program along with a successful return value. If operation is not carried out successfully, it causes a delayed error.

When a delayed error occurs, the system usually attempts to return an error on the next call to a system function that accesses the same file or resource. If the program has already terminated or does not make a suitable call, then the error is not reported.

Chapter 10

Common Object File Format (COFF)

The Common Object File Format (COFF) 10-1

Definitions and Conventions 10-3
- Sections 10-3
- Physical and Virtual Addresses 10-3
- Target Machine 10-4

File Header 10-5
- Magic Numbers 10-5
- Flags 10-6
- File Header Declaration 10-6

Optional Header Information 10-7
- Standard UNIX System **a.out** Header 10-7
- Optional Header Declaration 10-8

Section Headers 10-9
- Flags 10-10
- Section Header Declaration 10-11
- **.bss** Section Header 10-11

Sections 10-12

Relocation Information 10-13
- Relocation Entry Declaration 10-14

Line Numbers 10-15
- Line Number Declaration 10-16

Symbol Table 10-17
- Special Symbols 10-18
- Inner Blocks 10-19
- Symbols and Functions 10-21
- Symbol Table Entries 10-21
  - Symbol Names 10-22
  - Storage Classes 10-24
  - Storage Classes for Special Symbols 10-25
  - Symbol Value Field 10-26

Section Number Field 10-27
Section Numbers and Storage Classes 10-28
Type Entry 10-28
Type Entries and Storage Classes 10-30
Structure for Symbol Table Entries 10-32
Auxiliary Table Entries 10-33
File Names 10-34
Sections 10-34
Tag Names 10-35
End of Structures 10-35
Functions 10-36
Arrays 10-37
End of Blocks and Functions 10-37
Beginning of Blocks and Functions 10-38
Names Related to Structures, Unions, and Enumerations 10-38
Auxiliary Entry Declaration 10-39

String Table 10-41

Access Routines 10-42

The Common Object File Format (COFF)

This chapter describes the Common Object File Format (COFF) used on your computer with UNIX System V *COFF* is the format of the output file produced by the UNIX System assembler, **as**, and link editor, **ld**. This is the default format used by **cc** without the **-xenix** option.

The following list describes key features of *COFF*:

- Applications can add system-dependent information to the object file without causing access utilities to become obsolete.
- Space is provided for symbolic information used by debuggers and other applications.
- Programmers can modify the way the object file is constructed by providing directives at compile time.

The object file supports user-defined sections and contains extensive information for symbolic software testing. An object file contains

- a file header
- optional header information
- a table of section headers
- data corresponding to the section headers
- relocation information
- line numbers
- a symbol table
- a string table

Figure 10-1 shows the overall structure of a COFF object file.

Figure 10-1 Object File Format

FILE HEADER
Optional Information
Section 1 Header
...
Section *n* Header
Raw Data for Section 1
...
Raw Data for Section *n*
Relocation Info for Sect. 1
...
Relocation Info for Sect. *n*
Line Numbers for Sect. 1
...
Line Numbers for Sect. *n*
SYMBOL TABLE
STRING TABLE

The last four sections (relocation, line numbers, symbol table, and the string table) may be missing if the program is linked with the **-s** option of the **ld** command, or if the line number information, symbol table, and string table are removed by the **strip** command. The line number information does not appear unless the program is compiled with the **-g** option of the **cc** command. Also, if there are no unresolved external references after linking, the relocation information is no longer needed and is absent. The string table is also absent if the source file does not contain any symbols with names longer than eight characters.

An object file that contains no errors or unresolved references is considered executable.

Definitions and Conventions

Before proceeding further, you should become familiar with the following terms and conventions.

Sections

A section is the smallest portion of an object file that is relocated and treated as one separate and distinct entity. In the most common case, there are three sections named **.text**, **.data**, and **.bss**. Additional sections accommodate comments, multiple text or data segments, shared data segments, or user-specified sections. However, the operating system loads only **.text**, **.data**, and **.bss** into memory when the file is executed.

Note

It a mistake to assume that every COFF file will have a certain number of sections, or to assume characteristics of sections such as their order, their location in the object file, or the address at which they are to be loaded. This information is available only after the object file has been created. Programs manipulating COFF files should obtain it from file and section headers in the file.

Physical and Virtual Addresses

The physical address of a section or symbol is the offset of that section or symbol from address zero of the address space. The term physical address as used in COFF does not correspond to general usage. The physical address of an object is not necessarily the address at which the object is placed when the process is executed. For example, on a system with paging, the address is located with respect to address zero of virtual memory and the system performs another address translation. The section header contains two address fields, a physical address, and a virtual address; but in all versions of COFF on UNIX Systems, the physical address is equivalent to the virtual address.

Target Machine

Compilers and link editors produce executable object files that are intended to be run on a particular computer. In the case of cross-compilers, the compilation and link editing are done on one computer, with the intent of creating an object file that can be executed on another computer. The term, target machine, refers to the computer on which the object file is destined to run. In the majority of cases, the target machine is the same computer on which the object file is being created.

File Header

The file header contains the 20 bytes of information shown in Table 10.1. The last 2 bytes are flags that are used by **ld** and object file utilities.

Table 10.1

File Header Contents

Bytes	Declaration	Name	Description
0-1	**unsigned short**	**f_magic**	Magic number
2-3	**unsigned short**	**f_nscns**	Number of sections
4-7	**long int**	**f_timdat**	Time and date stamp indicating when the file was created, expressed as the number of elapsed seconds since 00:00:00 GMT, January 1, 1970
8-11	**long int**	**f_symptr**	File pointer containing the starting address of the symbol table
12-15	**long int**	**f_nsyms**	Number of entries in the symbol table
16-17	**unsigned short**	**f_opthdr**	Number of bytes in the optional header
18-19	**unsigned short**	**f_flags**	Flags (see Table 10.2.)

Magic Numbers

The magic number specifies the target machine on which the object file is executable.

Flags

The last 2 bytes of the file header are flags that describe the type of the object file. Currently defined flags are found in the header file **filehdr.h** and are shown in Table 10.2.

Table 10.2
File Header Flags

Mnemonic	Flag	Meaning
F_RELFLG	00001	Relocation information stripped from the file
F_EXEC	00002	File is executable (i.e., no unresolved external references)
F_LNNO	00004	Line numbers stripped from the file
F_LSYMS	00010	Local symbols stripped from the file
F_AR16WR	0000200	16-bit byte reversed word
F_AR32WR	0000400	32-bit byte reversed word

File Header Declaration

The C structure declaration for the file header is given in Figure 10-2. This declaration may be found in the header file **filehdr.h**.

Figure 10-2 File Header Declaration

```
struct filehdr
{
    unsigned short    f_magic;    /* magic number */
    unsigned short    f_nscns;    /* number of section */
    long              f_timdat;   /* time and date stamp */
    long              f_symptr;   /* file ptr to symbol table
    long              f_nsyms;    /* number entries in the sym
    unsigned short    f_opthdr;   /* size of optional header *
    unsigned short    f_flags;    /* flags */
};
#define FILHDR struct filehdr
#define FILHSZ sizeof(FILHDR)
```

Optional Header Information

The template for optional information varies among different systems that use COFF. Applications place all system-dependent information into this record. This allows different operating systems access to information that only that operating system uses without forcing all COFF files to save space for that information. General utility programs (for example, the symbol table access library functions, the disassembler, etc.) are made to work properly on any common object file. This is done by seeking past this record using the size of optional header information in the file header field **f_opthdr**.

Standard UNIX System a.out Header

By default, files produced by the link editor for a UNIX System always have a standard UNIX System **a.out** header in the optional header field. The UNIX System **a.out** header is 28 bytes. The fields of the optional header are described in Table 10.3.

Table 10.3

Optional Header Contents

Bytes	Declaration	Name	Description
0-1	**short**	**magic**	Magic number
2-3	**short**	**vstamp**	Version stamp
4-7	**long int**	**tsize**	Size of text in bytes
8-11	**long int**	**dsize**	Size of initialized data in bytes
12-15	**long int**	**bsize**	Size of uninitialized data in bytes
16-19	**long int**	**entry**	Entry point
20-23	**long int**	**text_start**	Base address of text
24-27	**long int**	**data_start**	Base address of data

Whereas the magic number in the file header specifies the machine on which the object file runs, the magic number in the optional header supplies information telling the operating system on that machine how that file should be executed. The magic numbers recognized by UNIX System V are given in Table 10.4.

Table 10.4
UNIX System V Magic Numbers

Value	Meaning
0407	Text segment is not write-protected or sharable; data segment is contiguous with the text segment.
0410	Data segment starts at the next segment following the text segment and the text segment is write-protected.
0413	Text and data segments are aligned within **a.out** so it can be directly paged.
0443	Defines **a.out** to be a target shared library.

Optional Header Declaration

The C language structure declaration currently used for UNIX System's **a.out** file headers is given in Figure 10-3. This declaration may be found in the header file **aouthdr.h**.

Figure 10-3 aouthdr Declaration

```
typedef struct aouthdr
{
        short    magic;         /* magic number */
        short    vstamp;        /* version stamp */
        long     tsize;         /* text size in bytes, padded
                                 * to full word boundary
                                 */
        long     dsize;         /* initialized data size */
        long     bsize;         /* uninitialized data size */
        long     entry;         /* entry point */
        long     text_start;    /* base of text for this file */
        long     data_start     /* base of data for this file */
} AOUTHDR;
```

Section Headers

Every object file has a table of section headers to specify the layout of data within the file. The section header table consists of one entry for every section in the file. The information in the section header is described in Table 10.5.

Table 10.5
Section Header Contents

Bytes	Declaration	Name	Description
0-7	**char**	**s_name**	8-character null padded section name
8-11	**long int**	**s_paddr**	Physical address of section
12-15	**long int**	**s_vaddr**	Virtual address of section
16-19	**long int**	**s_size**	Section size in bytes
20-23	**long int**	**s_scnptr**	File pointer to raw data
24-27	**long int**	**s_relptr**	File pointer to relocation entries
28-31	**long int**	**s_lnnoptr**	File pointer to line number entries
32-33	**unsigned short**	**s_nreloc**	Number of relocation entries
34-35	**unsigned short**	**s_nlnno**	Number of line number entries
36-39	**long int**	**s_flags**	Flags (see Table 10.6)

The size of a section is padded to a multiple of 4 bytes. File pointers are byte offsets that can be used to locate the start of data, relocation, or line number entries for the section. They can be readily used with the **fseek**(S) system call.

Flags

The lower 2 bytes of the flag field indicate a section type. The flags are described in Table 10.6.

Table 10.6
Section Header Flags

Mnemonic	Flag	Meaning
STYP_REG	0x00	Regular section (allocated, relocated, loaded)
STYP_DSECT	0x01	Dummy section (not allocated, relocated, not loaded)
STYP_NOLOAD	0x02	Noload section (allocated, relocated, not loaded)
STYP_GROUP	0x04	Grouped section (formed from input sections)
STYP_PAD	0x08	Padding section (not allocated, not relocated, loaded)
STYP_COPY	0x10	Copy section (for a decision function used in updating fields; not allocated, not relocated, loaded, relocation and line number entries processed normally)
STYP_TEXT	0x20	Section contains executable text
STYP_DATA	0x40	Section contains initialized data
STYP_BSS	0x80	Section contains only uninitialized data
STYP_INFO	0x200	Comment section (not allocated, not relocated, not loaded)
STYP_OVER	0x400	Overlay section (relocated, not allocated, not loaded)
STYP_LIB	0x800	For **.lib** section (treated like STYP_INFO)

Section Header Declaration

The C structure declaration for the section headers is described in Figure 10-4. This declaration may be found in the header file **scnhdr.h**.

Figure 10-4 Section Header Declaration

```
struct scnhdr
{
        char        s_name[8];          /* section name */
        long        s_paddr;            /* physical address */
        long        s_vaddr;            /* virtual address */
        long        s_size;             /* section size */
        long        s_scnptr;           /* file ptr to section raw data */
        long        s_relptr;           /* file ptr to relocation */
        long        s_lnnoptr;          /* file ptr to line number */
        unsigned short  s_nreloc;       /* number of relocation entries */
        unsigned short  s_nlnno;        /* number of line number entries */
        long        s_flags;            /* flags */
};

#define  SCNHDR  struct scnhdr
#define  SCNHSZ  sizeof(SCNHDR)
```

.bss Section Header

The one deviation from the normal rule in the section header table is the entry for uninitialized data in a **.bss** section. A **.bss** section has a size and symbols that refer to it, and symbols that are defined in it. At the same time, a **.bss** section has no relocation entries, no line number entries, and no data. Therefore, a **.bss** section has an entry in the section header table but occupies no space elsewhere in the file. In this case, the number of relocation and line number entries, as well as all file pointers in a **.bss** section header, are 0. The same is true of the STYP_NOLOAD and STYP_DSECT sections.

Sections

Figure 10-1 shows that section headers are followed by the appropriate number of bytes of text or data. The raw data for each section begins on a 4-byte boundary in the file.

Link editor SECTIONS directives allow users to do the following, among other things:

- describe how input sections are to be combined
- direct the placement of output sections
- rename output sections.

If no SECTIONS directives are given, each input section appears in an output section of the same name. For example, if a number of object files, each with a **.text** section, are linked together, the output object file contains a single **.text** section made up of the combined input **.text** sections.

Relocation Information

Object files have one relocation entry for each relocatable reference in the text or data. The relocation information consists of entries with the format described in Table 10.7.

Table 10.7

Relocation Section Contents

Bytes	Declaration	Name	Description
0-3	**long int**	**r_vaddr**	(Virtual) address of reference
4-7	**long int**	**r_symndx**	Symbol table index
8-9	**unsigned short**	**r_type**	Relocation type

The first 4 bytes of the entry are the virtual address of the text or data to which this entry applies. The next field is the index, counted from 0, of the symbol table entry that is being referenced. The type field indicates the type of relocation to be applied.

As the link editor reads each input section and performs relocation, the relocation entries are read. They direct how references found within the input section are treated. The currently recognized relocation types are given in Table 10.8.

Table 10.8
Relocation Types

Mnemonic	Flag	Meaning
R_ABS	0	Reference is absolute; no relocation is necessary. The entry will be ignored.
R_DIR16 *	01	Direct, 16-bit reference to a symbol's virtual address.
R_REL16 *	02	"PC-relative", 16-bit reference to a symbol's virtual address. Relative references occur in instructions such as jumps and calls.
R_DIR32	06	Direct 32-bit reference to the symbol's virtual address.
R_SEG12 *	011	Direct, 16-bit reference to the segment-selector bits of a 32-bit virtual address.
R_PCRLONG †	024	"PC_relative", 32-bit reference to a symbol's virtual address.

* 80286 Computer only.
† 80386 Computer only.

Relocation Entry Declaration

The structure declaration for relocation entries is given in Figure 10-5. This declaration may be found in the header file **reloc.h**.

Figure 10-5 Relocation Entry Declaration

```
struct reloc
{
    long            r_vaddr;    /* virtual address of reference */
    long            r_symndx;   /* index into symbol table */
    unsigned short  r_type;     /* relocation type */
};

#define RELOC    struct reloc
#define RELSZ    10
```

Line Numbers

When invoked with the **-g** option, the **cc** and **f77** commands cause an entry in the object file for every source line where a breakpoint can be inserted. You can then reference line numbers when using a software debugger like **sdb**. All line numbers in a section are grouped by function as shown in Table 10.9.

Table 10.9
Line Number Grouping

symbol index	0
physical address	line number
physical address	line number
.	.
.	.
.	.
symbol index	0
physical address	line number
physical address	line number

The first entry in a function grouping has line number 0 and has, in place of the physical address, an index into the symbol table for the entry containing the function name. Subsequent entries have actual line numbers and addresses of the text corresponding to the line numbers. The line number entries are relative to the beginning of the function and appear in increasing order of address.

Line Number Declaration

The structure declaration currently used for line number entries is given in Figure 10-6.

Figure 10-6 Line Number Entry Declaration

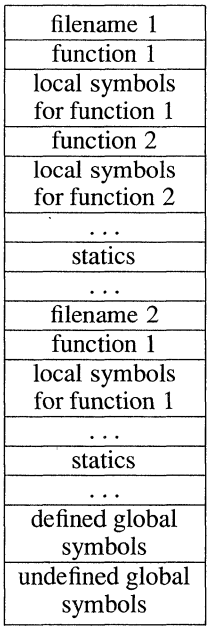
```
struct lineno
{
      union
      {
                long   l_symndx;   /* symtbl index of func name */
                long   l_paddr;    /* paddr of line number */
      } l_addr;
      unsigned short   l_lnno;     /* line number */
};

#define LINENO      struct lineno
#define LINESZ      6
```

Symbol Table

Because of symbolic debugging requirements, the order of symbols in the symbol table is very important. Symbols appear in the sequence shown in Figure 10-7.

Figure 10-7 COFF Symbol Table



The word statics in Figure 10-7 means symbols defined with the C language storage class static outside any function. The symbol table consists of at least one fixed-length entry per symbol with some symbols followed by auxiliary entries of the same size. The entry for each symbol is a structure that holds the value, the type, and other information.

Special Symbols

The symbol table contains some special symbols that are generated by **as** and other tools. These symbols are given in Table 10.10.

Table 10.10
Special Symbols in the Symbol Table

Symbol	Meaning
.file	filename
.text	address of **.text** section
.data	address of **.data** section
.bss	address of **.bss** section
.bb	address of start of inner block
.eb	address of end of inner block
.bf	address of start of function
.ef	address of end of function
.target	pointer to the structure or union returned by a function
.*x***fake**	dummy tag name for structure, union, or enumeration
.eos	end of members of structure, union, or enumeration
etext	next available address after the end of the output section **.text**
edata	next available address after the end of the output section **.data**
end	next available address after the end of the output section **.bss**

Six of these special symbols occur in pairs. The **.bb** and **.eb** symbols indicate the boundaries of inner blocks; a **.bf** and **.ef** pair brackets each function. An **.***x***fake** and **.eos** pair names and defines the limit of structures, unions, and enumerations that were not named. The **.eos** symbol also appears after named structures, unions, and enumerations.

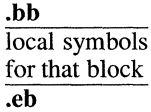
When a structure, union, or enumeration has no tag name, the compiler invents a name to be used in the symbol table. The name chosen for the symbol table is **.***x***fake**, where *x* is an integer. If there are three unnamed structures, unions, or enumerations in the source, their tag names are **.0fake**, **.1fake**, and **.2fake**. Each of the special symbols has different information stored in the symbol table entry as well as the auxiliary entries.

Inner Blocks

The C language defines a block as a compound statement that begins and ends with braces, { and }. An inner block is a block that occurs within a function (which is also a block).

For each inner block that has local symbols defined, a special symbol **.bb** is put in the symbol table immediately before the first local symbol of that block. Also a special symbol **.eb** is put in the symbol table immediately after the last local symbol of that block. The sequence is shown in Figure 10-8.

Figure 10-8 Special Symbols (**.bb** and **.eb**)



Because inner blocks can be nested by several levels, the **.bb**-**.eb** pairs and associated symbols may also be nested (see Figure 10-9).

Figure 10-9 Nested blocks

```
{               /*block 1*/
    inti;
    charc;
    ...
        {               /*block 2*/
        longa;
        ...
            {           /*block 3*/
            intx;
            ....
        }           /*block 3*/

    }           /*block 2*/

    {           /*block 4*/
        longi;
        ...
    }           /*block 4*/
}               /*block 1*/
```

The symbol table would look like Figure 10-10.

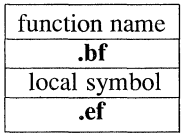
Figure 10-10 Example of the Symbol Table

.bb for block 1
i
c
.bb for block 2
a
.bb for block 3
x
.eb for block 3
.eb for block 2
.bb for block 4
i
.eb for block 4
.eb for block 1

Symbols and Functions

For each function, a special symbol **.bf** is put between the function name and the first local symbol of the function in the symbol table. Also, a special symbol **.ef** is put immediately after the last local symbol of the function in the symbol table. The sequence is shown in Figure 10-11.

Figure 10-11 Symbols for Functions



Symbol Table Entries

All symbols, regardless of storage class and type, have the same format for their entries in the symbol table. The symbol table entries each contain 18 bytes of information. The meaning of each of the fields in the symbol table entry is described in Table 10.11. It should be noted that indices for symbol table entries begin at 0 and count upward. Each auxiliary entry also counts as one symbol.

Table 10.11
Symbol Table Entry Format

Bytes	Declaration	Name	Description
0-7	(see text below)	**_n**	These 8 bytes contain either a symbol name or an index to a symbol
8-11	**long int**	**n_value**	Symbol value; storage class dependent
12-13	**short**	**n_scnum**	Section number of symbol
14-15	**unsigned short**	**n_type**	Basic and derived type specification
16	**char**	**n_sclass**	Storage class of symbol
17	**char**	**n_numaux**	Number of auxiliary entries

Symbol Names

The first 8 bytes in the symbol table entry are a union of a character array and two longs. If the symbol name is eight characters or less, the (null-padded) symbol name is stored there. If the symbol name is longer than eight characters, then the entire symbol name is stored in the string table. In this case, the 8 bytes contain two long integers, the first is zero, and the second is the offset (relative to the beginning of the string table) of the name in the string table. Since there can be no symbols with a null name, the zeroes on the first 4 bytes serve to distinguish a symbol table entry with an offset from one with a name in the first 8 bytes as shown in Table 10.12.

Table 10.12
Name Field

Bytes	Declaration	Name	Description
0-7	**char**	**n_name**	8-character null-padded symbol name
0-3	**long**	**n_zeroes**	Zero in this field indicates the name is in the string table
4-7	**long**	**n_offset**	Offset of the name in the string table

Special symbols generated by the C Compilation System are discussed earlier in the section ''Special Symbols'' in this chapter.

Storage Classes

The storage class field has one of the values described in Table 10.13. These **#define**'s may be found in the header file **storclass.h**.

Table 10.13
Storage Classes

Mnemonic	Value	Storage Class
C_EFCN	-1	physical end of a function
C_NULL	0	-
C_AUTO	1	automatic variable
C_EXT	2	external symbol
C_STAT	3	static
C_REG	4	register variable
C_EXTDEF	5	external definition
C_LABEL	6	label
C_ULABEL	7	undefined label
C_MOS	8	member of structure
C_ARG	9	function argument
C_STRTAG	10	structure tag
C_MOU	11	member of union
C_UNTAG	12	union tag
C_TPDEF	13	type definition
C_USTATIC	14	uninitialized static
C_ENTAG	15	enumeration tag
C_MOE	16	member of enumeration
C_REGPARM	17	register parameter
C_FIELD	18	bit field
C_BLOCK	100	beginning and end of block
C_FCN	101	beginning and end of function
C_EOS	102	end of structure
C_FILE	103	file name
C_LINE	104	used only by utility programs
C_ALIAS	105	duplicated tag
C_HIDDEN	106	like static, used to avoid name conflicts

All of these storage classes except for C_ALIAS and C_HIDDEN are generated by the **cc** or **as** commands. The compress utility, **cprs**, generates the C_ALIAS mnemonic. This utility (described in the *Programmer's Reference Manual*) removes duplicated structure, union, and enumeration definitions and puts alias entries in their places. The storage class C_HIDDEN is not used by any UNIX System V tools.

Some of these storage classes are used only internally by the C Compilation Systems. These storage classes are C_EFCN, C_EXTDEF, C_ULABEL, C_USTATIC, and C_LINE.

Storage Classes for Special Symbols

Some special symbols are restricted to certain storage classes. They are given in Table 10.14.

Table 10.14

Storage Class by Special Symbols

Special Symbol	Storage Class
.file	C_FILE
.bb	C_BLOCK
.eb	C_BLOCK
.bf	C_FCN
.ef	C_FCN
.target	C_AUTO
.*x*fake	C_STRTAG, C_UNTAG, C_ENTAG
.eos	C_EOS
.text	C_STAT
.data	C_STAT
.bss	C_STAT

Also some storage classes are used only for certain special symbols. They are summarized in Table 10.15.

Table 10.15

Restricted Storage Classes

Storage Class	Special Symbol
C_BLOCK	**.bb, .eb**
C_FCN	**.bf, .ef**
C_EOS	**.eos**
C_FILE	**.file**

Symbol Value Field

The meaning of the value of a symbol depends on its storage class. This relationship is summarized in Table 10.16.

Table 10.16
Storage Class and Value

Storage Class	Meaning of Value
C_AUTO	stack offset in bytes
C_EXT	relocatable address
C_STAT	relocatable address
C_REG	register number
C_LABEL	relocatable address
C_MOS	offset in bytes
C_ARG	stack offset in bytes
C_STRTAG	0
C_MOU	0
C_UNTAG	0
C_TPDEF	0
C_ENTAG	0
C_MOE	enumeration value
C_REGPARM	register number
C_FIELD	bit displacement
C_BLOCK	relocatable address
C_FCN	relocatable address
C_EOS	size
C_FILE	(see text below)
C_ALIAS	tag index
C_HIDDEN	relocatable address

If a symbol has storage class C_FILE, the value of that symbol equals the symbol table entry index of the next **.file** symbol. That is, the **.file** entries form a one-way linked list in the symbol table. If there are no more **.file** entries in the symbol table, the value of the symbol is the index of the first global symbol.

Relocatable symbols have a value equal to the virtual address of that symbol. When the section is relocated by the link editor, the value of these symbols changes.

Section Number Field

Section numbers are listed in Table 10.17

Table 10.17
Section Number

Mnemonic	Section Number	Meaning
N_DEBUG	-2	Special symbolic debugging symbol
N_ABS	-1	Absolute symbol
N_UNDEF	0	Undefined external symbol
N_SCNUM	1-077777	Section number where symbol is defined

A special section number (-2) marks symbolic debugging symbols, including structure/union/enumeration tag names, typedefs, and the name of the file. A section number of -1 indicates that the symbol has a value but is not relocatable. Examples of absolute-valued symbols include automatic and register variables, function arguments, and **.eos** symbols.

With one exception, a section number of 0 indicates a relocatable external symbol that is not defined in the current file. The one exception is a multiply-defined external symbol (i.e., FORTRAN common or an uninitialized variable-defined external to a function in C). In the symbol table of each file where the symbol is defined, the section number of the symbol is 0, and the value of the symbol is a positive number giving the size of the symbol. When the files are combined to form an executable object file, the link editor combines all the input symbols of the same name into one symbol with the section number of the **.bss** section. The maximum size of all the input symbols with the same name is used to allocate space for the symbol and the value becomes the address of the symbol. This is the only case where a symbol has a section number of 0 and a non-zero value.

Section Numbers and Storage Classes

Symbols having certain storage classes are also restricted to certain section numbers. They are summarized in Table 10.18.

Table 10.18
Section Number and Storage Class

Storage Class	Section Number
C_AUTO	N_ABS
C_EXT	N_ABS, N_UNDEF, N_SCNUM
C_STAT	N_SCNUM
C_REG	N_ABS
C_LABEL	N_UNDEF, N_SCNUM
C_MOS	N_ABS
C_ARG	N_ABS
C_STRTAG	N_DEBUG
C_MOU	N_ABS
C_UNTAG	N_DEBUG
C_TPDEF	N_DEBUG
C_ENTAG	N_DEBUG
C_MOE	N_ABS
C_REGPARM	N_ABS
C_FIELD	N_ABS
C_BLOCK	N_SCNUM
C_FCN	N_SCNUM
C_EOS	N_ABS
C_FILE	N_DEBUG
C_ALIAS	N_DEBUG

Type Entry

The type field in the symbol table entry contains information about the basic and derived type for the symbol. This information is generated by the C Compilation System only if the **-g** option is used. Each symbol has exactly one basic or fundamental type but can have more than one derived type. The format of the 16-bit type entry is:

d6	d5	d4	d3	d2	d1	typ

Bits 0 through 3, called **typ**, indicate one of the fundamental types given in Table 10.19.

Table 10.19
Fundamental Types

Mnemonic	Value	Type
T_NULL	0	type not assigned
T_ARG	1	Function argument (used only by compiler)
T_CHAR	2	character
T_SHORT	3	short integer
T_INT	4	integer
T_LONG	5	long integer
T_FLOAT	6	floating point
T_DOUBLE	7	double word
T_STRUCT	8	structure
T_UNION	9	union
T_ENUM	10	enumeration
T_MOE	11	member of enumeration
T_UCHAR	12	unsigned character
T_USHORT	13	unsigned short
T_UINT	14	unsigned integer
T_ULONG	15	unsigned long

Bits 4 through 15 are arranged as six 2-bit fields marked **d1** through **d6**. These **d** fields represent levels of the derived types given in Table 10.20.

Table 10.20
Derived Types

Mnemonic	Value	Type
DT_NON	0	no derived type
DT_PTR	1	pointer
DT_FCN	2	function
DT_ARY	3	array

The following examples demonstrate the interpretation of the symbol table entry representing type.

```
char *func();
```

Here **func** is the name of a function that returns a pointer to a character. The fundamental type of **func** is 2 (character), the **d1** field is 2 (function), and the **d2** field is 1 (pointer). Therefore, the type word in the symbol table for **func** contains the hexadecimal number 0x62, which is interpreted to mean a function that returns a pointer to a character.

```
short *tabptr[10][25][3];
```

Here **tabptr** is a three-dimensional array of pointers to short integers. The fundamental type of **tabptr** is 3 (short integer); the **d1**, **d2**, and **d3** fields each contains a 3 (array), and the **d4** field is 1 (pointer). Therefore, the type entry in the symbol table contains the hexadecimal number 0x7f3 indicating a three-dimensional array of pointers to short integers.

Type Entries and Storage Classes

Table 10.21 shows the type entries that are legal for each storage class.

Table 10.21
Type Entries by Storage Class

Storage Class	d Entry			typ Entry Basic Type
	Function?	Array?	Pointer?	
C_AUTO	no	yes	yes	Any except T_MOE
C_EXT	yes	yes	yes	Any except T_MOE
C_STAT	yes	yes	yes	Any except T_MOE
C_REG	no	no	yes	Any except T_MOE
C_LABEL	no	no	no	T_NULL
C_MOS	no	yes	yes	Any except T_MOE
C_ARG	yes	no	yes	Any except T_MOE
C_STRTAG	no	no	no	T_STRUCT
C_MOU	no	yes	yes	Any except T_MOE
C_UNTAG	no	no	no	T_UNION
C_TPDEF	no	yes	yes	Any except T_MOE
C_ENTAG	no	no	no	T_ENUM
C_MOE	no	no	no	T_MOE
C_REGPARM	no	no	yes	Any except T_MOE
C_FIELD	no	no	no	T_ENUM, T_UCHAR, T_USHORT, T_UNIT, T_ULONG
C_BLOCK	no	no	no	T_NULL
C_FCN	no	no	no	T_NULL
C_EOS	no	no	no	T_NULL
C_FILE	no	no	no	T_NULL
C_ALIAS	no	no	no	T_STRUCT, T_UNION, T_ENUM

Conditions for the **d** entries apply to **d1** through **d6**, except that it is impossible to have two consecutive derived types of function.

Although function arguments can be declared as arrays, they are changed to pointers by default. Therefore, no function argument can have array as its first derived type.

Structure for Symbol Table Entries

The C language structure declaration for the symbol table entry is given in Figure 10-12. This declaration may be found in the header file **syms.h**.

Figure 10-12 Symbol Table Entry Declaration

```
struct syment
{
    union
        {
        char _n_name[SYMNMLEN];   /* symbol name*/
        struct
            {
            long _n_zeroes;       /* symbol name */
            long _n_offset;       /* location in string table */
        } _n_n;
        char *_n_nptr[2];         /* allows overlaying */
    } _n;
    unsigned long n_value;        /* value of symbol */
    short n_scnum;                /* section number */
    unsigned short n_type;        /* type and derived */
    char n_sclass;                /* storage class */
    char n_numaux;                /* number of aux entries */
};

#define  n_name _n._n_name
#define  n_zeroes _n._n_n._n_zeroes
#define  n_offset _n._n_n._n_offset
#define  n_nptr _n._n_nptr[1]

#define  SYMNMLEN  8
#define  SYMESZ    18    /* size of a symbol table entry */
```

Auxiliary Table Entries

An auxiliary table entry of a symbol contains the same number of bytes as the symbol table entry. However, unlike symbol table entries, the format of an auxiliary table entry of a symbol depends on its type and storage class. They are summarized in Table 10.22.

Table 10.22
Auxiliary Symbol Table Entries

Name	Storage Class	Type Entry		Auxiliary Entry Format
		d1	typ	
.file	C_FILE	DT_NON	T_NULL	file name
.text,.data, .bss	C_STAT	DT_NON	T_NULL	section
tagname	C_STRTAG C_UNTAG C_ENTAG	DT_NON	T_NULL	tag name
.eos	C_EOS	DT_NON	T_NULL	end of structure
fcname	C_EXT C_STAT	DT_FCN	(Note 1)	function
arrname	(Note 2)	DT_ARY	(Note 1)	array
.bb,.eb	C_BLOCK	DT_NON	T_NULL	beginning and end of block
.bf,.ef	C_FCN	DT_NON	T_NULL	beginning and end of function
name related to structure, union, enumeration	(Note 2)	DT_PTR, DT_ARR, DT_NON	T_STRUCT, T_UNION, T_ENUM	name related to structure, union, enumeration

Notes to Table 10.22:

1. Any except T_MOE.
2. C_AUTO, C_STAT, C_MOS, C_MOU, C_TPDEF.

In Table 10.22, *tagname* means any symbol name including the special symbol **.xfake**, and *fcname* and *arrname* represent any symbol name for a function or an array respectively. Any symbol that satisfies more than one condition in Table 10.22 should have a union format in its auxiliary entry. It is a mistake to assume how many auxiliary entries are associated with any given symbol table entry. This information is available and should be obtained from the **n_numaux** field in the symbol table.

File Names

Each of the auxiliary table entries for a file name contains a 14-character file name in bytes 0 through 13. The remaining bytes are 0.

Sections

The auxiliary table entries for sections have the format as shown in Table 10.23.

Table 10.23

Format for Auxiliary Table Entries for Sections

Bytes	Declaration	Name	Description
0-3	**long int**	**x_scnlen**	section length
4-5	**unsigned short**	**x_nreloc**	number of relocation entries
6-7	**unsigned short**	**x_nlinno**	number of line numbers
8-17	-	-	unused (filled with zeroes)

Tag Names

The auxiliary table entries for tag names have the format shown in Table 10.24.

Table 10.24
Tag Names Table Entries

Bytes	Declaration	Name	Description
0-5	-	-	unused (filled with zeroes)
6-7	**unsigned short**	**x_size**	size of structure, union, and enumeration
8-11	-	-	unused (filled with zeroes)
12-15	**long int**	**x_endndx**	index of next entry beyond this structure, union, or enumeration
16-17	-	-	unused (filled with zeroes)

End of Structures

The auxiliary table entries for the end of structures have the format shown in Table 10.25.

Table 10.25

Table Entries for End of Structures

Bytes	Declaration	Name	Description
0-3	**long int**	**x_tagndx**	tag index
4-5	-	-	unused (filled with zeroes)
6-7	**unsigned short**	**x_size**	size of structure, union, or enumeration
8-17	-	-	unused (filled with zeroes)

Functions

The auxiliary table entries for functions have the format shown in Table 10.26.

Table 10.26

Table Entries for Functions

Bytes	Declaration	Name	Description
0-3	**long int**	**x_tagndx**	tag index
4-7	**long int**	**x_fsize**	size of function (in bytes)
8-11	**long int**	**x_lnnoptr**	file pointer to line number
12-15	**long int**	**x_endndx**	index of next entry beyond this point
16-17	**unsigned short**	**x_tvndx**	index of function's address in the transfer vector table (not used in UNIX System V.)

Arrays

The auxiliary table entries for arrays have the format shown in Table 10.27. Defining arrays with more than four dimensions produces a warning message.

Table 10.27
Table Entries for Arrays

Bytes	Declaration	Name	Description
0-3	**long int**	**x_tagndx**	tag index
4-5	**unsigned short**	**x_lnno**	line number of declaration
6-7	**unsigned short**	**x_size**	size of array
8-9	**unsigned short**	**x_dimen[0]**	first dimension
10-11	**unsigned short**	**x_dimen[1]**	second dimension
12-13	**unsigned short**	**x_dimen[2]**	third dimension
14-15	**unsigned short**	**x_dimen[3]**	fourth dimension
16-17	-	-	unused (filled with zeroes)

End of Blocks and Functions

The auxiliary table entries for the end of blocks and functions have the format shown in Table 10.28.

Table 10.28
End of Block and Function Entries

Bytes	Declaration	Name	Description
0-3	-	-	unused (filled with zeroes)
4-5	**unsigned short**	**x_lnno**	C-source line number
6-17	-	-	unused (filled with zeroes)

Beginning of Blocks and Functions

The auxiliary table entries for the beginning of blocks and functions have the format shown in Table 10.29.

Table 10.29
Format for Beginning of Block and Function

Bytes	Declaration	Name	Description
0-3	-	-	unused (filled with zeroes)
4-5	**unsigned short**	**x_lnno**	C-source line number
6-11	-	-	unused (filled with zeroes)
12-15	**long int**	**x_endndx**	index of next entry past this block
16-17	-	-	unused (filled with zeroes)

Names Related to Structures, Unions, and Enumerations

The auxiliary table entries for structure, union, and enumeration symbols have the format shown in Table 10.30.

Table 10.30
Entries for Structures, Unions, and Enumerations

Bytes	Declaration	Name	Description
0-3	**long int**	**x_tagndx**	tag index
4-5	-	-	unused (filled with zeroes)
6-7	**unsigned short**	**x_size**	size of the structure, union, or enumeration
8-17	-	-	unused (filled with zeroes)

Aggregates defined by **typedef** may or may not have auxiliary table entries. For example,

```
typedef struct people STUDENT;

struct people
{
        char name[20];
        long id;
};

typedef struct people EMPLOYEE;
```

The symbol EMPLOYEE has an auxiliary table entry in the symbol table, but the symbol STUDENT will not because it is a forward reference to a structure.

Auxiliary Entry Declaration

The C language structure declaration for an auxiliary symbol table entry is given in Figure 10-13. This declaration may be found in the header file **syms.h**.

Figure 10-13 Auxiliary Symbol Table Entry (1 of 2)

```
union auxent
{
      struct
      {
            long   x_tagndx;
            union
            {
                struct
                {
                      unsigned short x_lnno;
                      unsigned short x_size;
                } x_lnsz;
                long x_fsize;
            } x_misc;
            union
            {
                struct
                {
                      long x_lnnoptr;
                      long x_endndx;
                } x_fcn;
                struct
 .
 .
 .
```

Figure 10-13 Auxiliary Symbol Table Entry (Sheet 2 of 2)

```
.
.
.
                {
                    unsigned short x_dimen[DIMNUM];
                } x_ary;
            } x_fcnary;
            unsigned short x_tvndx;
        } x_sym;
        struct
        {
            char x_fname[FILNMLEN];
        } x_file;
        struct
        {
            long x_scnlen;
            unsigned short x_nreloc;
            unsigned short x_nlinno;
        } x_scn;
        struct
        {
            long x_tvfill;
            unsigned short x_tvlen;
            unsigned short x_tvran[2];
        } x_tv;
}
#define FILNMLEN  14
#define DIMNUM    4
#define AUXENT    union auxent
#define AUXESZ    18
```

String Table

Symbol table names longer than eight characters are stored contiguously in the string table with each symbol name delimited by a null byte. The first four bytes of the string table are the size of the string table in bytes; offsets into the string table, therefore, are greater than or equal to 4. For example, given a file containing two symbols (with names longer then eight characters, **long_name** and **another_one**) the string table has the format as shown in Figure 10-14:

Figure 10-14 String Table

'l'	'o'	'n'	'g'
'_'	'n'	'a'	'm'
'e'	'\0'	'a'	'n'
'o'	't'	'h'	'e'
'r'	'_'	'o'	'n'
'e'	'\0'	'...'	'...'

The index of **long_name** in the string table is 4 and the index of **another_one** is 14.

Access Routines

UNIX System V contains a set of access routines that are used for reading the various parts of a common object file. Although the calling program must know the detailed structure of the parts of the object file it processes, the routines effectively insulate the calling program from the knowledge of the overall structure of the object file.

The access routines can be divided into four categories:

1. functions that open or close an object file
2. functions that read header or symbol table information
3. functions that position an object file at the start of a particular section of the object file
4. a function that returns the symbol table index for a particular symbol

These routines can be found in the library **libld.a** and are listed in the System Services section of the *Programmer's Reference Manual.*

Appendix A

Converting from Previous Versions of the Compiler

Introduction A-1

Differences between Versions 5.1 and 5.0 A-2
New Features for the System V Release of C A-2
New Pragmas A-3

Differences between Versions 5.0 and 4.0 A-4
Enhancements and Additions A-4
Changes to the Language Syntax A-4
New Features for the Microsoft Implementation of C A-6

Differences between Versions 4.0 and 3.0 A-8
Enhancements and Additions A-8
Changes in the Language Syntax A-8
New Features for This Implementation of C A-11

Introduction

This appendix describes differences between Version 5.1 and Version 5.0, between Version 5.0 and Version 4.0, and between Version 4.0 and Version 3.0, of the System V Microsoft C Compiler. If you have an earlier version of the compiler, or if you have written programs for an earlier version, this chapter can help you convert your previous source code. The actions necessary to convert source code depend on which of the earlier versions you have used.

Version 5.1 is an update of Version 5.0. Code written for Version 5.0 should compile without change on the Version 5.1 compiler. The primary changes are new pragmas, new keywords, and new command-line changes. Version 5.0 is an update of Version 4.0. Generally, the two versions are compatible: most C source code written for Version 4.0 should compile without change on Version 5.0, although there are erroneous C constructs allowed in Version 4.0 that are not allowed in Version 5.0, and changes in the emerging ANSI C standard may force changes in source programs. For more information, see the *C Language Reference*. In some cases you may be able to enhance your programs by revising them to take advantage of new library functions and other features available with Version 5.0.

Differences between Versions 5.1 and 5.0

Changes in Version 5.1 since Version 5.0 fall into the following categories:

- New compiler options
- New pragmas
- New keywords

New Features for the System V Release of C

The following new options have been added to the System V implementation of the Microsoft C Compiler:

Option	Effect
-S	Generates assembly-language output. The resulting file is intended for the Macro Assembler, **masm(CP)**.
-xenix	Produces OMF-formatted object files using the language development tools and (if applicable) an *x.out* format executable file. It also suppresses warning messages about masm directives in any assembly language output files.

New Pragmas

The following new pragmas have been added to Version 5.1 of the C compiler:

Pragma	Effect
comment	Places a comment record in the object file.
linesize	Sets the number of characters per line in the source listing.
message	Sends a message to the standard output without terminating the compilation.
page	Skips the specified number of pages in the source listing.
pagesize	Sets the number of lines per page in the source listing.
skip	Skips the specified number of lines in the source listing.
subtitle	Specifies a subtitle for the source listing.
title	Specifies a title for the source listing.

The pragmas are described in Chapter 2.

A

Differences between Versions 5.0 and 4.0

Changes in Version 5.0 since Version 4.0 fall into the following categories:

- Enhancements and additions to the compiler software to allow for more flexible programming, improved code generation, and increased support for the developing ANSI standard
- Changes in the language syntax
- Changes in function operations, primarily to conform to the specifications for these functions in the ANSI standard

These features and the changes required to take advantage of them are discussed in the following sections.

Enhancements and Additions

Enhancements for Version 5.0 include the following:

- Improved code generation, including loop optimization; improved large-model code generation; and intrinsic functions
- Faster compilation speed
- Support for code that will be loaded into read-only memory (ROM)
- New error-message numbering

Changes to the Language Syntax

Some Version 5.0 changes were made to the C-language syntax to make it conform more closely to the new ANSI standard. Most of these changes do not affect source code written for the Version 4.0 compiler. The changes are summarized as follows:

- Full function prototyping is supported in Version 5.0. A function prototype is a forward declaration containing the types and, optionally, names of the parameters (if any) expected in the function call.

It can also include identifiers for the arguments, though they go out of scope at the end of the prototype. Prototypes allow the compiler to perform type checking on the actual arguments passed when the function is called. If the compiler does not find a prototype, the first occurrence of the function (definition or call) is used as the basis of a prototype for that function. That prototype is used to perform type checking against subsequent calls, subsequent declarations, or the definition. For more information about function prototyping, see the *C Language Reference.*

- The **const** and **volatile** type specifiers have been implemented for Version 5.0. The **const** type specifier declares an object as an unmodifiable value. It can be used for objects of any fundamental or aggregate type or for pointers to objects of any type. The **volatile** type specifier is implemented syntactically, but not semantically. For more information, see the *C Language Reference.*

Note

Programs that currently use **const** or **volatile** as identifiers must be recoded to use other names.

- In Version 5.0, variables of **enum** type are treated as if they are of **int** type in all cases. Therefore, **enum** variables can be used in indexing expressions and as operands of all relational and arithmetic operators.

- String concatenation is supported in Version 5.0. This feature causes adjacent string literals to be concatenated into a single string literal. This means, for example, that instead of using a backslash before a new-line character to indicate continuation of a long string literal, the literal can simply be broken into two or more quoted string literals on separate lines. For more information, see the *C Language Reference.*

- New preprocessor features in Version 5.0 include the stringizing operator (#), which allows arguments in macro expansions to be expanded into a string literal containing the expanded argument; and the concatenation operator (##), which concatenates the tokens on either side of the operator into a new token in macro expansions. For more information, see the *C Language Reference.*

Note

Previous versions of C allowed expansion of macro formal arguments appearing in string literals and character constants. Programs that rely on this feature *must* be recoded to use the stringizing operator. For information, see the discussion of string literals in the *C Language Reference*.

- The **long double** data type is now supported; the **long float** data type is no longer supported.
- The three-digit forms of hex escape sequences (\x*ddd*) and octal escape sequences (*ddd*) are now supported.
- The unary plus (+) operator is allowed, but ignored semantically.

New Features for the Microsoft Implementation of C

The following new **cc** command options have been added to the Microsoft C Compiler for Version 5.0:

Option	Effect
-Oi	Enables intrinsic code generation for all available functions
-Ol	Enables loop optimizations for an entire program
-Op	Forces consistent precision in floating-point math operations
-Sl	Specifies the line width for source listings
-Sp	Specifies the number of lines per page for source listings
-Ss	Specifies subtitles for source listings
-St	Specifies titles for source listings

-Tc	Tells the compiler that the following file is a C source file
-Zp	Packs structures on one-, two-, or four-byte boundaries

The following new pragmas have been added to the Microsoft C Compiler for Version 5.0 to control the specified features on a local basis:

Pragma	Effect
loop_opt	Turns loop optimizations on and off
pack	Specifies packing alignment for structures
intrinsic	Specifies which functions are compiled as intrinsic functions
function	Specifies which functions are compiled as standard function calls
same_seg	Tells the compiler to assume that specified variables are allocated in the same far data segment
alloc_text	Specifies modules to be grouped into a specified far text segment

Note that the existing **check_stack** pragma uses the following new format for specifying arguments:

#pragma check_stack([{**on**|**off**}])

Differences between Versions 4.0 and 3.0

Changes between Versions 4.0 and 3.0 fall into the same categories as those between Versions 5.0 and 4.0.

- Enhancements and additions to the compiler software to allow for more flexible programming, improved code generation, and increased support for the developing ANSI standard
- Changes in the language syntax

These features and the changes required to take advantage of them are discussed in the following sections.

Enhancements and Additions

Enhancements for Version 4.0 include the following:

- New options for **cc** and **xld**
- Improved code optimization
- New memory models (**compact** and **huge**)
- Source listings
- Numbered error messages
- Huge arrays, allowing a single array to be larger than 64K

These changes should have no effect on Version 3.0 source code.

For information on changes to the syntax of the **cc** command line, see the "Compiling with the cc Command" chapter of this guide.

Changes in the Language Syntax

Some Version 4.0 changes were made to the C-language syntax to make it conform more closely to the developing ANSI standard. Most of these changes do not affect source code written for the Version 3.0 compiler. The changes are summarized as follows:

- The **\a** escape sequence represents the bell (or alert) character in Version 4.0.

  You can make your source code more portable by using **\a** instead of **\x7**. For more information, see the *C Language Reference*.

- The **signed** keyword was added to improve portability.

  The **signed** keyword can be used to specify signed items. This keyword is particularly useful for declaring signed **char** types in programs compiled with the **-J** option. (**-J** changes the default mode for the **char** type to unsigned.) For more information on signed types, see the *C Language Reference*.

- The syntax was changed for making function calls with a variable number of arguments.

  The following two declarations contrast the Version 3.0 form and the Version 4.0 form:

```
int func (int,);        /* Forward declaration in
                        ** Version 3.0 syntax
                        */

int func (int,...);     /* Forward declaration in
                        ** Version 4.0 syntax
                        */
```

  This change was made to conform to changes in the ANSI standard for the C language. Both forms are supported in Version 4.0 of the C Compiler. Microsoft recommends the use of the Version 4.0 form in all programs.

- Prior to Version 4.0, the compiler allowed arbitrary strings of characters after a syntactically correct preprocessor command. To conform to the developing ANSI standard, this was disallowed in Version 4.0.

  Beginning with Version 4.0, the following usage, for example, causes the compiler to generate a warning message:

```
#endif    Block ends here
```

  In Versions 4.0 and later, such strings must be enclosed in comment delimiters, as in the following example:

```
#endif    /* Block ends here */
```

- Names of types defined with **typedef** are not keywords in Version 4.0, as they were in Version 3.0. In Version 4.0, these names are in the same naming class as names of functions and variables, and can be redefined in a nested block.

  For more information, see the *C Language Reference*.

- Beginning with Version 4.0, the **#pragma** directive is supported.

  A "pragma" is an instruction to the compiler. Its syntax is similar to the syntax of preprocessor directives, but its purpose is different. The syntax is as follows:

  #pragma *charstring*

  The only pragma instruction supported in the C Compiler, Version 4.0, is the **check_stack** pragma. This pragma is specific to System V, and is discussed in greater detail in the "Compiling with the cc Command" chapter of this guide.

- Hexadecimal and octal integer constants are handled differently in Version 4.0 than they are in Version 3.0.

  For more information, see the *C Language Reference*.

- The extended keywords **fortran**, **pascal**, **cdecl**, **near**, and **huge** are enabled by default in Version 4.0. They can be disabled by giving the **-Za** option on the command line.

- Two new reserved words, **const** and **volatile**, were added but not implemented for Version 4.0.

- In Version 3.0, when a near pointer is converted to type **long int**, it is first converted to type **short int**, then to **long int**; as a result, in Version 3.0 the expression in the **if** statement evaluates as true in the following fragment:

```
char *ptr = NULL;
long i;

i = (long) ptr;
if (i == 0L) {
     .
     .
     .
     }
```

  In Version 4.0, the conversion order of near pointers to long integers was changed so that it conforms to the order in which the

compiler does all other conversions that increase the length of a variable: first the size, then the mode. (For example, the compiler converts a variable with type **char** to type **unsigned long** by first converting it to **signed long**, then to **unsigned long**.) Because of this change, the preceding code now converts *ptr* to a far pointer by loading the appropriate segment register value, then changing that to a long integer. The expression following the *if* statement would most likely be false in Version 4.0, since the segment registers do not usually contain 0.

New Features for This Implementation of C

The following features were added to the C compiler for Version 4.0:

- Two new memory models: huge and compact
- The **huge**, **signed**, and **cdecl** keywords
- A pragma (**check_stack**) to control stack checking
- The **-J** option to change the default mode for the **char** type to unsigned
- The **-Gc** option to specify the alternative calling sequence and naming conventions used in Pascal and FORTRAN

These features are discussed in the "Working with Memory Models" chapter. In most cases, they will not affect existing Version 3.0 source code. However, you may be able to improve your existing programs by modifying them to take advantage of the new memory models or the **huge** keyword.

Appendix B

Writing Portable Programs

Introduction B-1

Program Portability B-3

Machine Hardware B-4
- Byte Length B-4
- Word Length B-4
- Storage Alignment B-5
- Byte Order in a Word B-6
- Bit Fields B-7
- Pointers B-7
- Address Space B-9
- Character Set B-9

Compiler Differences B-11
- Signed/Unsigned char and Sign Extension B-11
- Shift Operations B-11
- Identifier Length B-12
- Register Variables B-12
- Type Conversion B-12
- Functions with a Variable Number of Arguments B-14
- Side Effects and Evaluation Order B-14

Environment Differences B-16

Portability of Data B-17

Type-Size Summary B-18

Byte-Ordering Summary B-20

Introduction

The standard definition of the C programming language leaves many details to be decided in specific implementations of the language. These unspecified features of the language detract from its portability and must be studied when attempting to write portable C code.

Most of the issues affecting C portability arise from differences either in target-machine hardware or in compilers. C was designed to compile efficient code for the target machine (initially a Digital Equipment Corporation PDP-11®), so many of the language features not precisely defined are those that reflect a particular machine's hardware characteristics.

This appendix highlights the various aspects of C that may not be portable across different machines and compilers. It also briefly discusses the portability of a C program in terms of its environment. The environment is determined by the system calls and library routines a program uses during execution, file path names it requires, and other items not guaranteed to be constant across different systems.

The C language has been implemented on many different computers with widely different hardware characteristics, from small eight-bit microprocessors to large mainframes. This appendix is concerned with the portability of C code in the MS-DOS, XENIX, and System V programming environments. This is a more restricted problem to consider, since all MS-DOS, System V, and XENIX operating systems to date run on hardware with the following basic characteristics:

- ASCII character set
- Eight-bit bytes
- Two-byte or four-byte integers
- Two's-complement arithmetic

These features are not formally defined for the language and may not be found in all implementations of C. However, the remainder of this appendix is devoted to those systems where these basic assumptions hold.

The C-language definition contains no specification of how input and output are performed. These specifications are left to system calls and library routines on individual systems. Within the System V and XENIX systems there are system calls and library routines that can be considered

portable. This version of the C Compiler includes system calls and library routines that can be considered portable across System V, XENIX, and MS-DOS systems. The run-time library for the System V C Compiler for MS-DOS is composed primarily of System V and XENIX compatible routines. By restricting the use of XENIX and System V routines to those included in the MS-DOS library, the System V programmer can develop MS-DOS programs in the System V environment; C programs written on MS-DOS are easily portable to XENIX or System V.

Program Portability

A program is "portable" if it can be compiled and run successfully on different machines without alteration. There are many ways to write portable programs. One way is to avoid using inherently nonportable language features. Another is to isolate any nonportable interactions with the environment, such as I/O to nonstandard devices. For example, programs should avoid hard-coded path names unless a path name is common to all systems.

Files required at compile time (such as include files) may also introduce nonportability if the path names used are not the same on all machines. In some cases, include files containing machine-specific definitions can be used to make the source code itself portable.

Machine Hardware

Differences in the hardware of the various target machines and differences in the corresponding C compilers cause the greatest number of portability problems. This section lists problems commonly encountered.

Byte Length

By definition, the **char** data type in C must be large enough to hold as positive integers all members of a machine's character set. For the machines described in this appendix, the **char** size is an eight-bit byte.

Word Length

The size of the basic data types for a given implementation are not formally defined in the C language. Therefore, they often follow the most natural size for the underlying machine. It is safe to assume that **short** is no longer than **long**. Beyond that, no assumptions are portable. For example, on some machines **short** is the same length as **int**, whereas on others **long** is the same length as **int**.

Two areas where different **int** sizes affect program portability are the following:

1. Array indexing. For very large arrays, a variable of type **int** may not be long enough to store the indices of the highest-numbered array elements.

2. Pointer subtraction. On some machines, an **int** variable may not be long enough to store the results of pointer subtraction. See the section on "Pointers" in this appendix for more information about this problem.

Programs that need to assume the size of a particular data type should avoid hard-coded constants where possible. Such information can usually be written in a fairly portable way. For example, the maximum positive integer (on a two's-complement machine) can be obtained with the following directive:

```
#define MAXPOS    ((int)(((unsigned)-1) >> 1))
```

This is preferable to the following code:

```
#ifdef PDP11
#define MAXPOS 32767
#else
.
.
.
#endif
```

To find the number of bytes in an **int**, use **sizeof(int)** rather than 2, 4, or some other nonportable constant.

Storage Alignment

The C language defines no particular layout for storage of data items relative to each other. The layout for storage of structure elements, or unions within the structure or union, is also left undefined by the language.

Some processors require that data types longer than one byte be aligned on even-byte address boundaries. Others, such as the 8086/8088, have no such hardware restriction. However, even with these machines, most compilers generate code that aligns words, structures, arrays, and long words on even addresses or on even long-word addresses. Therefore, the following code sequence may give different results, depending on specific alignment requirements on different machines:

```
struct s_tag {
       char c;
       int  i;
       };
printf("%d\n",sizeof(struct s_tag));
```

This variation in data storage has two major implications: data accessed as nonprimitive data types are not portable, and code that makes assumptions about the layout on a particular machine is not portable.

Therefore, unions containing structures are nonportable if the union is used to access the same data in different ways. Unions are only likely to be portable if they are used exclusively to store different data in the same space at different times. For example, if the following union were used to obtain four bytes from a long word, the code would not be portable to some machines:

```
union {
      char c[4];
      long lw;
      } u;
```

The **sizeof** operator should always be used when reading and writing structures, as follows:


```
struct s_tag st;
.
.
.
write(fd, &st, sizeof(st));
```

Using the **sizeof** operator ensures portability of the source code, but does not produce a portable data file. Portability of data is discussed in the "Portability of Data" section in this appendix.

Byte Order in a Word

The variation in byte order in a word affects the portability of data more than the portability of source code. However, any program that makes use of knowledge of the internal byte order in a word is not portable. For example, on some XENIX or System V systems there is an include file, **misc.h**, that contains the following structure declaration:

```
/*
* structure to access an
* integer in bytes
*/
struct {
      char  lobyte;
      char  hibyte;
      };
```

With certain less-restrictive compilers, this declaration could be used to access the high- and low-order bytes of an integer separately and in a completely nonportable way. The correct way to do this is to use mask and shift operations to extract the required byte, as shown in the following example:

```
#define LOBYTE(i)  (i & 0xff)
#define HIBYTE(i)  ((i >> 8) & 0xff)
```

These definitions provide a portable way to extract the least-significant and the next-least-significant bytes of an integer. Since the **int** type can be either two or four bytes, depending on the machine, even these definitions do not provide a completely portable way to access the bytes of an **int**.

One result of the byte-ordering problem is that the following code sequence will not always perform as intended:

```
int c = 0;

read(fd, &c, 1);
```

On machines where the low-order byte is stored first, the value of *c* is the byte value read. On other machines, the byte is read into some byte other than the low-order one, so the value of *c* is different.

Bit Fields

Bit fields are not implemented in all C compilers. The C Compiler implements bit fields and allows them to have any length up to the size of a **long**. However, in many implementations no bit field may be larger than an **int**, and no bit field can overlap an **int** boundary. If necessary, the compiler will leave gaps and move to the next **int** boundary. To ensure portability no individual field should exceed 16 bits.

The C language makes no guarantees about whether bit fields are assigned left to right or right to left. Therefore, although bit fields may be useful for storing flags and other small data items, their use in unions to dissect bits from other data is definitely nonportable.

Pointers

The C language is fairly generous in allowing manipulation of pointers, to the extent that most compilers do not generate warnings for nonportable pointer operations. A common nonportable use of pointers is the use of casts to assign one pointer to another pointer of a different data type. This practice usually makes some assumption about the internal byte ordering and layout of the data type, and is therefore nonportable. In the following code, the byte order in the array *c* is not portable:

```
char c[4];
long *lp;

lp = (long *)&c[0];
*lp = 0x12345678L;
```

Code like this is usually unnecessary or invalid. It is acceptable, however, when the **malloc** function is used to allocate space for variables that do not have **char** type. The routine is declared as type **char ***, and the return value is cast to the type to be stored in the allocated memory. If this type is not **char ***, then a compiler may issue a warning concerning illegal

type conversion. In addition, the **malloc** function is designed always to return a starting address suitable for storing all types of data. A compiler may not know this, so it may give an additional warning about possible data-alignment problems. In the following example, **malloc** is used to obtain memory for an array of 50 integers:


```
extern void *malloc( );
int *ip;

ip = (int *)malloc(50 * sizeof(int));
```

This example will elicit a warning message from some compilers.

The *C Language Reference* states that a pointer can be assigned (or cast) to an integer large enough to hold it. Note that the size of the **int** type depends on the given machine and implementation. This type is **long** on some machines and **short** on others. The size may also be modified by **near** and **far** declarations. In general, do not assume that the following statement is always true:

```
sizeof(char *) == sizeof(int)
```

For example, the following construction is nonportable, assuming that the function identifier *func* is not previously declared:

```
int p;
p = (char *)func( );
```

This example assumes that a **char** pointer has the same length as an **int**.

Another consequence of different-sized **int** types on different machines is that pointer subtraction may not give the expected results. As an example of this case, subtracting pointers to the beginning and end of a very large array may give a result that is too large to store in an **int** variable, as shown in the following example:

```
int arr[20000], *b = arr, *e = &arr[20000];
int diff;
diff = e - b;     /* result too large to store in
                     int variable diff */
```

To correct this problem, coerce the result of the pointer subtraction **long** type, then assign the result to a variable of **unsigned int** type, as shown in the following example:

```
unsigned int udiff;
udiff = (long) ((int huge *)e - (int huge *)b);
```

In most implementations, the null pointer value **NULL** is defined to be the **int** value 0. The length of the 0 value can lead to problems for functions that expect pointer arguments longer than an **int.** For portable code, always use the following form to pass a **NULL** value of the correct size:

```
func( (char *)NULL );
```

Address Space

The address space available to a program varies considerably from system to system. Some small processors allow only 64K for program text and data combined. Others allow up to 64K of data and 64K of program text. Larger machines may allow considerably more text and possibly more data as well.

Large programs, or programs that require large data areas, may have portability problems on small machines.

Character Set

The C language does not require the use of the ASCII character set. In fact, the only character-set requirements are that all characters must fit in the **char** data type, and all characters must have positive values.

In the ASCII character set, all characters have values between 0 and 127 and therefore can be represented in seven bits. On an eight-bits-per-byte machine they are all positive, regardless of whether **char** is treated as signed or unsigned.

A set of character-classi fication macros is included as part of the run-time library for the C Compiler. These macros should be used for most tests on character quantities. The macros are defined in the include file **ctype.h**, and are described in the *C Library Guide.*

The character-classi fication macros provide insulation from the internal structure of the character set. In addition, the names of the macros are often more meaningful than the equivalent line of code. Compare the following two lines:

```
if(isupper(c))

if((c >= 'A') && (c <= 'Z'))
```

With some of the other macros, such as **isxdigit** to test for a hexadecimal digit, the advantage is even greater. Also, the internal implementation of the macros makes them more efficient than an explicit test with an **if** statement.

Compiler Differences

There are a number of C compilers running under various operating systems. The main areas of differences between compilers are outlined in this section.

Signed/Unsigned char and Sign Extension

The current state of the signed versus unsigned **char** problem is best described as unsatisfactory. The sign-extension problem is a serious barrier to writing portable C, and the best solution at present is to write defensive code that does not rely on particular implementation features.

Shift Operations

The left-shift operator (<<) shifts its operand a number of bits left, filling vacated bits with zeros. This is called a logical shift. When the right-shift operator (>>) is applied to an unsigned quantity, it performs a logical-shift operation; when it is applied to a signed quantity, the vacated bits may be filled with zeros (logical shift) or with sign bits (arithmetic shift). The decision is implementation dependent, and code that assumes a particular implementation is nonportable.

With compilers that use arithmetic right shift, it is necessary to shift and mask the appropriate number of high-order bits to avoid sign extension, as follows:

```
char c;

c = (c >> 3) & 0x1f;
```

You can also avoid sign extension by using the divide operator (/) as follows:

```
char c;

c = c / 8;
```

Identifier Length

The use of long symbols and identifier names will cause portability problems with some compilers. To avoid these problems, a program should keep the following symbols as short as possible:

- C preprocessor symbols
- C local symbols
- C external symbols

Some loaders also place restrictions on the number of unique characters in C external symbols. Symbols unique in the first six characters are unique to most C-language processors.

In some C implementations, the case of letters in identifiers is not significant.

Register Variables

The number and type of register variables in a function depend on the machine hardware and the compiler. Excess and invalid register declarations are treated as nonregister declarations and should not cause a portability problem. On an 8086, 8088 or 80286 processor, up to two register declarations are significant, and they must be applied to types of size **int** or smaller. On the 80386 processor, three register declarations are significant.

Since the compiler ignores excess variables of **register** type, the most important **register**-type variables should be declared first. In this way, register variables that the compiler ignores will be those that are the least important.

Type Conversion

The C language has some rules for implicit type conversion; it also allows explicit type conversions by type casting. The most common portability problem in implicit type conversion is unexpected sign extension. This is a potential problem whenever something of type **char** is compared with an **int**.

The following example will never evaluate true on a machine that sign-extends **char** types but treats hexadecimal numbers as unsigned:

```
char c;

if(c == 0x80) {
    .
    .
    .
    }
```


The following construction is also nonportable:

```
char c;
unsigned int u;

if (u == (unsigned)c) {
     .
     .
     .
     }
```

Two problems can arise in the preceding example:

1. The **char** type may be considered either signed or unsigned, depending on the implementation.

2. For implementations that consider the **char** type to be signed, two different methods of carrying out the conversion are possible: the **char** value may be sign extended to **int** type first, then converted to **unsigned** type; or the **char** type may be converted to an unsigned type of the same size, then zero extended to **int** length.

The only safe comparison between **char** type and **int** is the following:

```
int c;

if(c == 'x') {
    .
    .
    .
    }
```

This comparison is reliable because C guarantees all character constants to be positive.

Type conversion also occurs when arguments are passed to functions. Types **char** and **short** become **int**. Extending the **char** type can produce unexpected results. For example, the following program yields a result of -128 on some machines:

```
char c = 128;
printf("%d\n",c);
```


The unexpected negative value is produced because *c* is converted to **int** when it is passed to the **printf** function. The function itself has no knowledge of the original type of the argument and is expecting an **int**. The correct way to handle this situation is to code defensively and allow for the possibility of sign extension, as in the following example:

```
char c = 128;
printf("%d\n", c & 0xff);
```

Functions with a Variable Number of Arguments

Functions with a variable number of arguments present a particular portability problem if the type of the arguments is also variable. In such cases the code is dependent on the size of various data types. For portability, these cases should be avoided.

Side Effects and Evaluation Order

The C language makes few guarantees about the order of evaluation of operands in an expression or arguments to a function call. Therefore, the following statement is not portable:

```
func(i++, i++);
```

Even the following statement is unwise if **func** is ever likely to be replaced by a macro, since the macro may use *i* more than once:

```
func(i++);
```

Certain System V- and XENIX-compatible macros commonly appear in user programs; some of these use their argument only once, and therefore can safely be called with a side-effect argument. To determine whether a macro handles side effects correctly, examine the code for that macro to see whether or not the argument is evaluated more than once.

Operands to the following operators are guaranteed to be evaluated left to right:

, **&&** **||** **?:**

Note that the comma operator here is a separator for two C statements. A list of items separated by commas in a declaration list is not guaranteed to be processed left to right. Therefore, the following declaration on an 8086 or 8088 processor, where only two register variables may be declared, could give any two of the four variables **register** type, depending on the compiler:

```
register int a, b, c, d;
```

To give register storage to the most important variables, use separate declaration statements and declare the most important variables first. The order of processing of individual declaration statements is guaranteed to be sequential in the following statements:

```
register int a;
register int b;
register int c;
register int d;
```

Environment Differences

Most programs make system calls and use library routines for various services. This section indicates some of those routines that are not always portable and those that particularly aid portability.

System calls specific to an operating system are not portable if they are not present on all other operating-system implementations of C. Most of the system calls defined in the UNIX System V run-time library are compatible with DOS system calls and are therefore portable to a DOS environment.

Any program is nonportable that contains hard-coded path names to files or directories, or that contains user identifier numbers, log-in names, terminal lines, or other system-dependent parameters. These types of constants should be in header files, passed as command-line arguments, or obtained from the environment.

Note that the members of the **printf** and **scanf** families of functions, including **fprintf**, **fscanf**, **printf**, **sprintf**, **scanf**, **vfprintf**, **vprintf**, **vsprintf**, and **sscanf**, have evolved in several ways, and some features are not completely portable. Some of the format-conversion characters have changed their meanings, in particular those relating to uppercase and lowercase in the output of hexadecimal numbers and the specification of **long** integers on 16-bit word machines. The C specifications for these routines are given in the *C Library Guide*.

Users should be wary of porting object files that reference the **setjmp** or **longjmp** functions from System V or XENIX to MS-DOS, unless these object files were compiled with the **-dos** option. The MS-DOS versions of these functions use a larger buffer size and may cause memory to be overwritten. Such object files can be ported from MS-DOS to System V without problems, and the corresponding source files can be ported in either direction.

Portability of Data

Data files are almost always nonportable across different central-processing-unit (CPU) architectures. As mentioned above, structures, unions, and arrays have varying internal layout and padding requirements on different machines. In addition, byte ordering within words and actual word length may differ.

The only way to achieve data-file portability is to write and read data files as one-dimensional character arrays. This procedure prevents alignment and padding problems if the data are written and read as characters, and interpreted that way. Thus ASCII text files can usually be moved between different machine types without significant problems.

Type-Size Summary

Table B.1 summarizes the sizes of the various data types as defined in the C Compiler, Version 5.1.

Table B.1
C Type Sizes

Type Name (Alternate Names)	Storage	Range of Values
char (signed char)	1 byte	-128 to 127
int (signed) (signed int)	Implementation dependent (2 bytes in UNIX C 5.1)	(-32,768 to 32,767 for UNIX C Version 5.1) (-2,147,483,648 to 2,147,483,647 for 386)
short (short int) (signed short) (signed short int)	2 bytes	-32,768 to 32,767
long (long int) (signed long) (signed long int)	4 bytes	-2,147,483,648 to 2,147,483,647
unsigned[1] **char**	1 byte	0 to 255
unsigned (unsigned int)	Implementation dependent (2 bytes in C 5.1)	(0 to 65,535 for C 5.1) (0 to 4,294,967,295 for 386)
unsigned short (unsigned short int)	2 bytes	0 to 65,535

Table B.1
C Type Sizes

Type Name (Alternate Names)	Storage	Range of Values
unsigned long (unsigned long int)	4 bytes	0 to 4,294,967,295
enum	Implementation dependent (2 bytes in C 5.1)	(0 to 65,535 for C 5.1) (0 to 4,294,967,295 for 386)
float	4 bytes	Approximately 3.4E-38 to 3.4E+38 (7-digit precision)
double	8 bytes	Approximately 1.7E-308 to 1.7E+308 (15-digit precision)
long double	Implementation dependent (8 bytes in C 5.1)	Approximately 1.7E-308 to 1.7E+308 (15-digit precision)

1 Any type size modified by the **unsigned** keyword can be modified by the **signed** keyword instead. The **signed** keyword is useful if the **-J** option has been used to change the default sign of the **char** type.

Byte-Ordering Summary

Tables B.2 and B.3 summarize byte ordering for **short** and **long** types, respectively. The following conventions are used in these tables:

1. The lowest physically addressed byte of the data item is **a0**; **a1** has the byte address **a0 + 1**, and so on.

2. The least-significant byte of the data item is **b0**; **b1** is the next least significant, and so on.

Since byte ordering is machine specific, any program that actually makes use of the following information is guaranteed to be nonportable:

Table B.2
Byte Ordering for Short Types

CPU	Byte Order
8086	**b0 b1**
80286	**b0 b1**
PDP-11®	**b0 b1**
VAX-11®	**b0 b1**
M68000	**b1 b0**
Z8000®	**b1 b0**

Table B.3
Byte Ordering for Long Types

CPU	Byte Order
8086	**b0 b1 b2 b3**
80286	**b0 b1 b2 b3**
PDP-11®	**b2 b3 b0 b1**
VAX-11®	**b0 b1 b2 b3**
M68000	**b3 b2 b1 b0**
Z8000®	**b3 b2 b1 b0**

Appendix C

Writing Programs for Read-Only Memory

Introduction C-1

System V Dependent Library Routines C-2

Introduction

This appendix presents information for developers who will be downloading code written with the C Compiler into read-only memory (ROM). Code of this type is more commonly known as "ROMable" code. Information is given about the run-time library routines that directly interface with System V.

System V Dependent Library Routines

Because ROMable programs are often run outside a System V environment, they cannot include calls to run-time library routines that perform their operations through calls to System V functions. Table C.1 lists the library routines that call System V functions.

Table C.1
System V Dependent Library Routines

abort	**_exit**	**fwrite**	**read**
access	**ifclose**	**getch**	**rmdir**
chdir	**fgetc**	**getcwd**	**scanf**
chmod	**fgetchar**	**getpid**	**sopen**
chsize	**fgets**	**gets**	**sprintf**
close	**flush**	**getw**	**sscanf**
creat	**fopen**	**labs**	**stat**
dup	**fprintf**	**localtime**	**system**
dup2	**fputc**	**locking**	**tell**
eof	**fputchar**	**lseek**	**time**
execl	**fputs**	**mkdir**	**tmpfile**
execle	**fread**	**mktemp**	**unlink**
execlp	**freopen**	**open**	**utime**
execlpe	**fscanf**	**perror**	**vfprintf**
execv	**fseek**	**printf**	**vprintf**
execve	**fstat**	**putch**	**vsprintf**
execvp	**ftell**	**puts**	**write**
execvpe	**ftime**	**putw**	

A program containing calls to any of these routines cannot run in a non-System V environment unless you do one of the following:

- Write replacements for these System V-dependent routines as needed.
- Edit the program to remove the calls to the listed routines.
- Obtain the library source files from System V and edit them so that they do not include System V function calls, and write functional equivalents of the System V functions that can be called from your program.

Note that certain functions that are not listed above may call System V functions indirectly: that is, they may be part of a series of nested calls that call routines in the list.

Appendix D

C Error Messages and Exit Codes

Introduction D-1

Command-Line Error Messages D-2
- Command-Line Fatal-Error Messages D-2
- Command-Line Error Messages D-2
- Command-Line Warning Messages D-4

Compiler Error Messages D-7
- Fatal-Error Messages D-8
- Compilation-Error Messages D-14
- Warning Messages D-29
- Compiler Limits D-39

Compiler Exit Codes D-41

Introduction

This appendix lists error messages you may encounter as you develop a program, and gives a brief description of actions you can take to correct the errors. It also describes the exit codes returned by the compiler.

Command-Line Error Messages

Messages that indicate errors on the command line used to invoke the compiler have one of the following formats:

command line fatal error D1xxx: messagetext	(fatal error)
command line error D2xxx: messagetext	(error)
command line warning D4xxx: messagetext	(warning error)

If possible, the compiler continues operation, printing a warning message. In some cases, command-line errors are fatal and the compiler terminates processing.

Command-Line Fatal-Error Messages

The following messages identify fatal errors. The compiler driver cannot recover from a fatal error; it terminates after printing the error message.

`D1000 UNKNOWN COMMAND LINE FATAL ERROR`
The compiler detected an unknown fatal-error condition.

`D1001 could not execute` *'filename'*
The compiler could not find the given file in the current working directory or any of the other directories named in the **PATH** variable.

`D1002 too many open files, cannot redirect` *'filename'*
No more file descriptors were available to redirect the output of the **-P** option to a file.

Command-Line Error Messages

When the compiler driver encounters any of the errors listed in this section, it continues compiling the program (if possible) and outputs additional error messages. However, no object file is produced.

`D2000 UNKNOWN COMMAND LINE ERROR`
The compiler detected an unknown error condition.

`D2001 too many symbols predefined with -D`
Too many symbolic constants were defined using the **-D** option on the command line.

The limit on command-line definitions is normally 16; you can use the **-U** or **-u** option to increase the limit to 200.

`D2002 a previously defined model specification has been overridden`
Two different memory models were specified; the model specified later on the command line was used.

`D2003 missing source file name`
You did not give the name of the source file to be compiled.

`D2007 bad` *option* `flag, would overwrite` *'string1'* `with` *'string2'*
The specified option was given more than once, with conflicting arguments *string1* and *string2*.

`D2008 too many` *option* `flags,` *'string'*
Too many letters were given with the specified option (for example, with the **-O** option).

`D2009 unknown option` *character* `in` *'optionstring'*
One of the letters in the given option was not recognized.

`D2012 too many linker flags on command line`
You tried to pass more than 128 separate options and object files to the linker.

`D2013 incomplete model specification`
Not enough characters were given for the **-A***string* option. The option requires all three letters (to specify the data-pointer size, code-pointer size, and segment setup).

`D2014 -ND not allowed with -Ad`
You cannot rename the default data segment unless you give the **-Au***xx* option (**SS != DS**, load **DS**) on the command line.

`D2016 -Gw and -ND` *name* `are incompatible`
You tried to rename the default data segment to the given name when you specified the **-Gw** option.

Renaming the default data segment is illegal in this case because the **-Gw** option requires the **-Aw***xx option*.

`D2017 -Gw and -Au flags are incompatible`
You tried to specify the **-Au***xx* option (**SS != DS**, load **DS**) with the **-Gw** option.

Specifying **-Au***xx with* **-Gw** *is illegal because the* **-Gw** *option requires the* **-Aw***xx option.*

`D2019 cannot overwrite the source file, 'name'`
You specified the source file as an output-file name.

The compiler does not allow the source file to be overwritten by one of the compiler output files.

`D2020 -Gc option requires extended keywords to be enabled (-Ze)`
The **-Gc** option and the **-Za** option were specified on the same command line.

The **-Gc** option requires the extended keyword **cdecl** to be enabled if library functions are to be accessible.

`D2021 invalid numerical argument 'string'`
A non-numerical string was specified following an option that required a numerical argument.

`D2023 invalid model specification - small model only`

`D2024 : -Gm and -ND are incompatible options`
You compiled with both the **-Gm** and **-ND** compiler options. These options are incompatible because **-Gm** indicates that string literals and near const data items should be allocated in the **CONST** segment, while the **-ND** option attempts to allocate the same items in a different, named segment.

Command-Line Warning Messages

The messages listed in this section indicate potential problems but do not hinder compilation and linking.

`D4000 UNKNOWN COMMAND LINE WARNING`
An unknown fatal condition has been detected by the compiler.

`D4001 listing has precedence over assembly output`
Two different listing options were chosen; the assembly listing is not created.

D4002 ignoring unknown flag *'string'*
One of the options given on the command line was not recognized and is ignored.

D4003 80186/286 selected over 8086 for code generation
Both the **-G0** option and either the **-G1** or **-G2** option were given; **-G1** or **-G2** takes precedence.

D4004 optimizing for time over space
This message confirms that the **-Ot** option is used for optimizing.

D4006 only one of -P/-E/-EP allowed, -P selected
Only one preprocessor output option can be specified at one time.

D4007 -C ignored (must also specify -P or -E or -EP)
The **-C** option must be used in conjunction with one of the preprocessor output flags, **-E**, **-EP**, or **-P**.

D4008 non-standard model -- defaulting to small model libraries
A nonstandard memory model was specified with the option. The library search records in the object model were set to use the small-model libraries.

D4009 threshold only for far/huge data, ignored
The **-Gt** option cannot be used in memory models that have near data pointers. It can be used only in compact, large, and huge models.

D4011 preprocessing overrides source listing
Only a preprocessor listing was generated, since the compiler cannot generate both a source listing and a preprocessor listing at the same time.

D4012 function declarations override source listing
The compiler cannot generate both a source-listing file and the function prototype declarations at the same time.

D4013 combined listing has precedence over object listing
When **-Fc** is specified along with either **-Fl** or **-Fa**, the combined listing (**-Fc**) is created.

`D4014 invalid value` *number* `for` *'string'*`. Default` *number* `is used`
An invalid value was given in a context where a particular numerical value was expected.

`D4017 conflicting stack checking options - stack checking disabled`
Both the **-Ge** and the **-Gs** flags are given in one compile command (**-Ge** enables stack checking, **-Gs** disables it).

Compiler Error Messages

The error messages produced by the C compiler fall into three categories:

1. Fatal-error messages
2. Compilation-error messages
3. Warning messages

The messages for each category are listed below in numerical order, with a brief explanation of each error. To look up an error message, first determine the message category, then find the error number. All messages give the file name and line number where the error occurs.

Fatal-Error Messages

Fatal-error messages indicate a severe problem, one that prevents the compiler from processing your program any further. These messages have the following format:

filename(line) : fatal error C1xxx: messagetext

After the compiler displays a fatal-error message, it terminates without producing an object file or checking for further errors.

Compilation-Error Messages

Compilation-error messages identify actual program errors. These messages appear in the following format:

filename(line) : error C2xxx: messagetext

The compiler does not produce an object file for a source file that has compilation errors in the program. When the compiler encounters such errors, it attempts to recover from the error. If possible, it continues to process the source file and produce error messages. If errors are too numerous or too severe, the compiler stops processing.

Warning Messages

Warning messages are informational only; they do not prevent compilation and linking. These messages appear in the following format:

filename(line) : warning C4xxx: messagetext

You can use the **-W** option to control the level of warnings that the compiler generates. This option is described in the "Compiling with the cc Command" chapter of this guide.

Fatal-Error Messages

The following messages identify fatal errors. The compiler cannot recover from a fatal error; it terminates after printing the error message.

`C1000 UNKNOWN FATAL ERROR`
An unknown error condition has been detected by the compiler.

`C1001 Internal Compiler Error`
The compiler detected an internal inconsistency.

Note that the file name refers to an internal compiler file, *not* your source file.

`C1002 out of heap space`
The compiler has run out of dynamic memory space. This usually means that your program has many symbols and/or complex expressions.

To correct the problem, divide the file into several smaller source files, or break expressions into subexpressions.

`C1003 error count exceeds` *n*`; stopping compilation`
Errors in the program were too numerous or too severe to allow recovery, and the compiler must terminate.

`C1004 unexpected EOF`
This message appears when you have insufficient disk space for the compiler to create the temporary files it needs. The space required is approximately two times the size of the source file. This message can also occur when a comment does not have a closing delimiter (*/), or when an **#if** directive occurs without a corresponding closing **#endif** directive.

`C1005 string too big for buffer`
A string in a compiler intermediate file overflowed a buffer.

`C1006 write error on compiler intermediate file`
The compiler was unable to create the intermediate files used in the compilation process.

The following conditions commonly cause this error:

1. A system file or the inode table is full at time of compilation
2. Not enough space on a device containing a compiler intermediate file

`C1007 unrecognized flag` *'string'* `in` *'option'*
The *string* in the command-line *option* was not a valid option.

`C1009 compiler limit possibly a recursively defined macro`
The expansion of a macro exceeds the available space.

Check to see if the macro is recursively defined, or if the expanded text is too large.

`C1010 compiler limit : macro expansion too big`
The expansion of a macro exceeds the available space.

`C1012 bad parenthesis nesting - missing` *'character'*
The parentheses in a preprocessor directive were not matched; *character* is either a left or right parenthesis.

`C1013 cannot open source file` *'filename'*
The given file either did not exist, could not be opened, or was not found. Make sure your environment settings are valid and that you have given the correct path name for the file.

`C1014 too many include files`
Nesting of **#include** directives exceeds 10 levels.

`C1016 #if[n]def expected an identifier`
You must specify an identifier with the **#ifdef** and **#ifndef** directives.

`C1017 invalid integer constant expression`
The expression in an **#if** directive must evaluate to a constant.

`C1018 unexpected '#elif'`
The **#elif** directive is legal only when it appears within an **#if**, **#ifdef**, or **#ifndef** directive.

`C1019 unexpected '#else'`
The **#else** directive is legal only when it appears within an **#if**, **#ifdef**, or **#ifndef** directive.

`C1020 unexpected '#endif'`
An **#endif** directive appears without a matching **#if**, **#ifdef**, or **#ifndef** directive.

`C1021 bad preprocessor command 'string'`
The characters following the number sign (#) do not form a valid preprocessor directive.

`C1022 expected '#endif'`
An **#if**, **#ifdef**, or **#ifndef** directive was not terminated with an **#endif** directive.

`C1026 parser stack overflow, please simplify your prc`
Your program cannot be processed because the space required to parse the program causes a stack overflow in the compiler.

To solve this problem, try to simplify your program.

`C1027 DGROUP data allocation exceeds 64K`
More than 64K of variables was allocated to the default data segment.

For compact-, medium-, large-, or huge-model programs, use the **-Gt** option to move items into separate segments.

`C1032 cannot open object listing file 'filename'`
One of the following statements about the file name or path name given (*filename*) is true:

1. The given name is not valid.
2. The file with the given name cannot be opened for lack of space.
3. A read-only file with the given name already exists.

`C1033 cannot open assembly-language output file 'filename'`
One of the conditions listed under error message C1032 prevents the given file from being opened.

`C1034 cannot open source file 'filename'`
One of the conditions listed under error message C1032 prevents the given file from being opened.

`C1035 expression too complex, please simplify`
The compiler cannot generate the code for a complex expression. Break the expression into simpler subexpressions and recompile.

`C1036 cannot open source listing file 'filename'`
One of the conditions listed under error message C1032 prevents the given file from being opened.

`C1037 cannot open object file 'filename'`
One of the conditions listed under error message C1032 prevents the given file from being opened.

`C1039 unrecoverable heap overflow in Pass 3`
The post-optimizer compiler pass overflowed the heap and could not continue.

Try recompiling with the **-Od** option (see "Compiling with the cc Command") or try rewriting the function containing the line that caused the error.

`C1040 unexpected EOF in source file 'filename'`
The compiler detected an unexpected end-of-file condition while creating a source listing or mingled source/object listing.

This error probably occurred because the source file was edited during compilation.

C1041 cannot open compiler intermediate file - no more files
The compiler could not create intermediate files used in the compilation process because no more file descriptors were available.

C1042 cannot open compiler intermediate file - no such file or directory
The compiler could not create intermediate files used in the compilation process because the /tmp directory did not exist.

C1043 cannot open compiler intermediate file
The compiler could not create intermediate files used in the compilation process. The exact reason is unknown.

C1044 out of disk space for compiler intermediate file
The compiler could not create intermediate files used in the compilation process because no more space was available.

To correct the problem, make more space available on the disk and recompile.

C1045 floating point overflow
The compiler generated a floating-point exception while doing constant arithmetic on floating-point items at compile time, as in the following example:

```
float fp_val = 1.0e100;
```

In this example, the double-precision constant *1.0e100* exceeds the maximum allowable value for a floating-point data item.

C1047 too many *option* flags, *'string'*
The *option* appeared too many times. The *string* contains the occurrence of the option that caused the error.

C1048 Unknown option *'character'* in *'optionstring'*
The *character* was not a valid letter for *optionstring*.

C1049 invalid numerical argument *'string'*
A numerical argument was expected instead of *string*.

C1050 code segment *'segmentname'* too large
A code segment grew to within 36 bytes of 64K during compilation.

A 36-byte pad is used because of a bug in some 80286 chips that can cause programs to exhibit strange behavior when, among other conditions, the size of a code segment is within 36 bytes of 64K.

C1052 too many #if/#ifdef's
You have exceeded the maximum nesting level for **#if/#ifdef** directives.

C1053 compiler limit : struct/union nesting
Structure and union definitions were nested to more than 10 levels.

C1054 compiler limit : initializers too deeply nested
The compiler limit on nesting of initializers was exceeded. The limit ranges from 10 to 15 levels, depending on the combination of types being initialized.

To correct this problem, simplify the data type being initialized to reduce the levels of nesting, or assign initial values in separate statements after the declaration.

C1056 compiler limit : out of macro expansion space
The compiler has overflowed an internal buffer during the expansion of a macro; reduce the complexity of the macro.

C1057 unexpected EOF in macro expansion; (missing ')'?)
The compiler has encountered the end of the source file while gathering the arguments of a macro invocation. Usually this is the result of a missing closing parenthesis ()) on the macro invocation.

C1059 out of near heap space
The compiler has run out of storage for items that it stores in the "near" (default data segment) heap. This usually means that your program has too many symbols or complex expressions. To correct the problem, divide the file into several smaller source files, or break expressions into smaller subexpressions.

C1060 out of far heap space
The compiler has run out of storage for items that it stores in the "far" heap. Usually this is the result of too many symbols in the symbol table.

C1064 : too many text segments
You defined more than 10 distinct text segments with the **alloc_text** pragma.

Compilation-Error Messages

The messages listed below indicate that your program has errors. When the compiler encounters any of the errors listed in this section, it continues parsing the program (if possible) and outputs additional error messages. However, no object file is produced.

`C2000 UNKNOWN ERROR`
The compiler detected an unknown error condition.

`C2001 newline in constant`
A new-line character in a character or string constant was not in the correct escape-sequence format (**\n**).

`C2002 out of macro actual parameter space`
Arguments to preprocessor macros exceeded 256 bytes.

`C2003 expected 'defined id'`
The identifier to be checked in an **#if** directive was not enclosed in parentheses.

`C2004 expected 'defined(id)'`
An **#if** directive caused a syntax error.

`C2005 #line expected a line number, found 'token'`
A **#line** directive lacked the required line-number specification.

`C2006 #include expected a file name, found 'token'`
An **#include** directive lacked the required file-name specification.

`C2007 #define syntax`
A **#define** directive caused a syntax error.

`C2008 'character' : unexpected in macro definition`
The given character was used incorrectly in a macro definition.

`C2009 reuse of macro formal 'identifier'`
The given identifier was used twice in the formal-parameter list of a macro definition.

`C2010 'character' : unexpected in formal list`
The given character was used incorrectly in the formal-parameter list of a macro definition.

`C2011 'identifier' : definition too big`
The given macro definitions exceeded 256 bytes.

`C2012 missing name following '<'`
An **#include** directive lacked the required file-name specification.

`C2013 missing '>'`
The closing angle bracket (>) was missing from an **#include** directive.

`C2014 preprocessor command must start as first non whitespace`
Non-white-space characters appear before the number sign (#) of a preprocessor directive on the same line.

`C2015 too many chars in constant`
A character constant containing more than one character or escape sequence was used.

`C2016 no closing single quote`
A character constant was not enclosed in single quotation marks.

`C2017 illegal escape sequence`
The character or characters after the escape character (\) did not form a valid escape sequence.

`C2018 unknown character '0x`*character*`'`
The given hexadecimal number does not correspond to a character.

`C2019 expected preprocessor command, found '`*character*`'`
The given character followed a number sign (#), but it was not the first letter of a preprocessor directive.

`C2020 bad octal number '`*character*`'`
The given character was not a valid octal digit.

`C2021 expected exponent value, not '`*character*`'`
The given character was used as the exponent of a floating-point constant but was not a valid number.

`C2022 '`*number*`' : too big for char`
The *number* was too large to be represented as a character.

`C2023 divide by 0`
The second operand in a division operation (/) evaluated to zero, giving undefined results.

`C2024 mod by 0`
The second operand in a remainder operation (%) evaluated to zero, giving undefined results.

C2025 *'identifier'* : enum/struct/union type redefinition
The given identifier had already been used for an enumeration, structure, or union tag.

C2026 *'identifier'* : member of enum redefinition
The given identifier had already been used for an enumeration constant, either within the same enumeration type or within another enumeration type with the same visibility.

C2028 struct/union member needs to be inside a struc
Structure and union members must be declared within the structure or union.

This error may be caused by an enumeration declaration that contains a declaration of a structure member, as in the following example:


```
enum a {
        january,
        february,
        int march;     /* structure declaration:
                ** illegal
                */
        };
```

C2029 *'identifier'* : bit-fields allowed only in structs
Only structure types may contain bit fields.

C2030 *'identifier'* : struct/union member redefinition
The *identifier* was used for more than one member of the same structure or union.

C2031 *'identifier'* : function cannot be struct/union member
The given function was declared to be a member of a structure.

To correct this error, use a pointer to the function instead.

C2032 *'identifier'* : base type with near/far/huge not allowed
The given structure or union member was declared with the **near**, **far**, or **huge** keyword.

C2033 *'identifier'* : bit-field cannot have indirection
The given bit field was declared as a pointer (*), which is not allowed.

C2034 *'identifier'* : bit-field type too small for number of bits
The number of bits specified in the bit-field declaration exceeded the number of bits in the given base type.

C2035 enum/struct/union *'identifier'* : unknown size
The given structure or union had an undefined size.

C2036 left of *'member'* must have struct/union type
The expression before the member-selection operator (->) was not a pointer to a structure or union type, or the expression before the member-selection operator (.) did not evaluate to a structure or union. In this message, *member* is a member designator in one of the following forms:

->identifier
.identifier

C2037 left of '->' or '.' specifies undefined struct/union *'identifier'*
The expression before the member-selection operator (-> or .) identified a structure or union type that was not defined.

C2038 *'identifier'* : not struct/union member
The given identifier was used in a context that required a structure or union member.

C2039 '->' requires struct/union pointer
The expression before the member-selection operator (->) was a structure or union name, not a pointer to a structure or union as expected.

C2040 '.' requires struct/union name
The expression before the member-selection operator (.) was a pointer to a structure or union, not a structure or union name as expected.

C2041 keyword 'enum' illegal
The **enum** keyword appeared in a structure or union declaration, or an **enum** type definition was not formed correctly.

C2042 signed/unsigned keywords mutually exclusive
The signed and unsigned keywords may not appear in the same declaration.

C2043 illegal break
A **break** statement is legal only when it appears within a **do**, **for**, **while**, or **switch** statement.

`C2044 illegal continue`
A **continue** statement is legal only when it appears within a **do**, **for**, or **while** statement.

`C2045` *'identifier'* `: label redefined`
The given label appeared before more than one statement in the same function.

`C2046 illegal case`
The **case** keyword may appear only within a **switch** statement.

`C2047 illegal default`
The **default** keyword may appear only within a **switch** statement.

`C2048 more than one default`
A **switch** statement contained more than one **default** label.

D

`C2049 cast has illegal formal parameter list`
A formal parameter list was given in a type-cast expression.

`C2050 non-integral switch expression`
A switch expression was not integral.

`C2051 case expression not constant`
Case expressions must be integral constants.

`C2052 case expression not integral`
Case expressions must be integral constants.

`C2053 case value` *number* `already used`
The given case value was already used in this **switch** statement.

`C2054 expected '(' to follow` *'identifier'*
The context requires parentheses after the function *identifier*.

`C2055 expected formal parameter list, not a type list`
An argument-type list appeared in a function definition instead of a formal parameter list.

`C2056 illegal expression`
An expression was illegal because of a previous error. (The previous error may not have produced an error message.)

`C2057 expected constant expression`
The context requires a constant expression.

`C2058 constant expression is not integral`
The context requires an integral constant expression.

C2059 syntax error : *'token'*
The given token caused a syntax error.

C2060 syntax error : EOF
The end of the file was encountered unexpectedly, causing a syntax error. This error can be caused by a missing closing curly brace (}) at the end of your program.

C2061 syntax error : identifier *'identifier'*
The given identifier caused a syntax error.

C2062 type *'type'* unexpected
The given type was misused.

C2063 *'identifier'* : not a function
The given identifier was not declared as a function, but an attempt was made to use it as a function.

C2064 term does not evaluate to a function
An attempt was made to call a function through an expression that did not evaluate to a function pointer.

C2065 *'identifier'* : undefined
The given identifier was not defined.

C2066 cast to function returning . . . is illegal
An object was cast to a function type.

C2067 cast to array type is illegal
An object was cast to an array type.

C2068 illegal cast
A type used in a cast operation was not a legal type.

C2069 cast of 'void' term to non-void
The **void** type was cast to a different type.

C2070 illegal sizeof operand
The operand of a **sizeof** expression was not an identifier or a type name.

C2071 *'class'* : bad storage class
The given storage class cannot be used in this context.

C2072 *'identifier'* : initialization of a function
An attempt was made to initialize a function.

C2073 *'identifier'* : cannot initialize array in function
An attempt was made to initialize the given array within a function. Arrays can be initialized only at the external level.

C2074 cannot initialize struct/union in function
An attempt was made to initialize the given structure or union within a function. Structures and unions can be initialized only at the external level.

C2075 *'identifier'* : array initialization needs curly braces
The braces ({ }) around the given array initializer were missing.

C2076 *'identifier'* : struct/union initialization needs curly braces
The braces ({}) around the given structure or union initializer were missing.

C2077 non-integral field initializer *'identifier'*
An attempt was made to initialize a bit-field member of a structure with a nonintegral value.

C2078 too many initializers
The number of initializers exceeded the number of objects to be initialized.

C2079 *'expression'* uses undefined struct/union
The given identifier was declared as a structure or union type that had not been defined.

C2082 redefinition of formal parameter *'identifier'*
A formal parameter to a function was redeclared within the function body.

C2083 array *'identifier'* already has a size
The dimensions of the given array had already been declared.

C2084 function *'identifier'* already has a body
The given function had already been defined.

C2085 *'identifier'* : not in formal parameter list
The given parameter was declared in a function definition for a nonexistent formal parameter.

C2086 *'identifier'* : redefinition
The given identifier was defined more than once.

C2087 *'identifier'* : missing subscript
The definition of an array with multiple subscripts was missing a subscript value for a dimension other than the first dimension, as in the following example:

```
int func(a)
     char a[10][];          /* Illegal */
     {
     .
     .
     .
     }

int func(a)
     char a[][5];          /* Legal */
     {
     .
     .
     .
     }
```

C2088 use of undefined enum/struct/union *'identifier'*
The given identifier referred to a structure or union type that was not defined.

C2089 typedef specifies a near/far function
The use of the **near** or **far** keyword in a **typedef** declaration conflicted with the use of **near** or **far** for the declared item, as in the following example:

```
typedef int far FARFUNC( );
FARFUNC near *fp;
```

C2090 function returns array
A function cannot return an array. (It can return a pointer to an array.)

C2091 function returns function
A function cannot return a function. (It can return a pointer to a function.)

C2092 array element type cannot be function
Arrays of functions are not allowed; however, arrays of *pointers* to functions are allowed.

C2093 cannot initialize a static or struct with address of automatic vars
You cannot use the address of an auto variable in the initializer of a static item.

C2094 label *'identifier'* was undefined
The function did not contain a statement labeled with the given identifier.

C2095 *function*: actual has type void: parameter *numbe*
An attempt was made to pass a **void** argument to a function. Formal parameters and arguments to functions cannot have type **void**; they can, however, have type **void** * (pointer to **void**).

C2096 struct/union comparison illegal
You cannot compare two structures or unions. (You can, however, compare individual members within structures and unions.)

C2097 illegal initialization
An attempt was made to initialize a variable using a nonconstant value.

C2098 non-address expression
An attempt was made to initialize an item that was not an lvalue.

C2099 non-constant offset
An initializer used a nonconstant offset.

C2100 illegal indirection
The indirection operator (*) was applied to a nonpointer value.

C2101 '&' on constant
The address-of operator (**&**) did not have an lvalue as its operand.

C2102 '&' requires lvalue
The address-of operator must be applied to an lvalue expression.

C2103 '&' on register variable
An attempt was made to take the address of a register variable.

C2104 '&' on bit-field
An attempt was made to take the address of a bit field.

`C2105 'operator' needs lvalue`
The given operator did not have an lvalue operand.

`C2106 'operator' : left operand must be lvalue`
The left operand of the given operator was not an lvalue.

`C2107 illegal index, indirection not allowed`
A subscript was applied to an expression that did not evaluate to a pointer.

`C2108 non-integral index`
A nonintegral expression was used in an array subscript.

`C2109 subscript on non-array`
A subscript was used on a variable that was not an array.

`C2110 '+' : 2 pointers`
An attempt was made to add one pointer to another.

`C2111 pointer + non-integral value`
An attempt was made to add a nonintegral value to a pointer.

`C2112 illegal pointer subtraction`
An attempt was made to subtract pointers that did not point to the same type.

`C2113 '-' : right operand pointer`
The right operand in a subtraction operation (–) was a pointer, but the left operand was not.

`C2114 'operator' : pointer on left; needs integral right`
The left operand of the given operator was a pointer; the right operand must be an integral value.

`C2115 'identifier' : incompatible types`
An expression contained incompatible types.

`C2116 'operator' : bad` *left* `(or` *right*`) operand`
The specified operand of the given operator was illegal for that operator.

`C2117 'operator' : illegal for struct/union`
Structure and union type values are not allowed with the given operator.

`C2118 negative subscript`
A value defining an array size was negative.

`C2119 'typedefs' both define indirection`
Two **typedef** types were used to declare an item and both **typedef** types had indirection. For example, the declaration of *p* in the following example is illegal:

```
typedef int *P_INT;
typedef short *P_SHORT;
/* this declaration is illegal */
P_SHORT P_INT p;
```

`C2120 'void' illegal with all types`
The **void** type was used in a declaration with another type.

`C2121 typedef specifies different enum`
An attempt was made to use a type declared in a **typedef** statement to specify both an enumeration type and another type.

`C2122 typedef specifies different struct`
An attempt was made to use a type declared in a **typedef** statement to specify both a structure type and another type.

`C2123 typedef specifies different union`
An attempt was made to use a type declared in a **typedef** statement to specify both a union type and another type.

`C2125` *identifier* `: allocation exceeds 64K`
The given item exceeds the size limit of 64K.

The only items that are allowed to exceed 64K are huge arrays.

`C2126` *identifier* `: automatic allocation exceeds 32K`
The space allocated for the local variables of a function exceeded the limit of 32K.

`C2127 parameter allocation exceeds 32K`
The storage space required for the parameters to a function exceeded the limit of 32K.

`C2128` *identifier* `: huge array cannot be aligned to segment boundary`
The given array violated one of the restrictions imposed on huge arrays; see the "Working with Memory Models" chapter for more information on these restrictions.

C2129 static function *'identifier'* not found
A forward reference was made to a static function that was never defined.

C2130 #line expected a string containing the file name, found *'token*
A file name was missing from a **#line** directive.

C2131 attributes specify more than one near/far/huge
More than one **near**, **far**, or **huge** attribute was applied to an item, as in the following example:

```
typedef int near NINT;
NINT far a;          /* Illegal */
```

C2132 syntax error : unexpected identifier
An identifier appeared in a syntactically illegal context.

C2133 array *'identifier'* : unknown size
An attempt was made to declare an unsized array as local variable, as in the following example:

```
int mat_add(array1)
     int array1[];       /* Legal */
     {
     int array2[];           /* Illegal */
     .
     .
     .
     }
```

C2134 *identifier* : struct/union too large
The size of a structure or union exceeded the compiler limit (2^{32} bytes). This limit is 64K on 80286 systems.

C2135 missing ')' in macro expansion
A macro reference with arguments was missing a closing parenthesis ()).

C2137 empty character constant
The illegal character constant '' was used.

C2138 unmatched close comment '/*'
The compiler detected an open-comment delimiter (/*) without a matching close-comment delimiter (*/).

This error usually indicates an attempt to use illegal nested comments.

`C2139 type following 'type' is illegal`
An illegal type combination such as the following was used:

```
long char a;
```

`C2140 argument type cannot be function returning ...`
A function was declared as a formal parameter of another function, as in the following example:

```
int func1(a)
     int a( );      /* Illegal */
```

`C2141 value out of range for enum constant`
An enumeration constant had a value outside the range of values allowed for type **int**.

`C2142 ellipsis requires three periods`
The compiler detected the token ".." and assumed that "..." was intended.

`C2143 syntax error : missing 'token1' before 'token2'`
The compiler expected *token1* to appear before *token2*. This message may appear if a required closing curly brace (}), right parenthesis ()), or semicolon (;) is missing.

`C2144 syntax error : missing 'token' before type 'type'`
The compiler expected the given token to appear before the given type name. This message may appear if a required closing curly brace (}), right parenthesis ()), or semicolon (;) is missing.

`C2145 syntax error : missing 'token' before identifier`
The compiler expected the given token to appear before an identifier. This message may appear if a semicolon (;) does not appear after the last declaration of a block.

`C2146 syntax error : missing 'token' before identifier 'identifier'`
The compiler expected the given token to appear before the given identifier.

`C2147 array : unknown size`
An attempt was made to increment an index or pointer to an array whose base type has not yet been declared.

`C2148 array too large`
An array exceeded the maximum legal size (2^{32} bytes).

`C2149` *identifier* `: named bit-field cannot have 0 width`
The given named bit field had a zero width. Only unnamed bit fields are allowed to have zero width.

`C2150` *identifier* `: bit-field must have type int, signed int, or unsigned int`
The ANSI C standard requires bit fields to have types of **int**, **signed int**, or **unsigned int**. This message appears only if you compiled your program with the **-Za** option.

`C2151 more than one cdecl/fortran/pascal attribute specified`
More than one keyword specifying a function-calling convention was given.

`C2152` *identifier* `: pointers to functions with different attributes`
An attempt was made to assign a pointer to a function declared with one calling convention (**cdecl**, **fortran**, or **pascal**) to a pointer to a function declared with a different calling convention.

`C2153 hex constants must have at least 1 hex digit`
At least one hexadecimal digit must follow the "x". The hexadecimal constants 0x and 0X are illegal.

`C2154 'name' : does not refer to a segment`
The *name* was the first identifier given in an **alloc_text** pragma argument list and it is already defined as something other than a segment name.

`C2155 'name' : already in a segment`
The function *name* appears in more than one **alloc_text** pragma.

`C2156 pragma must be at outer level`
Certain pragmas must be specified at a global level, outside a function body, and there is an occurrence of one of these pragmas within a function.

`C2157 'name' : must be declared before use in pragma list`
The function *name* in the list of functions for an **alloc_text** pragma has not been declared prior to being referenced in the list.

C2158 *'name'* : is a function
Name was specified in the list of variables in a **same_segment** pragma, but was previously declared as a function.

C2159 more than one storage class specified
Illegal declaration—only one storage class is allowed.

C2160 ## cannot occur at the beginning of a macro definition
A macro definition cannot begin with a token-pasting (##) operator.

C2161 ## cannot occur at the end of a macro definition
A macro definition cannot end with a token-pasting (##) operator.

2162 expected macro formal parameter
The token following a stringizing operator (#) must be a formal parameter name.

2163 *'string'* : not available as an intrinsic
A function specified in the list of functions for an intrinsic or function pragma is not one of the functions available in intrinsic form.

C2165 *'keyword'* : cannot modify pointers to data
Bad use of **fortran**, **pascal** or **cdecl** keyword to modify pointer to data.

C2167 *'name'* : too many actual parameters for intrinsic
A reference to the intrinsic function *name* contains too many actual parameters.

C2168 *'name'* : too few actual parameters for intrinsic
A reference to the intrinsic function *name* contains too few actual parameters.

C2169 *'name'* : is an intrinsic, it cannot be defined
An attempt was made to provide a function definition for a function already declared as an intrinsic.

C2170 *identifier* : intrinsic not declared as a function
You tried to use the **intrinsic** pragma for an item other than a function, or for a function that does not have an intrinsic form.

C2177 constant too big
Information was lost because a constant value was too large to be represented in the type to which it was assigned. (1)

C2171 *'operator'* : bad operand
Illegal operand type for the specified unary operator.

C2187 : cast of near function pointer to far function pointer
You attempted to cast a near function pointer as a far function pointer.

C2189 : constant item, -Gm and data_seg pragma are incompatible
You compiled with the **-Gm** option and allocated a string literal or **near const** data item within the scope of a **data_seg** pragma. The **-Gm** option indicates that the data item should be allocated in the **CONST** data segment, while the **data_seg** pragma indicates that the same item should be allocated in a different, named segment.

Warning Messages

The messages listed in this section indicate potential problems but do not hinder compilation and linking. The number in parentheses at the end of each warning-message description (if any) gives the minimum warning level that must be set for the message to appear.

C4000 UNKNOWN WARNING
The compiler detected an unknown error condition.

C4001 macro *'identifier'* requires parameters
The given identifier was defined as a macro taking one or more arguments, but it was used in the program without arguments. (1)

C4002 too many actual parameters for macro *'identifier'*
The number of actual arguments specified with the given identifier was greater than the number of formal parameters given in the macro definition of the identifier. (1)

C4003 not enough actual parameters for macro *'identifier'*
The number of actual arguments specified with the given identifier was less than the number of formal parameters given in the macro definition of the identifier. (1)

C4004 missing close parenthesis after 'defined'
The closing parenthesis was missing from an **#if defined** phrase. (1)

C4005 *'identifier'* : redefinition
The given identifier was redefined. (1)

C4006 #undef expected an identifier
The name of the identifier whose definition was to be removed was not given with the **#undef** directive. (1)

C4009 string too big, trailing chars truncated
A string exceeded the compiler limit on string size. To correct this problem, break the string into two or more strings. (1)

C4011 identifier truncated to *'identifier'*
Only the identifier's first 31 characters are significant. (1)

C4014 *'identifier'* : bit-field type must be unsigned
The given bit field was not declared as an **unsigned** type.

Bit fields must be declared as **unsigned** integral types. A conversion has been supplied. (1)

C4015 *'identifier'* : bit-field type must be integral
The given bit field was not declared as an integral type.

Bit fields must be declared as **unsigned** integral types. A conversion has been supplied. (1)

C4016 *'identifier'* : no function return type
The given function had not yet been declared or defined, so the return type was unknown.

The default return type (**int**) is assumed. (2)

C4017 cast of int expression to far pointer
A **far** pointer represents a full segmented address. On an 8086/8088 processor, casting an **int** value to a **far** pointer may produce an address with a meaningless segment value. (1)

C4020 too many actual parameters
The number of arguments specified in a function call was greater than the number of parameters specified in the argument-type list or function definition. (1)

`C4021 too few actual parameters`
The number of arguments specified in a function call was less than the number of parameters specified in the argument-type list or function definition. (1)

`C4022 pointer mismatch : parameter` *n*
The pointer type of the given parameter was different from the pointer type specified in the argument-type list or function definition. (1)

`C4024 different types : parameter` *n*
The type of the given parameter in a function call did not agree with the type given in the argument-type list or function definition. (1)

`C4025 function declaration specified variable argument list`
The argument-type list in a function declaration ended with a comma or a comma followed by ellipsis dots (,...), indicating that the function could take a variable number of arguments, but no formal parameters were declared for the function. (1)

`C4026 function was declared with formal argument list`
The function was declared to take arguments, but the function definition did not declare formal parameters. (1)

`C4027 function was declared without formal argument list`
The function was declared to take no arguments (the argument-type list consisted of the word **void**), but formal parameters were declared in the function definition or arguments were given in a call to the function. (1)

`C4028 parameter` *n* `declaration different`
The type of the given parameter did not agree with the corresponding type in the argument-type list or with the corresponding formal parameter. (1)

`C4029 declared parameter list different from definition`
The argument-type list given in a function declaration did not agree with the types of the formal parameters given in the function definition. (1)

C4030 first parameter list is longer than the second
A function was declared more than once with different argument-type lists in the declarations. (1)

C4031 second parameter list is longer than the first
A function was declared more than once with different argument-type lists. (1)

C4032 unnamed struct/union as parameter
The structure or union type being passed as an argument was not named, so the declaration of the formal parameter cannot use the name and must declare the type. (1)

C4033 function must return a value
A function is expected to return a value unless it is declared as **void**. (2)

C4034 sizeof returns 0
The **sizeof** operator was applied to an operand that yielded a size of zero. (1)

C4035 *identifier* : no return value
A function declared to return a value did not do so. (2)

C4036 unexpected formal parameter list
A formal parameter list was given in a function declaration. The formal parameter list is ignored. (1)

C4037 *'identifier'* : formal parameters ignored
No storage class or type name appeared before the declarators of formal parameters in a function declaration, as in the following example:

```
int *f(a,b,c);
```

The formal parameters are ignored. (1)

C4038 *'identifier'* : formal parameter has bad storage class
The given formal parameter was declared with a storage class other than **auto** or **register**. (1)

C4039 *'identifier'* : function used as an argument
A formal parameter to a function was declared to be a function, which is illegal. The formal parameter is converted to a function pointer. (1)

C4040 near/far/huge on *'identifier'* ignored
The **near** or **far** keyword has no effect in the declaration of the given identifier and is ignored. (1)

C4041 formal parameter *'identifier'* is redefined
The given formal parameter was redefined in the function body, making the corresponding actual argument unavailable in the function. (1)

C4042 *'identifier'* : has bad storage class
The specified storage class cannot be used in this context (for example, function parameters cannot be given **extern** class). The default storage class for that context was used in place of the illegal class. (1)

C4043 *'identifier'* : void type changed to int
An item other than a function was declared to have **void** type. (1)

C4044 huge on *'identifier'* ignored, must be an array
The **huge** keyword was used to declare the given nonarray item. (1)

C4045 *'identifier'* : array bounds overflow
Too many initializers were present for the given array. The excess initializers are ignored. (1)

C4046 '&' on function/array, ignored
An attempt was made to apply the address-of operator (**&**) to a function or array identifier. (1)

C4047 *'operator'* : different levels of indirection
An expression involving the specified operator had inconsistent levels of indirection. (1)

The following example illustrates this condition:

```
char **p;
char *q;
.
.
.
p = q;
```

`C4048 array's declared subscripts different`
An array was declared twice with different sizes. The larger size is used. (1)

`C4049 'operator' : indirection to different types`
The indirection operator (*) was used in an expression to access values of different types. (1)

`C4051 data conversion`
Two data items in an expression had different types, causing the type of one item to be converted. (2)

`C4052 different enum types`
Two different **enum** types were used in an expression. (1)

`C4053 at least one void operand`
An expression with type **void** was used as an operand. (1)

`C4056 overflow in constant arithmetic`
The result of an operation exceeded 0x7FFFFFFF. (1)

`C4057 overflow in constant multiplication`
The result of an operation exceeded 0x7FFFFFFF. (1)

`C4058 address of frame variable taken, DS != SS`
The program was compiled with the default data segment (**DS**) not equal to the stack segment (**SS**), and the program tried to point to a frame variable with a near pointer. (1)

`C4059 segment lost in conversion`
The conversion of a **far** pointer (a full segmented address) to a **near** pointer (a segment offset) resulted in the loss of the segment address. (1)

`C4060 conversion of long address to short address`
The conversion of a long address (a 32-bit pointer) to a short address (a 16-bit pointer) resulted in the loss of the segment address. (1)

`C4061 long/short mismatch in argument: conversion supplied`
The base types of the actual and formal arguments of a function were different. The actual argument is converted to the type of the formal parameter. (1)

`C4062 near/far mismatch in argument: conversion supplied`
The pointer sizes of the actual and formal arguments of a function were different. The actual argument is converted to the type of the formal parameter. (1)

`C4063 'identifier' : function too large for post-optimizer`
The given function was not optimized because not enough space was available. To correct this problem, reduce the size of the function by dividing it into two or more smaller functions. (0)

`C4064 procedure too large, skipping` *description* `optimization and continuing`
Some optimizations for a function were skipped because not enough space was available for optimization. (0)

To correct this problem, reduce the size of the function by dividing it into two or more smaller functions.

The *description* in this message may appear as any of the following:

```
loop inversion
branch sequence
cross jump
```

`C4065 recoverable heap overflow in post-optimizer - some optimizations may be missed`
Some optimizations were skipped because not enough space was available for optimization. To correct this problem, reduce the size of the function by dividing it into two or more smaller functions. (0)

`C4066 local symbol table overflow - some local symbols may be missing in listings`
The listing generator ran out of heap space for local variables, so the source listing may not contain symbol-table information for all local variables.

`C4067 unexpected characters following 'directive' directive - newline expected`
Extra characters followed a preprocessor directive, as in the following example (1):

```
#endif    NO_EXT_KEYS
```

This is accepted in Version 3.0, but not in Versions 4.0 and 5.0. Versions 4.0 and 5.0 require comment delimiters, such as the following:

```
#endif    /* NO_EXT_KEYS */
```

`C4068 unknown pragma`
The compiler did not recognize a pragma and ignored it. (1)

`C4069 conversion of near pointer to long integer`
A near pointer was converted to a long integer, which involves first extending the high-order word with the current data-segment value, *not* 0 as in Version 3.0. (1)

`C4071 'identifier' : no function prototype given`
The given function was called before the compiler found the corresponding function prototype. (3)

`C4072 Insufficient memory to process debugging information`
You compiled the program with the **-Zi** option, but not enough memory was available to create the required debugging information. (1)

`C4073 scoping too deep, deepest scoping merged when debugging`
Declarations appeared at a static nesting level greater than 13. As a result, all declarations will seem to appear at the same level. (1)

`C4074 non standard extension used - 'extension'`
The given nonstandard language extension was used when the **-Ze** option was in effect. These extensions are given in the "Compiling with the cc Command" chapter of this guide. (If the **-Za** option is in effect, this condition generates an error.) (3)

C4075 size of switch expression or case constant too large - converted to int
A value appearing in a **switch** or **case** statement was larger than an **int**. The compiler converts the illegal value to an **int**. (1)

C4076 *'type'* : may be used on integral types only
The type modifiers **signed** and **unsigned** can be combined only with other integral types.

C4077 unknown check_stack option
Unknown option given when using the old form of the **check_stack** pragma. The option must be empty, +, or -.

C4079 unexpected char *'character'*
Unexpected separator *character* found in argument list of a pragma.

C4080 missing segment name
The first argument in the argument list for the **alloc_text** pragma is missing a segment name. This happens if the first token in the argument list is not an identifier.

C4081 expected a comma
There is a missing comma (,) between two arguments of a pragma.

C4082 expected an identifier
There is a missing identifier in list of arguments to a pragma.

C4083 missing '('
There is a missing opening parenthesis (( ) in the argument list for a pragma.

C4084 expected a pragma keyword
The token following the **pragma** keyword is not an identifier.

C4085 expected [on|off]
Bad argument given for new form of **check_stack** pragma.

C4086 expected [1|2|4]
Bad argument given for **pack** pragma.

C4087 *'name'* : declared with *void parameter list*
The function *name* was declared as taking no parameters, but a call to the function specifies actual parameters.

C4090 different *'const'* attributes
The program passed a pointer to a *const* item to a function where the corresponding formal parameter is a pointer to a non-*const* item, which means the item could be modified by the function undetected.

`C4091 no symbols were declared`
An empty declaration was detected. (2)

`C4092 untagged enum/struct/union declared no symbol`
An empty declaration was detected that used an untagged enum/struct/union. (2)

`C4093 unescaped newline in character constant in non-active code`
The constant expression of an **#if**, **#elif**, **#ifdef**, or **#ifndef** preprocessor directive evaluated to 0, making the following code inactive, and a new-line character appeared between a single or double quotation mark and the matching single or double quotation mark in that inactive code.

`C4094 unexpected newline`
A new-line character appeared in a pragma where a comma, right parenthesis, or identifier was expected, as in the following examples:

```
#pragma intrinsic (memset
#pragma intrinsic (memset,
```

`C4095 too many arguments for pragma`
More than one argument was given for a pragma that can take only one argument.

`C4106 : pragma requires integer between 1 and 127`
You must supply an integer constant in the range 1-127, inclusive, for the given pragma.

`C4107 : pragma requires integer between 15 and 255`
You must supply an integer constant in the range 15-255, inclusive, for the given pragma.

`C4108 : pragma requires integer between 79 and 132`
You must supply an integer constant in the range 79-132, inclusive, for the given pragma.

`C4109 : unexpected identifier '`*token*`'`
The designated line contains an unexpected token.

`C4110 : unexpected token 'int constant'`
The designated line contains an unexpected integer constant.

`C4111 : unexpected token string`
The designated line contains an unexpected string.

`C4112 : macro name 'name' is reserved, 'command' ignored`
You attempted to define a predefined macro name or the preprocessor operator **defined**. This warning error also occurs if you attempt to undefine a predefined macro name. If you attempt to define or undefine a predefined macro name using command-line options, *'command'* will still be either **#define** or **#undef**.

Compiler Limits

To operate the C Compiler, you must have sufficient disk space available for the compiler to create temporary files used in processing. The space required is approximately two times the size of the source file.

Table D.1 summarizes the limits imposed by the C compiler. If your program exceeds one of these limits, an error message will inform you of the problem.

Table D.1

Limits Imposed by the C Compiler

Program Item	Description	Limit
String literals	Maximum length of a string, including the terminating null character (**\0**)	4k bytes
Constants	Maximum size of a constant is determined by its type; see the *C Language Reference* for a discussion of constants	
Identifiers	Maximum length of an identifier	31 bytes (additional characters are discarded)
Declarations	Maximum level of nesting for structure/union definitions	10 levels

Preprocessor directives	Maximum size of a macro definition	512 bytes
	Maximum number of actual arguments to a macro definition	8 arguments
	Maximum length of an actual preprocessor argument	256 bytes
	Maximum level of nesting for **#if**, **#ifdef**, and **#ifndef** directives	32 levels
	Maximum level of nesting for include files	10 levels

The compiler does not set explicit limits on the number and complexity of declarations, definitions, and statements in an individual function or in a program. If the compiler encounters a function or program that is too large or too complex to be processed, it produces an error message to that effect.

Compiler Exit Codes

All the programs in the C Compiler package return an exit code (sometimes called an "errorlevel" code) that can be used by other programs such as **make**. If the program finishes without errors, it returns a code of 0. The code returned varies depending on the error encountered.

Code	Meaning
0	No fatal error
2	Program error (such as compiler error)
4	System level error (such as out of disk space or compiler internal error)

Index

Special Characters

{ } (braces) 1-6
[ ] (brackets) 1-6
| (bar) 1-6
- (dash) option character
  linker 3-5
- (hyphen) option character, cc 2-6
_ (underscore), in names 2-12, 2-23

A

Address space B-9
Addresses
  components 5-4
  far 5-4
  huge 5-4
  near 5-4
Alignment *See* Storage alignment
alloc_text pragma 5-33
argc variable 4-2
Argument type list 2-39
Arguments
  linker options 3-5
  listing options 2-13
  main function *See* main function
  variable number of 6-6, B-14
argv variable 4-2
Assembly language
  interface 8-12
  return values 8-9
  routines
    entry 8-8
    exit 8-11
Assembly-language interface, described 8-1
Assembly-listing files
  creating 2-11, 2-12
  extensions 2-13
  format 2-22

B

Bar (|) 1-6
BASE 7-14
Bibliography 1-9
Bit fields B-7
Bold font 1-6
Braces ({ }) 1-6
Brackets ([ ]) 1-6
Byte length B-4
Byte order B-20, B-6

C

C calling conventions
  described 8-1
C compiler
  impure small model 5-8
  M option 2-6
  manifest defines 2-30
  model and segment options 2-6
  pure small model 5-8
C language
  calling sequence 8-7
  interface with assembly language 8-12
  return values 8-9
-c option 2-9
-C option 2-33
Call sequence 8-2
Calling conventions
  C 6-6
  FORTRAN/Pascal 6-6
Calling sequence
  assembly language 8-7
  C language 8-7
Canonic Frame 7-8
Capital letters
  small 1-6
  use of 1-6
cc command
  file processing 2-3
  format 2-2
cc options
  assembly listing 2-11, 2-12
  -c 2-9
  -C 2-33
  command line, order 2-6
  comments, preserving 2-33
  constants and macros, defining 2-29

cc options *(continued)*
-D 2-29
data segments, naming 5-31, 5-34, 6-9
data threshold, setting 5-30
default libraries 2-8
differences from linker options 3-5
-E 2-32
-EP 2-32
-F 3-6
-Fa 2-12, 2-22
-Fc 2-12
-Fe 2-11
-Fl 2-12
-Fm 2-12
-Fo 2-9
format 2-6
-Fs 2-12
function declarations, generating 2-39
-Gs 6-6
-Gt 5-30
-I 2-34
include files, searching for 2-34
line numbers 2-40
-link 2-2, 3-2
linker information, passing 3-2
listing 2-6
-M 5-25, 5-26, 5-27
-Mc 5-9
memory models
  code-pointer size 5-26
  compact 5-9
  data-pointer size 5-26
  default libraries 2-6
  huge 5-11
  large 5-10
  medium 5-9
  mixed 5-25, 5-26, 5-27
  segments, setting up 5-27
  small 5-7
-Mh 5-11
-Ml 5-10
-Mm 5-9
-Ms 5-7
naming
  executable files 2-11
  modules 5-31
  object files 2-9
-ND 5-31, 5-34, 6-9
-NM 5-31
-NT 5-31
-o 2-11
-Oa 6-5
object files
  naming 2-9

cc options *(continued)*
object files *(continued)*
  specifying 2-3
object listing 2-11, 2-12
-Od 2-40
-Oi 6-4
-Ol 6-5
optimization
  alias checking, relaxing 6-5
  disabling 2-40
  execution time 6-4
  intrinsic functions 6-4
  loops 6-5
  -Oi 6-4
  program speed 6-3
option character
  hyphen (-) 2-6
-Ot 6-4
-P 2-32
predefined identifiers, removing
    definitions of 2-32
preprocessed listing 2-32
preprocessor
  -C 2-33
  -D 2-28
  -U and -u 2-32
-S 2-12, 2-22
source files, specifying 2-3, 2-8
source listing 2-12
source/object listing 2-12
special keywords, disabling 5-15
-Ss 2-15
-St 2-15
stack probes, removing 6-6
standard places, ignoring 2-34
subtitle 2-15
suppressing
  linking 2-9
syntax checking 2-38
-Tc 2-4, 2-8
text segments, naming 5-31
titles 2-15
-U and -u 2-32
Version 4.0, new for A-11
Version 5.0, new for A-6
-W0, -W1, -W2, and -W3 2-37
warning level 2-37
-X 2-34
-Za 5-15
-Zd 3-6
-Zg 2-39
-Zi 2-40
-Zs 2-38
cdecl keyword

cdecl keyword *(continued)*
-Gc option, used with 6-7
Character
classification, macros B-9
set B-9
types
signed B-11
unsigned B-11
check_stack pragma 6-6
Class name, LSEG 7-8
Code pointers, mixed memory models 5-26
COFF 2-2
Combination Attribute 7-29
Command line
arguments
executable file 4-2
cc 2-2
error messages D-2
length, maximum 2-2
Commands
notational conventions 1-6
COMMENT 7-48
RECORD 7-48
Comments, preserving 2-33
Common Object File Format 2-2
Compact memory models *See* Memory models
Compilation
error messages D-7
Compiler
differences, other compilers
portability problems B-11
differences, Version 4.0
cc options A-11
enhancements and additions A-8
language changes A-8
differences, Version 5.0
enhancements and additions A-4
language changes A-4
new cc options A-6
pragmas, new A-7
documentation 1-2
error messages *See* Error messages, compiler
naming conventions 2-23
stopping 2-2
Compiler, converting from previous versions *See* Compiler differences
Compiler guide, organization 1-2
Compiler options *See* cc options
Complete name, LSEG 7-8
Conditional compilation 2-29
Constants
defining 2-29
manifest *See* Constants, symbolic
Constants *(continued)*
symbolic 2-29
Controlling
linker 3-5
preprocessor 2-32
segments 3-6
stack size 3-6
Conventions, notational 1-6
Conversion
near pointers to long integers A-10
pointer arguments 5-22
Correctable error messages D-7
ctype.h macros B-9
Customized memory models *See* Mixed memory models

D

-D option 2-29
Dash (-)
linker option character 3-5
Data
passing to programs 4-2
portability B-17
segment
data threshold, setting 5-30
default, contents 5-30
default name 5-31
mixed memory models 5-27
naming 5-31
types, size of B-4
Data pointers, mixed memory models 5-26
_DATA segment 5-31
Data Structures
x.out symbol table 7-58
Data threshold, setting 5-30
data_seg pragma 5-33
Debugging, preparing for
-Zi and -Od options 2-40
Default libraries
object files, used in 3-3
DGROUP group 5-31
Differences from previous versions *See* Compiler differences
Directory names, notational conventions 1-6
Documentation, compiler 1-2
DS register 5-27

E

-E option 2-32
EAX register 8-9, 8-11
EBP register 8-8, 8-11
EBX register 8-11
ECX register 8-11
EDI register 8-8, 8-11
EDX register 8-9, 8-11
EIGHT
  LEAF
    DESCRIPTOR 7-32
EIGHT LEAF DESCRIPTOR 7-32
Ellipses, use of 1-6
environ variable 4-3
Environment
  portability problems B-16
  table
    pointer to 4-3
  variable names, notational conventions 1-6
  variables
    INCLUDE 2-34
    LIB 3-4
    PATH 4-1
    SET 4-2
envp variable 4-3
-EP option 2-32
errno variable
  defined 9-3
  described 9-3
Error messages
  compiler
    command line D-2
    compilation D-7
    correctable D-7
    fatal D-7, D-8
    identifying 2-35
    redirecting 2-35
    warning D-29, D-8
  format *See* Error messages, compiler
  source listings 2-16
  warning messages, setting level of 2-37
Errors
  catching signals 9-5
  delayed 9-6
  errno variable 9-3
  error constants 9-3
  error numbers 9-3
  printing error messages 9-4
  processing 9-1
  routine system I/O 9-6
  sharing resources 9-6
  signals 9-5
Errors *(continued)*
  standard error file 9-2
  system 9-6
ESI register 8-8, 8-11
ESP register 8-8
Evaluation order B-14
exec function 4-1
Executable files
  cc command and 2-5
  command-line arguments 4-2
  extensions 2-11
  naming, default 2-11
  naming with cc 2-11
  passing data to 4-2
  running 4-1
Executable Format 7-59
Execution-time optimization 6-4
Extensions
  executable files 2-11
  listing files, defaults for 2-12
  map files 2-13
  object files 2-10
  object-listing files 2-13
  source-listing files 2-13
  source/object-listing files 2-13

F

-F option 3-6
-Fa option 2-12, 2-22
Far keyword 5-20
far keyword
  default addressing conventions 5-1
  effects
    data declarations 5-16, 6-8
    function declarations 5-20
  library routines, used with 5-16
  small-model programs, used in 5-8
Far pointers 5-14
Fatal-error messages D-7, D-8
-Fc option 2-12
-Fe option 2-11
File names
  notational conventions 1-6
Files
  assembly listing 2-12, 2-22
  executable *See* Executable files
  listing, preprocessed 2-32
  map
    creating 2-12, 2-15, 3-6
    default names 2-13
    listing formats 2-27

Files *(continued)*
map *(continued)*
-MAP linker option 3-6
object
cc command, used with 2-3, 2-4
listing 2-12, 2-13, 2-21
source 2-3
source listing *See* Source-listing files
source/object listing *See* Source/object-listing files
FIXUP
RECORD 7-41
FIXUPP 7-41
Fixups
definition 7-14
segment-relative 7-15, 7-20
self-relative 7-15, 7-19
-Fl option 2-12
-Fm option 2-12
-Fo option 2-9
fortran keyword 6-7
FRAME
definition 7-6
specifying 7-17
FRAME NUMBER 7-7
-Fs option 2-12
Functions
arguments, variable number of 6-6, B-14
calling conventions
C 6-6
FORTRAN/Pascal 6-6
declarations
generating 2-39
near and far keywords 5-20

G

getenv function 4-3
Global symbols *See* Public symbols
GROUP 7-7
Group Definition Record 7-31
GRPDEF 7-31
-Gs option 6-6
-Gt option 5-30

H

Hardware Reference Numbers 7-64
HIBYTE 7-15
Huge arrays 5-11
huge keyword
data declarations, effects in 5-16, 6-8
default addressing conventions 5-14
library routines, used with 5-16
small-model programs, used in 5-8
Huge memory model *See* Memory models
Huge pointers 5-14
Hyphen (-), cc option character 2-6

I

-I option 2-34
iAPX-286, -386
address translation
logical to physical 7-2
descriptor tables 7-2
GDT 7-2
LDT 7-2
logical address space 7-2
memory management 7-2
pointers
to logical addresses 7-2
protected mode 7-2
segment selector 7-2
INDEX field 7-2
RPL field 7-2
TI field 7-2
system architecture 7-2
Identifier length *See* Names, length
Identifiers
predefined
listed 2-30
M_I86 2-30
M_I86xM 2-30
M_XENIX 2-30
removing definitions of 2-32
Implicit bss 7-57
Include files
directory specification 2-34
portability problems B-3
search path 2-34
INCLUDE variable
overriding 2-34
Index fields 7-13
Indices 7-13
Intel Object Module Format 2-2

Italics 1-6
Iterated Segments 7-56

K

Key sequences, notational conventions 1-6
Keywords
  cdecl 6-7
  far 5-20
  fortran 6-7
  near 5-20
  pascal 6-7
  Version 4.0, new for A-11

L

Large memory model *See* Memory models, large
Large Model 7-58
LIB variable 3-3, 3-4
Libraries
  default
    -A options 2-8
    -M options 3-2
    overriding 3-4
  mixed-model programs 5-29
  names in object files 3-2
  search
    path 3-3, 3-4
  specifying 3-3
  standard places 3-4
Library
  routines
    exec 4-1
    getenv 4-3
    putenv 4-3
    system 4-1
    system dependent C-2
LIDATA 7-39
LINE
  NUMBERS
    RECORD 7-37
-LINENUMBERS (-LI) linker option 3-6
linesize pragma 2-24
-link option 2-2, 3-2
Linker
  error messages 2-35
Linker options
  abbreviations 3-5
Linker options *(continued)*
  cc options, differences from 3-5
  line numbers, displaying 3-6
  -LINENUMBERS (-LI) 3-6
  map file 3-6
  -MAP (-M) 3-6
  numerical arguments 3-5
  rules 3-5
  segments
    number of 3-6
  -SEGMENTS (-SE) 3-6
  stack size, setting 3-6
  -STACK (-ST) 3-6
  -T 6-9
  translating far calls 6-9
LINNUM 7-37
List of Names Record 7-26
Listing files
  assembly 2-11, 2-12, 2-22
  map 2-12
  object 2-11, 2-12, 2-21
  preprocessed 2-32
  source 2-11, 2-12, 2-16
  source/object 2-12, 2-22
listing pragmas 2-24
LNAMES 7-26
LOBYTE 7-15
LOCATION, types 7-14
LOGICAL
  ITERATED
    DATA
      RECORD 7-39
Logical Segment 7-7
Long pointers *See* Far pointers
Loop optimization 6-5
loop_opt pragma 2-41, 6-5
LSEG 7-7

M

-M option 5-25, 5-26, 5-27
M option
  cc 2-6
Macros
  character classification B-9
  defined 2-29
  notational conventions 1-6
main function
  arguments to 4-2
Manifest constants, notational conventions 1-6
Manifest defines

Manifest defines *(continued)*
C compiler 2-30
Map files
creating 2-12, 2-15, 3-6
extensions 2-13, 3-6
-Fm option 2-15
format 2-27
-MAP linker option 3-6
program entry point 2-28
segment lists 2-27
symbol tables 2-27
-MAP linker option 3-6
MAS 7-6
-Mc option 5-9
Medium memory model *See* Memory models
Memory Address Space 7-6
Memory addresses *See* Addresses
Memory models
compact 5-9
default 5-2, 5-8
huge 5-11
large 5-10
medium 5-9
mixed *See* Mixed memory models
options
code-pointer size 5-26
compact model 5-9
data-pointer size 5-26
default libraries 2-8
huge model 5-11
large model 5-10
medium model 5-9
segment setup 5-27
small model 5-7
small 5-2, 5-7, 5-19
standard
advantages 5-6
common features 5-6
disadvantages 5-6
Version 4.0, new for A-11
Memory models, customized *See* Mixed memory models
-Mh option 5-11
M_I86 identifier 2-30
M_I86xM identifier 2-30
Mixed memory models
code pointers 5-26
creating 5-25
data pointers 5-26
library support 5-29
near, far, huge keywords 5-14
segment setup options 5-27
-Ml option 5-10
-Mm option 5-9
MODE 7-15
MODEND 7-46
MODULE 7-6
END
RECORD 7-46
Module header record 7-9
Modules, naming 5-31
-Ms option 5-7
M_XENIX identifier 2-30

N

Names
executable files 2-11
global 2-12, 2-23
length B-12
modules, changing 5-31
object files 2-9
segments, changing 5-31
underscores (_), using in 2-12, 2-23
Naming conventions
compiler 2-23
segments 5-32
-ND option 5-31, 5-34, 6-9
Near keyword 5-20
near keyword
data declarations, effects in 5-16, 6-8
default addressing conventions 5-14
function declarations, effects in 5-20
library routines, used with 5-16
Near pointer 5-14
-NM option 5-31
Non-Iterated Segments 7-57
Notational conventions 1-6
-NT option 5-31
Numeric record types 7-50

O

-O (optimization) options 2-41
-o option 2-11
-Oa option, cc 6-5
object file format 2-2
Object File Format
Executable 7-54
Object files
cc command 2-3, 2-4
default extension 2-3, 2-8
extensions 2-10

Object files *(continued)*
library names in 3-2
naming 2-9
specifying to cc 2-3
Object listing *See* Object-listing files
Object Module Format 2-2
Object Module Formats 7-5, 7-6
Object-listing files
creating 2-12
extensions 2-13
format 2-21
-Od option 2-40
OFFSET 7-14
-Oi option 6-4
-Ol option 6-5
OMF 2-2, 7-6
omf Subset 7-54
Optimization
alias checking, relaxing 6-5
default 2-1
disabling 2-40
execution time 6-4
intrinsic pragmas 6-4
listing files 2-14
loops 6-5
options 2-41
stack probes, removing 6-6
Optimizing *See* Optimization
Optional fields, notational conventions 1-6
Options, cc *See* cc options
Options, linker *See* Linker options
-Ot option 6-4
Overlay Name, LSEG 7-8
Overview 1-1

P

-P option 2-32
page pragma 2-25
pagesize pragma 2-25
PARAGRAPH NUMBER 7-7
pascal keyword 6-7
Path names
notational conventions 1-6
portability problems B-3
PATH variable 4-1, 4-2
perror function 9-4
Physical Segment 7-7
Placeholders 1-6
Pointers
arguments, size conversion 5-22
code 5-26
Pointers *(continued)*
far 5-14, 5-26
huge 5-14
manipulation B-7
near
conversion to long integers A-10
customized memory models 5-26
near keywords, used with 5-14
subtracting in huge-model programs 5-11
Portability
address space B-9
bit fields B-7
byte length B-4
byte order B-20, B-6
case distinctions B-12
character set B-9
data B-17
data types, size of B-4
environment differences B-16
evaluation order B-14
functions with variable number of arguments B-14
guidelines B-2
hardware B-4
identifier length B-12
include files B-3
path names B-3
pointer manipulation B-7
register variables B-12
shift operations B-11
side effects B-14
sign extension B-11
signed and unsigned char types B-11
storage alignment B-5
type conversion B-12
word length B-4
Pragmas
alloc_text 5-33
check_stack 6-6
data_seg 5-33
pragmas
linesize 2-24
listing 2-24
Pragmas
loop_opt 2-41, 6-5
pragmas
page 2-24
pagesize 2-24
Pragmas
same_seg 5-33, 5-34, 6-9
pragmas
skip 2-24
skip page 2-24

pragmas *(continued)*
  subtitle 2-24
  title 2-24
Pragmas
  Version 4.0, new for A-11
  Version 5.0, new for A-7
Preprocessor
  options
    comments, preserving 2-33
    -D 2-29
    predefined identifiers, removing definitions of 2-32
    use 2-28
Product names, notational conventions 1-6
Prompts 1-6
PSEG
  definition 7-7
  NUMBER 7-7
PUBDEF 7-33
PUBLIC
  NAMES
    DEFINITION
      RECORD 7-33
Public names *See* Public symbols
Public symbols, listing 2-15, 3-6
putenv function 4-3

Q

Quotation marks, use of 1-6

R

Record format, sample 7-24
Record formats 7-4
Record order 7-22
Record types 7-51
  numeric 7-50
Register variables 6-1, B-12
Registers
  EAX 8-9, 8-11
  EBP 8-8, 8-11
  EBX 8-11
  ECX 8-11
  EDI 8-8, 8-11
  EDX 8-9, 8-11
  ESI 8-8, 8-11
  ESP 8-8
Relocatable memory images 7-4
Return values 8-4
  assembly language 8-9
Routine entry sequence 8-3
Routine exit sequence 8-5
Routines
  assembly language
    entry 8-8
    exit 8-11
Run file *See* Executable file

S

-S option 2-12, 2-22
same_seg pragma 5-33, 5-34, 6-9
Sample x.out File 7-56
Search paths
  changing
    include files 2-34
    libraries 3-4
  include files 2-34
  libraries 3-3, 3-4
SEGDEF 7-27
Segment addressing 7-11
Segment definition 7-10
Segment definition record 7-27
Segment lists
  map files 2-27
  source listings 2-21
Segment Name, LSEG 7-8
Segment Numbers 7-64
Segment registers 8-11
Segment-Relative fixups 7-15
Segment-Relative Fixups 7-20
Segments
  data
    default name 5-31
    mixed memory models 5-27
    names 5-31
    naming 5-31
    threshold, effect of 5-30
  default 5-4
  defined 5-4
  names, changing 5-31
  naming conventions 5-32
  number allowed 3-6
  setting up 5-27
  source listing 2-21
  stack 5-27
  text
    default name 5-31
    naming 5-31
-SEGMENTS (-SE) linker option 3-6

Self-Relative fixups 7-15, 7-19
SET variable 4-2
Shift operations B-11
Short pointers *See* Near pointers
Side effects B-14
Sign extension B-11
Signals
  catching 9-5
  on program errors 9-5
Signed char type B-11
sizeof operator 5-11
skip pragma 2-25
Small capitals, use of 1-6
Small memory model *See* Memory models
Small model 5-19
  impure 5-8
  pure 5-8
Source files
  default extension 2-3, 2-8
  specifying to cc 2-3
Source listing *See* Source-listing files
Source-listing files
  creating 2-12
  described 2-11
  error messages 2-16
  extensions 2-13
  format 2-16, 2-17
  segment lists 2-21
  subtitles 2-15
  symbol tables 2-19
  titles 2-15
Source/object-listing files
  creating 2-12
  extensions 2-13
  format 2-22
Special Header Fields 7-58
Special keywords, disabling 5-15
-Ss option 2-15
SS register 5-27
-St option 2-15
Stack
  probes 6-6
  segments, mixed memory models 5-27
  size
    setting 3-6
Stack order 8-2
-STACK (-ST) linker option 3-6
Standard files
  redirecting 9-2
Standard places
  changing 2-34
  ignoring 2-34
  libraries 3-4
stderr, the standard error file 9-2
Storage alignment B-5
Strings
  notational conventions 1-6
subtitle pragma 2-26
Subtitles, source listings 2-15
Switches *See* Options
Symbol definition 7-12
Symbol Table 7-58
Symbol tables
  map files, used in 2-27
  object files, used in (-Zi option) 2-4
  source listings, used in 2-19
Syntax conventions *See*
    Notational conventions
sys_errno array, described 9-4
System errors
  described 9-6
  reporting 9-6
system function 4-1

T

-T linker option 6-9
TARGET 7-15
-Tc option 2-4, 2-8
_TEXT segment 5-31
Text segments
  default name 5-31
  naming 5-31
THEADR 7-26
title pragma 2-26
Titles, source listings 2-15
T-MODULE 7-6
T-Module Header Record (THEADR
TYPDEF 7-32
Types
  checking 2-39
  conversion B-12

U

-U and -u options 2-32
Underscore (_) in names 2-12, 2-23
Unsigned char type B-11
Uppercase letters, use of 1-6

V

Variables, register *See* Register variables
Vertical bar (|) 1-6

W

-W0, -W1, -W2, and -W3 options 2-37
Warning error messages 2-37, D-29, D-8
Wild card
  characters 2-9

X

-X option 2-34
x.out
  file layout 7-56
  general description 7-54
  implicit bss 7-57
  iterated segments 7-56
  large model 7-58
  non-iterated segments 7-57
  special fields 7-58
  symbol table 7-58
x.out Examples 7-60
x.out Executable Format 7-59
x.out Format 7-54
x.out Include Files 7-60
x.out Segmented OMF Specification 7-54

Z

-Za option 5-15
-Zd option 3-6
-Zg option 2-39
-Zi option 2-40
-Zs option 2-38

SCO UNIX® System V/386

Development System

C Language Reference

The Santa Cruz Operation, Inc.

SCO Document Number: 6-26-89-6.0/3.2.0

Contents

1 Introduction

Overview of the C Language 1-1
About This Manual 1-3
Notational Conventions 1-5

2 Elements of C

Introduction 2-1
Character Sets 2-2
Constants 2-10
Identifiers 2-17
Keywords 2-19
Comments 2-20
Tokens 2-22

3 Program Structure

Introduction 3-1
Source Program 3-2

4 Declarations

Introduction 4-1
Type Specifiers 4-2
Declarators 4-9
Variable Declarations 4-17

5 Expressions and Assignments

Introduction 5-1
C Operators 5-14
Assignment Operators 5-32
Precedence and Order of Evaluation 5-37
Type Conversions 5-41

6 Statements

Introduction 6-1
The break Statement 6-3
The Compound Statement 6-4
The continue Statement 6-5
The do Statement 6-6

The Expression Statement 6-7
The for Statement 6-9
The goto and Labeled Statements 6-11
The if Statement 6-13
The Null Statement 6-15
The return Statement 6-16
The switch Statement 6-18

7 Functions

Introduction 7-1
Function Definitions 7-3

8 Preprocessor Directives and Pragmas

Introduction 8-1
Manifest Constants and Macros 8-3
Include Files 8-12
Conditional Compilation 8-14
Line Control 8-19
Pragmas 8-21

A Differences Between K&R C and Microsoft C

Introduction A-1

B Syntax Summary

Tokens B-1
Expressions B-7
Declarations B-9
Statements B-14
Definitions B-15
Preprocessor Directives B-16
Pragmas B-17

Chapter 1

Introduction

Overview of the C Language 1-1

About This Manual 1-3

Notational Conventions 1-5

Overview of the C Language

The C language is a general-purpose programming language known for its efficiency, economy, and portability. While these characteristics make it a good choice for almost any kind of programming, C has proven especially useful in systems programming because it facilitates writing fast, compact programs that are readily adaptable to other systems. Well-written C programs are often as fast as assembly-language programs, and they are typically easier for programmers to read and maintain.

C was designed to combine efficiency and power in a relatively small language. C does not include built-in functions to perform tasks such as input and output, storage allocation, screen manipulation, and process control. To perform such tasks, C programmers rely on "run-time libraries," a set of predefined functions and macros. The run-time library functions available for use in Microsoft® C programs are discussed in a separate manual, the *UNIX System V C Library Guide.*

C's design makes it both flexible and compact. Because the language is relatively sparse, it neither assumes nor imposes a particular programming model. You can use the run-time routines supplied, or tailor your own variations for special purposes. The design also helps to isolate language features from processor-specific features in a particular C implementation, which makes it easier to write portable code. While the strict definition of the language makes it independent of any particular operating system or machine, you can easily add system-specific routines to take advantage of the most efficient features of a particular machine.

Note

Microsoft is committed to conformity with the developing standard for the C language as set forth in the Draft Proposed American National Standard — Programming Language C (hereinafter referred to as the ANSI C standard. Microsoft extensions to the ANSI C standard are noted in the text. Because the extensions are not a part of the ANSI C standard, their use may restrict portability of programs between systems. See your compiler guide for information on enabling and disabling Microsoft extensions.

The C language includes the following significant features:

- A full set of loop, conditional, and transfer statements to control program flow logically and efficiently and to encourage structured programming.

- A large set of operators. Many of these operators correspond to common machine instructions, allowing a direct translation into machine code. The variety of operators allows you to specify different kinds of operations clearly and with a minimum of code.

- Several sizes of integers, as well as single- and double-precision floating-point types. You can also design more complex data types, such as arrays and data structures, to suit specific program needs.

- Declarations of "pointers" to variables and functions. A pointer to an item corresponds to the item's machine address. Pointers can make programs more efficient, since they let you refer to items in the same way the machine does. C also supports pointer arithmetic, which lets you access and manipulate memory addresses directly.

- A C preprocessor that acts on the text of files before they are compiled. You can use the C preprocessor to define program constants, substitute fast macro definitions for function calls, and compile parts of programs based on specified conditions.

C is a flexible language that leaves many programming decisions up to you. In keeping with this philosophy, C imposes few restrictions in matters such as type conversion. Although this characteristic of the language can make your programming job easier, you must know the language well to understand how programs will behave.

About This Manual

The *C Language Reference* defines the C language as implemented by Microsoft Corporation. It is intended as a reference for programmers experienced in C or other programming languages. Thorough knowledge of programming fundamentals is assumed.

Consult your compiler guide for an explanation of how to compile and link C programs on your system; this manual also contains information specific to the implementation of C on your system.

This manual is organized as follows:

Chapter 1, "Introduction," introduces this guide and outlines the notational conventions used in this manual.

Chapter 2, "Elements of C," describes the letters, numbers, and symbols that can be used in C programs and the combinations of characters that have special meanings to the C compiler.

Chapter 3, "Program Structure," discusses the components and structure of C programs and explains how C source files are organized.

Chapter 4, "Declarations," describes how to specify the attributes of C variables, functions, and user-defined types. C provides a number of predefined data types and lets the programmer declare "aggregate" types and pointers. Function prototypes, a relatively new feature of C, are discussed in this chapter, as well as in Chapter 7, "Functions."

Chapter 5,"Expressions and Assignments," describes the operands and operators that form C expressions and assignments. The chapter also discusses the type conversions and side effects that may occur when expressions are evaluated.

Chapter 6, "Statements," describes C statements, which control the flow of program execution.

Chapter 7, "Functions," discusses C functions. In particular, this chapter explains function prototypes, formal parameters, and return values. It also describes how to define, declare, and call functions.

Chapter 8, "Preprocessor Directives and Pragmas," describes the instructions recognized by the C preprocessor, a text processor that is automatically invoked before compilation. This chapter also introduces "pragmas," special instructions to the compiler that you can place in source files.

Appendix A, "Differences," lists the differences between Microsoft C and the description of the C language found in Appendix A of *The C Programming Language* by Brian W. Kernighan and Dennis M. Ritchie.

Appendix B, "Syntax Summary," summarizes the syntax of the C language as implemented by Microsoft.

Notational Conventions

This manual uses the following notational conventions:

keywords

Bold type indicates text that must be typed exactly as shown. Text that is shown in bold type includes C keywords, such as **goto** and **char**, and operators, such as the addition operator (+) and the multiplication operator (*).

placeholders

Terms in italics may appear in syntax descriptions or in the text. In these instances, the terms are being used as placeholders that you would replace with specific terms or values in an actual C program. For example, in

goto *name*;

name appears in italics to show that this is a general form for the **goto** statement. In an actual program statement, you must supply a particular identifier for the placeholder *name*.

Occasionally, italics are used to emphasize particular words in the text.

`Examples`

Examples of C programs and program elements appear in a special typeface to look similar to listings on the screen or the output of commonly used computer printers:

```
int x, y;
.
.
.
swap (&x, &y);
```

Input: *output*

Some examples show both program output and user input; in these cases, input is shown in a darker font.

Repeating . . . elements

Vertical ellipsis dots are used in program examples or syntax to indicate that a portion of the program is omitted.

In the following example, the vertical ellipsis dots indicate that zero or more declarations, followed by one or more statements, may appear between the braces:

```
{
[declaration]
.
.
.
statement
[statement]
.
.
.
}
```

In the following excerpt, two program lines are shown. The ellipsis dots between the lines indicate that additional program lines appear between these two lines but are not shown:

```
int x, y;
.
.
.
swap (&x, &y);
```

Horizontal ellipsis dots following an item indicate that more items of the same form may appear. For instance,

= {*expression* [, *expression*]...}

indicates that one or more expressions separated by commas may appear between the braces ({ }).

[optional items]

Brackets enclose optional items in syntax descriptions. For example,

return [*expression*]**;**

is a syntax description showing that *expression* is an optional item in the **return** statement.

Single brackets are used to indicate brackets used by C-language array declarations and subscript expressions. For instance, *a[10]* is an example of brackets in a C subscript expression.

''Defined terms''

Quotation marks set off terms defined in the text. For example, the term ''token'' appears in quotation marks when it is defined.

Some C constructs, such as strings, require quotation marks. Quotation marks required by the language have the form " " rather than `` ''. The following example shows a C string:

```
"abc"
```

Quotation marks also occasionally indicate a term that is being used in a colloquial sense.

KEY+NAMES

Names of special key combinations, such as CTRL+Z, appear in small capital letters.

Chapter 2

Elements of C

Introduction 2-1

Character Sets 2-2
- Letters, Digits, and Underscore 2-3
- White-Space Characters 2-3
- Punctuation and Special Characters 2-4
- Escape Sequences 2-5
- Operators 2-7

Constants 2-10
- Integer Constants 2-10
- Floating-Point Constants 2-12
- Character Constants 2-13
- String Literals 2-14

Identifiers 2-17

Keywords 2-19

Comments 2-20

Tokens 2-22

Introduction

This chapter describes the elements of the C programming language, including the names, numbers, and characters used to construct a C program. The following topics are discussed in this chapter:

- Character sets
- Constants
- Identifiers
- Keywords
- Comments
- Tokens

Character Sets

Two character sets are defined for use in C programs: the "C character set" and the "representable character set."

The C character set consists of the letters, digits, and punctuation marks having specific meanings in the C language. You construct a C program by combining the characters of the C character set into meaningful statements.

The C character set is a subset of the representable character set. The representable character set includes each letter, digit, and symbol that can be represented graphically with a single character. The extent of the representable character set depends on the type of terminal, console, or character device being used.

All characters in a C program must be part of the C character set. However, string literals, character constants, comments, and file names in **#include** directives can include any character from the representable character set.

Since each character in the C character set has an explicit meaning in the language, the compiler generates error messages when it finds inappropriate or inappropriately used characters in a program.

The sections that follow describe the characters and symbols of the C character set and explain how and when to use them.

Letters, Digits, and Underscore

The C character set includes the uppercase and lowercase letters of the English alphabet, the 10 decimal digits of the Arabic number system, and the underscore (_) character.

- Uppercase English letters

  A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

- Lowercase English letters

  a b c d e f g h i j k l m n o p q r s t u v w x y z

- Decimal digits

  0 1 2 3 4 5 6 7 8 9

- Underscore character (_)

These characters are used to form the constants, identifiers, and keywords described later in this chapter.

The C compiler treats uppercase and lowercase letters as distinct characters. For example, if a lowercase *a* is specified in an identifier, you cannot substitute an uppercase *A*; you must use the lowercase letter.

White-Space Characters

The space, tab, line-feed, carriage-return, form-feed, vertical-tab, and new-line characters are called ''white-space characters'' because they serve the same purpose as the spaces between words and lines on a printed page. These characters separate the items you define, such as constants and identifiers, from other items in a program.

The C compiler ignores white-space characters unless you use them as separators or as components of character constants or string literals. Therefore, you can use extra white-space characters to make a program more readable. The compiler also treats comments as white space. (Comments are described in ''Comments.'')

Punctuation and Special Characters

The punctuation and special characters in the C character set have various uses, from organizing program text to defining the tasks that the compiler or compiled program will carry out. Table 2.1 lists the punctuation and special characters in the C character set.

Table 2.1

Punctuation and Special Characters

Character	Name	Character	Name
,	Comma	!	Exclamation mark
.	Period	|	Vertical bar
;	Semicolon	/	Forward slash
:	Colon	\	Backslash
?	Question mark	~	Tilde
'	Single quotation mark	+	Plus sign
"	Double quotation mark	#	Number sign
(	Left parenthesis	%	Percent sign
)	Right parenthesis	&	Ampersand
[	Left bracket	^	Caret
]	Right bracket	*	Asterisk
{	Left brace	-	Minus sign
}	Right brace	=	Equal sign
<	Left angle bracket	>	Right angle bracket

These characters have special meanings in C. Their uses are described throughout this manual. Any punctuation character from the representable character set that does not appear in Table 2.1 can be used only in string literals, character constants, comments, and file names in **#include** directives.

Escape Sequences

Strings and character constants can contain "escape sequences." Escape sequences are character combinations representing white-space and non-graphic characters. An escape sequence consists of a backslash (\) followed by a letter or by a combination of digits.

Escape sequences are typically used to specify actions such as carriage returns and tab movements on terminals and printers and to provide literal representations of nonprinting characters and characters that normally have special meanings, such as the double-quotation-mark character ("). Table 2.2 lists the C escape sequences.

Table 2.2

Escape Sequences

Escape Sequence	Name
\n	New line
\t	Horizontal tab
\v	Vertical tab
\b	Backspace
\r	Carriage return
\f	Form feed
\a	Bell (alert)
\'	Single quotation mark
\"	Double quotation mark
\\	Backslash
\ddd	ASCII character in octal notation
\x*ddd*	ASCII character in hexadecimal notation

If a backslash precedes a character that does not appear in Table 2.2, the backslash is ignored and the character is represented literally. For example, the pattern \c represents the character *c* in a string literal or character constant. However, the use of lowercase letters in escape sequences is reserved by ANSI for future standardization. Therefore, occurrences of undefined escape sequences, though currently innocuous, could pose future portability problems.

The sequence *\ddd* lets you specify any character in the ASCII (American Standard Code for Information Interchange) character set as a three-digit octal character code. Similarly, the sequence *\xddd* lets you specify any ASCII character as a three-digit hexadecimal character code. For example, you can give the ASCII backspace character as the normal C escape sequence (*\b*), or you can code it as *\010* (octal) or *\x008* (hexadecimal).

You can use only the digits 0 through 7 in an octal escape sequence. Though you do not need to use all three digits (as in the form shown in the previous paragraph), you must use at least one. For example, you can specify the ASCII backspace character in octal notation as *\10*. Similarly, you must use at least one digit for a hexadecimal escape sequence, but you can omit the second and third digits. Therefore you could specify the hexadecimal escape sequence for the backspace character either as *\x08* or as *\x8*.

Note

When you use octal and hexadecimal escape sequences in strings, it is safest to give all three digits of the escape sequence. If you don't specify all digits of the escape sequence, and the character immediately following the escape sequence happens to be an octal or hexadecimal digit, the compiler interprets that character as part of the sequence. For example, if you printed the string *"\x07Bell"*, the result would be *{ell* because *\x07B* is interpreted as the ASCII left-brace character (*{*). The string *\x007Bell* (note the two leading zeros) is the correct way to represent the bell character followed by the word *Bell*. The string *\x7Bell* would generate a compiler diagnostic message because 7BE hexadecimal is too big a number to fit in one byte.

Escape sequences let you send nongraphic control characters to a display device. For example, the escape character *\033* is often used as the first character of a control command for a terminal or printer. Some escape sequences are device specific. For instance, the vertical tab and form feed (*\v* and *\f*) do not affect screen output, but they do perform appropriate operations for a printer.

You should always represent nongraphic characters by escape sequences in C programs, since using the characters directly may generate compiler diagnostic messages.

You can also use the backslash character (\) as a continuation character. When a new-line character immediately follows the backslash, the compiler ignores the backslash and the new line and treats the next line as part of the previous line. This is useful primarily for preprocessor definitions longer than a single line. In the past this feature was also used to create strings longer than one line. However, the string concatenation feature (see "String Literals") is now preferred for creating long string literals.

Operators

"Operators" are symbols (both single characters and character combinations) that specify how values are to be manipulated. Each symbol is interpreted as a single unit, called a "token." (Tokens are defined in "Tokens.")

Table 2.3 lists the symbols that make up the C unary operators and names each operator. Table 2.4 lists the C binary and ternary operators and names them. You must specify operators exactly as they appear in the tables, with no white space between the characters of multicharacter operators. Note that three operator symbols (asterisk, minus sign, and ampersand) appear in both tables. Their interpretation as unary or binary depends on the context in which they appear. The **sizeof** operator is not included in these tables. It consists of a keyword (**sizeof**) rather than a symbol, and is listed in "Keywords."

Table 2.3
Unary Operators

Operator	Name
!	Logical NOT
~	Bitwise complement
-	Arithmetic negation
*	Indirection
&	Address of
+	Unary plus[a]

[a] The unary plus operator is implemented syntactically, but not semantically.

Table 2.4
Binary and Ternary Operators

Operator	Name	Operator	Name
+	Addition	&&	Logical AND
-	Subtraction		
*	Multiplication	//	Logical OR
/	Division	,	Sequential evaluation
%	Remainder	?:	Conditional[a]
<<	Left shift	++	Increment
>>	Right shift	--	Decrement
<	Less than	=	Simple assignment
<=	Less than or equal to	+=	Addition assignment
>	Greater than	-=	Subtraction assignment
>=	Greater than or equal to	*=	Multiplication assignment
==	Equality	/=	Division assignment
!=	Inequality	%=	Remainder assignment
&	Bitwise AND	>>=	Right-shift assignment
/	Bitwise inclusive OR	<<=	Left-shift assignment
^	Bitwise exclusive OR	&=	Bitwise-AND-assignment
/=	Bitwise inclusive-OR assignment	^=	Bitwise exclusive-OR assignment

[a] The conditional operator is a ternary operator, not a multicharacter operator. A conditional expression has the following form: *expression* **?** *expression* **:** *expression.*

For a complete description of each operator, see the "Expressions and Assignments" chapter.

Constants

A *constant* is a number, character, or character string that can be used as a value in a program. A constant's value cannot be modified.

The C language has four kinds of constants: integer constants, floating-point constants, character constants, and string literals.

Integer Constants

Syntax

digits

0*odigits*

0x*hdigits*
0X*hdigits*

An ''integer constant'' is a decimal, octal, or hexadecimal number that represents an integral value in one of the following forms:

- A ''decimal constant'' has the form *digits*, where *digits* represents one or more decimal digits (0 through 9), the first of which is not a zero.
- An ''octal constant'' has the form **0***odigits*, where *odigits* represents one or more octal digits (0 through 7). The leading zero is required.
- A ''hexadecimal constant'' has the form **0x***hdigits* or **0X***hdigits*, where *hdigits* represents one or more hexadecimal digits (0 through 9 and either uppercase or lowercase *a* through *f*. The leading **0x** or **0X** is required.

No white-space characters can separate the digits of an integer constant.

Table 2.5 gives examples of the three forms of integer constants.

Table 2.5
Examples of Integer Constants

Decimal Constants	Octal Constants	Hexadecimal Constants
10	*012*	*0xa* or *0xA*
132	*0204*	*0x84*
32179	*076663*	*0x7db3* or *0x7DB3*

Integer constants always specify positive values. If you need to use a negative value, place a minus sign (-) in front of a constant to form a constant expression with a negative value. (In this case, the minus sign is interpreted as the unary arithmetic negation operator.)

Every integer constant is given a type based on its value. A constant's type determines which conversions must be performed when the constant is used in an expression or when the minus sign (-) is applied, as summarized in the following rules:

- Decimal constants are considered signed quantities and are given **int** type, or **long** type if the size of the value requires it.

- Octal and hexadecimal constants are given **int**, **unsigned int**, **long**, or **unsigned long** type, depending on the size of the constant. If the constant can be represented as an **int**, it is given **int** type. If it is larger than the maximum positive value that can be represented by an **int**, but small enough to be represented in the same number of bits as an **int**, it is given **unsigned int** type. Similarly, a constant that is too large to be represented as an **unsigned int** is given **long** or **unsigned long** type, if necessary.

Table 2.6 shows the ranges of values and the corresponding types for octal and hexadecimal constants on a machine whose **int** type is 16 bits long.

Table 2.6
Types Assigned to Octal and Hexadecimal Constants

Hexadecimal Range	Octal Range	Type
0x0 - 0x7FFF	0 - 077777	**int**
0x8000 - 0xFFFF	0100000 - 0177777	**unsigned int**
0x10000 - 0x7FFFFFFF	0200000 - 017777777777	**long**
0x80000000 - 0xFFFFFFFF	020000000000 - 037777777777	**unsigned long**

The consequence of the typing rules shown in Table 2.6 is that hexadecimal and octal constants are always zero extended when converted to longer types. (For more information on type conversions, see the "Expressions and Assignments." chapter.)

You can force any integer constant to be given **long** type by appending the letter *l* or *L* to the end of the constant. Table 2.7 illustrates some forms of **long** integer constants.

Table 2.7

Examples of Long Integer Constants

Decimal Constants	Octal Constants	Hexadecimal Constants
10L	*012L*	*0xaL* or *0xAL*
79l	*0115l*	*0x4fl* or *0x4Fl*

Types are described in the "Declarations" chapter and conversions are described in the "Expressions and Assignments" chapter.

Floating-Point Constants

Syntax

[*digits*][*.digits*][**E**|**e**[-|+]*digits*]

A "floating-point constant" is a decimal number that represents a signed real number. The value of a signed real number includes an integer portion, a fractional portion, and an exponent. The *digits* are zero or more decimal digits (0 through 9), and **E** (or **e**) is the exponent symbol. You can omit either the digits before the decimal point (the integer portion of the value) or the digits after the decimal point (the fractional portion), but not both. You can leave out the decimal point only if you include an exponent.

The exponent consists of the exponent symbol (**E** or **e**) followed by a constant integer value. The integer value may be negative. No white-space characters can separate the digits or characters of the constant.

Floating-point constants always specify positive values. However, you can place a minus sign (-) in front of the constant to form a constant floating-point expression with a negative value. In this case, the minus sign is treated as an arithmetic operator.

All floating-point constants have type **double**.

Examples

The following examples illustrate some forms of floating-point constants and expressions:

```
15.75
1.575E1
1575e-2
-0.0025
-2.5e-3
25E-4
```

You can omit the integer portion of the floating-point constant, as shown in the following examples:

```
-.125
-.175E-2
```

Character Constants

Syntax

'char'

A ''character constant'' is formed by enclosing a single character from the representable character set within single quotation marks (' '). An escape sequence is regarded as a single character and is therefore valid in a character constant. Note that escape characters must be represented by escape sequences or diagnostic messages will be generated. The value of a character constant is the numerical value of the character.

In the syntax above, *char* can be any character from the representable character set (including any escape sequence) except a single quotation mark ('), bäckslash (\), or new-line character (**\n**). To use a single quotation mark or backslash character as a character constant, precede it with a backslash, as shown in Table 2.8.

Table 2.8
Examples of Character Constants

Constant	Value
' '	Single blank space
'a'	Lowercase a
'?'	Question mark
'\b'	Backspace
'\x1B'	ASCII escape character
'\''	Single quotation mark
'\\'	Backslash

Character constants have type **int**, and are therefore sign extended in type conversions. (See "Type Conversions," for more information.)

String Literals

Syntax

"characters" ["*characters*"]...

A "string literal" is a sequence of characters from the representable character set enclosed in double quotation marks (" "). This example demonstrates a simple string literal:

```
"This is a string literal."
```

In a string literal, *characters* is a placeholder for zero or more characters from the representable character set, including any escape sequence. The double quotation mark ("), backslash (\), or new line must be represented by their escape sequences (\", \\, and **\n**). Non-printing characters should always be represented by a corresponding escape sequence. Each escape sequence is considered a single character.

To force a new line within a string literal, enter the new-line (**\n**) escape sequence at the point in the string where you want the line broken, as follows:

```
"Enter a number between 1 and 100\nOr press Return"
```

The traditional way to form string literals that take up more than one line is to type a backslash, then press RETURN. The backslash causes the

compiler to ignore the following new-line character. For example, the string literal

```
"Long strings can be bro\
ken into two or more pieces."
```

is identical to the string

```
"Long strings can be broken into two or more pieces."
```


Two or more string literals separated only by white space will be concatenated into a single string. For example, long strings passed as literals to the **printf** function can now be continued in any column of a succeeding line without affecting their appearance when output, if entered as follows:

```
printf ("This is the first half of the string,"
          " this is the second half") ;
```

As long as each part of the string is enclosed in double quotation marks, the parts will be concatenated and output as a single string:

```
This is the first half of the string, this is the second ha
```

You can use string concatenation anywhere you might previously have used a backslash followed by a new-line character to enter strings longer than one line. Because ensuing strings can start in any column of the source code without affecting their on-screen representation, strings can be positioned to enhance source-code readability. For example, the following pointer, initialized as two distinct string literals separated only by white space, is stored as a single string. When properly referenced, as in the following example, it produces a result identical to the previous example:

```
char *string = "This is the first half of the string,"
            " this is the second half" ;

printf("%s" , string) ;
```

To use a double quotation mark or backslash within a string literal, precede it with a backslash as shown in the following examples:

```
"First\\Second"

"\"Yes, I do,\" she said."
```

Note that an escape sequence (such as \\ or \") within a string literal counts as a single character.

The characters of a string are stored in order at contiguous memory locations. A null character (represented by the **\0** escape sequence) is automatically appended to, and marks the end of, each string literal. Each string in a program is generally considered to be distinct; however, two identical strings are not guaranteed to receive separate storage. Therefore, programs should not be designed to allow modification of string literals during execution.

String literals have type array of **char** (**char [ ]**). This means that a string is an array with elements of type **char**. The number of elements in the array is equal to the number of characters in the string, plus one for the terminating null character.

Identifiers

Syntax

letter|_[*letter*|*digit*|_]...

"Identifiers" are the names you supply for variables, types, functions, and labels in your program. An identifier is a sequence of one or more letters, digits, or underscores (_) that begins with a letter or underscore. Identifiers can contain any number of characters, but only the first 31 characters are significant to the compiler. (Other programs that read the compiler output, such as the linker, may recognize even fewer characters.)

You create an identifier by specifying it in the declaration of a variable, type, or function. You can then use the identifier in later program statements to refer to the associated item. Although statement labels are a special kind of identifier and have their own naming class, their creation is similar to that of variables and functions. (Declarations are described in the "Declarations" chapter. Statement labels are described in the "Statements" chapter.)

Because the C compiler considers uppercase and lowercase letters distinct characters, you can create distinct identifiers that have the same spelling but different cases for one or more of the letters.

An identifier cannot have the same spelling and case as a keyword of the language. Keywords are described in "Keywords."

You should not use leading underscores in identifiers you create: identifiers beginning with an underscore can cause conflicts with the names of system routines or variables, and produce errors. Programs containing names beginning with leading underscores are not guaranteed to be portable.

Note

Some linkers may further restrict the number and type of characters for globally visible symbols. (Visibility is defined in "Lifetime and Visibility.") Also the linker, unlike the compiler, may not distinguish between uppercase and lowercase letters. Consult your linker documentation for information about naming restrictions imposed by the linker.

Examples

The following are examples of identifiers:

```
j
cnt
temp1
top_of_page
skip12
```


Since uppercase and lowercase letters are considered distinct characters, each of the following identifiers is unique:

```
add
ADD
Add
aDD
```

Keywords

"Keywords" are predefined identifiers that have special meanings to the C compiler. They can be used only as defined. The name of a program item cannot have the same spelling and case as a C keyword.

The C language has the following keywords:

auto	**double**	**int**	**struct**
break	**else**	**long**	**switch**
case	**enum**	**register**	**typedef**
char	**extern**	**return**	**union**
const	**float**	**short**	**unsigned**
continue	**for**	**signed**	**void**
default	**goto**	**sizeof**	**volatile**
do	**if**	**static**	**while**

You cannot redefine keywords. However, you can specify text to be substituted for keywords before compilation by using C preprocessor directives (see the "Functions" chapter).

The **volatile** keyword is implemented syntactically, but currently has no semantics associated with it. You cannot use **volatile** as a variable name in your programs.

The following identifiers may be keywords in some implementations. See your compiler guide for more information.

cdecl
far
fortran
huge
near
pascal

Comments

Syntax

/ characters */*

A ''comment'' is a sequence of characters that is treated as a single white-space character by the compiler, but is otherwise ignored. In a comment, *characters* can include any combination of characters from the representable character set, including new-line characters, but excluding the ''end comment'' delimiter (*/). Comments can occupy more than one line, but they cannot be nested.

Comments can appear anywhere a white-space character is allowed. Since the compiler treats a comment as a single white-space character, you cannot include comments within tokens. However, since the compiler ignores the characters of the comment, you can include keywords in comments without producing errors.

To suppress compilation of a large portion of a program or a program segment that contains comments, bracket the desired portion of code with the **#if** and **#endif** preprocessor directives, rather than ''commenting out'' the code (see ''Conditional Compilation'').

Examples

The following examples illustrate some comments:

```
/* Comments can separate and document
   lines of a program. */

/* Comments can contain keywords such as for
   and while. */

/*****************************************
   Comments can occupy several lines.
 *****************************************/
```

Since comments cannot contain nested comments, the following example causes an error:

```
/* You cannot /* nest */ comments */
```

The error occurs because the compiler recognizes the first */, after the word *nest*, as the end of the comment. It tries to process the remaining text and produces an error when it cannot do so.

Tokens

In a C source program, the basic element recognized by the compiler is the character group known as a "token." A token is source-program text the compiler will not attempt to further analyze into component elements. For example, the following program fragment uses the word *elsewhere* as the name of a function. Although **else** is a keyword in C, there is no confusion between the function name token and the C keyword token it contains.

```
main()
{
    int i = 0;
     if (i)
     elsewhere() ;
}
```

However, if you were to type *elsewhere* as *else where* with a space between *else* and *where*, the preceding example would elicit a compiler diagnostic message noting the lack of a semicolon before the **else** keyword.

The operators, constants, identifiers, and keywords described in this chapter are examples of tokens. Punctuation characters such as brackets ([ ]), braces ({ }), angle brackets (< >), parentheses, and commas are also tokens.

Tokens are delimited by white-space characters and by other tokens, such as operators and punctuation characters. To prevent the compiler from breaking an item down into two or more tokens, white-space characters are not permitted within an identifier, multicharacter operator, or keyword.

When the compiler interprets tokens, it includes as many characters as possible in a single token before moving on to the next token. Because of this behavior, the compiler may not interpret tokens as you intended if they are not properly separated by white space.

Example

Consider the following expression:

```
i+++j
```

In this example, the compiler first makes the longest possible operator (++) from the three plus signs, then processes the remaining plus sign as an addition operator (+). Thus, the expression is interpreted as *(i++) + (j)*, not *(i) + (++j)*. In this and similar cases, use white space and parentheses to avoid ambiguity and ensure proper expression evaluation.

Chapter 3

Program Structure

Introduction 3-1

Source Program 3-2

Source Files 3-4

Functions and Program Execution 3-6

Lifetime and Visibility 3-7
- Blocks 3-7
- Lifetime 3-7
- Visibility 3-8
- Summary 3-9

Naming Classes 3-12

Introduction

This chapter defines terms used later in this manual to describe the C language, and discusses the structure of C source programs. It gives an overview of features of C that are described in detail in other chapters. The syntax and meaning of declarations and definitions are discussed in the "Declarations" chapter and the chapter on "Functions." The C preprocessor and pragmas are described in "Preprocessor Directives and Pragmas."

Source Program

A C "source program" is a collection of any number of directives, pragmas, declarations, definitions, and statements. These constructs are discussed briefly in the following paragraphs. To be valid constructs in Microsoft C, each must have the syntax described in this manual, though they can appear in any order in the program (subject to the rules outlined throughout this manual). However, order of appearance does affect how variables and functions can be used in a program. (See "Lifetime and Visibility," for more information.)

Directives

A "directive" instructs the C preprocessor to perform a specific action on the text of the program before compilation.

Pragmas

A "pragma" instructs the compiler to perform a particular action at compile time.

Declarations and Definitions

A "declaration" establishes an association between the name and the attributes of a variable, function, or type. In C, all variables must be declared before being used.

A "definition" of a variable establishes the same associations as a declaration, but also causes storage to be allocated for the variable. Therefore, all definitions are implicitly declarations, but not all declarations are definitions. For example, variable declarations that begin with the **extern** storage-class specifier are "referencing," rather than "defining," declarations. Referencing declarations do not cause storage to be allocated and cannot be initialized. (For more information on storage classes, see the "Declarations" chapter.)

"Function declarations" (or "prototypes") establish the name of the function, its return type, and, optionally, its formal parameters. A function definition includes the same elements as the prototype, plus the function body. If you do not supply an explicit declaration for a function, the compiler constructs a prototype from whatever information is available in the first reference to the function, whether that is a definition or a call.

Both function and variable declarations may appear inside or outside a function definition. Any declaration within a function definition is said to appear at the "internal" (local) level. A declaration outside all function definitions is said to appear at the "external" (global) level.

Variable definitions, like declarations, can appear at the internal level or at the external level. Function definitions always occur at the external level.

Note that declarations of types (for example, structure, union, and **typedef** declarations) that do not include the name of a variable of the type being declared do not cause storage allocation.

Example

The following example illustrates a simple C source program. This source program defines the function named *main* and declares the function named *printf* with a prototype. The program uses defining declarations to initialize the global variables *x* and *y*. The local variables *z* and *w* are declared, but not initialized. Storage is allocated for all these variables, but only *x, y, u,* and *v* contain meaningful values when declared because they are initialized either explicitly or implicitly. The values in *z* and *w* are not meaningful until values are assigned to them in the executable statements.

```
int x = 1;                          /* Defining declarations */
int y = 2;                        /* of external variables */

extern int printf(char *,...);      /* Function "prototype"
                                       or declaration       */

main ()                             /* Function definition
                                       for main function    */
{
        int z;                      /* Definitions for      */
        int w;                    /* two uninitialized      */
                                  /* local variables        */

       static int v;              /* Definition of variable
                                     with global lifetime   */
       extern int u;              /* Referencing declaration
                                     of external variable
                                     defined elsewhere      */

        z = y + x;                  /* Executable statements */
        w = y - x;
        printf("z= %d   w= %d", z, w);
       printf("v= %d   u= %d", v, u);
}
```

Source Files

A source program can be divided into one or more "source files." A C source file is a text file containing all or part of a C source program. (For example, a source file may contain just a few of the functions that the program needs.) When you compile a program, you must separately compile, and then link, the individual source files composing the total program. You can also use the **#include** directive to combine separate source files into larger source files before you compile. (For information on "include" files, see the "Preprocessor Directives and Pragmas" chapter.)

A source file can contain any combination of complete directives, pragmas, declarations, and definitions. You cannot split items such as function definitions or large data structures between source files. The last character in a source file must be a new-line character.

A source file need not contain executable statements. For example, you may find it useful to place definitions of variables in one source file and then declare references to these variables in other source files that use them. This technique makes the definitions easy to find and change. For the same reason, manifest constants and macros are often organized into separate include files that may be referenced in source files as required.

Directives in a source file apply only to that source file and its include files. Moreover, each directive applies only to the part of the file that follows the directive. To apply a common set of directives to a whole source program, you must include the directives in all source files that make up the program.

Pragmas usually affect a specific region of a source file. The implementation determines the specific compiler action that a pragma defines. (Your compiler guide describes the effects of particular pragmas.)

Example

The following example illustrates a C source program contained in two source files. Once you have compiled these source files, you can link and then execute them as a single program.

The *main* and *max* functions are assumed to be in separate files, and execution of the program is assumed to begin with the *main* function.

```
/*************************************************************
        Source file 1 - main function
 *************************************************************/

#define ONE     1
#define TWO     2
#define THREE   3

extern int max(int a, int b);     /* Function prototype  */

main ()                           /* Function definition */
{
        int w = ONE, x = TWO, y = THREE;
        int z = 0;
        z = max(x,y);
        w = max(z,w);
}
```


In Source file 1 (above), a prototype of the *max* function is declared. This kind of declaration is sometimes called a "forward declaration." The definition for the *main* function includes calls to *max*.

The lines beginning with a number sign *(#)* are preprocessor directives. These directives tell the preprocessor to replace the identifiers *ONE*, *TWO*, and *THREE* with the corresponding number throughout Source file 1. However, the directives do not apply to Source file 2 (follows), which will be separately compiled and then linked with Source file 1.

```
/*************************************************************
        Source file 2 - definition of max function
 *************************************************************/

int max (int a, int b)          /* Note formal parameters are
                                   included in function header */
  {
        if ( a > b )
                return (a);
        else
                return (b);
  }
```

Source file 2 contains the function definition for *max*. This definition satisfies the calls to *max* in Source file 1. Note that the definition for *max* follows the form specified in the ANSI C standard. For more information on this new form and function prototyping, see the "Functions" chapter.

Functions and Program Execution

Every C program has a primary function that must be named **main**. The **main** function serves as the starting point for program execution. It usually controls program execution by directing the calls to other functions in the program. A program usually stops executing at the end of **main**, although it can terminate at other points in the program for a variety of reasons depending on the execution environment.

The source program usually has more than one function, with each function designed to perform one or more specific tasks. The **main** function can call these functions to perform their respective tasks. When **main** calls another function, it passes execution control to the function so that execution begins at the first statement in the function. The function returns control when a **return** statement is executed or when the end of the function is reached.

You can declare any function, including **main**, to have parameters. When one function calls another, the called function receives values for its parameters from the calling function. These values are called "arguments." You can declare formal parameters to **main** so that it can receive values from outside the program. (Most commonly, these arguments are passed from the command line when the program is executed.)

Traditionally, the first three parameters of the **main** function are declared to have the names *argc*, *argv*, and *envp*. The *argc* parameter is declared to hold the total number of arguments passed to **main**. The *argv* parameter is declared as an array of pointers, each element of which points to a string representation of an argument passed to **main**. The *envp* parameter is a pointer to a table of string values that set up the environment in which the program executes.

The operating system supplies values for the *argc*, *argv*, and *envp* parameters, and the user supplies the actual arguments to **main**. The operating system, not the C language, determines the argument-passing convention used on a particular system. For more information, see your compiler guide.

If you declare formal parameters to a function, you must declare them when you define the function. Function declarations are described in the "Declarations," and "Functions" chapters, including function definitions.

Lifetime and Visibility

To understand how a C program works, you must understand the rules that determine how variables and functions can be used in the program. Three concepts are crucial to understanding these rules: the "block" (or compound statement), "lifetime" (sometimes called extent), and "visibility" (sometimes called scope).

Blocks

A block is a sequence of declarations, definitions, and statements enclosed within braces. There are two types of blocks in C. The "compound statement" (discussed more fully in the "Statements" chapter) is one type of block. The other, the "function definition," consists of a compound statement comprising the function body plus the function's associated "header" (the function name, return type, and formal parameters). A block may encompass other blocks, with the exception that no block can contain a function definition. A block within other blocks is said to be "nested" within the encompassing blocks.

Note that, while all compound statements are enclosed within braces, not everything enclosed within braces constitutes a compound statement. For example, though the specifications of array, structure, or enumeration elements may appear within braces, they are not considered compound statements.

Lifetime

"Lifetime" is the period, during execution of a program, in which a variable or function exists. All functions in a program exist at all times during its execution.

Lifetime of a variable may be internal (local) or external (global). An item with a local lifetime (a "local item") has storage and a defined value only within the block where the item is defined or declared. A local item is allocated new storage each time the program enters that block, and it loses its storage (and hence its value) when the program exits the block. If the lifetime of the variable is global (a "global item"), it has storage and a defined value for the entire duration of a program.

The following rules specify whether a variable has local or global lifetime:

- Variables declared at the internal level (that is, within a block) usually have local lifetimes. You can ensure global lifetime for a variable within a block by including the **static** storage class specifier in its declaration. Once declared **static**, the variable will retain its value from one entry of the block to the next. However, it will still be "visible" only within its own block and blocks nested within its own block. (Visibility of objects is discussed in the next section. For information on storage-class specifiers, see the "Declarations" chapter.)

- Variables declared at the external level (that is, outside all blocks in the program) always have global lifetimes.

Visibility

An item's "visibility" determines the portions of the program in which it can be referenced by name. An item is visible only in portions of a program encompassed by its "scope," which may be limited (in order of increasing restrictiveness) to the file, function, block, or function prototype in which it appears.

In C, only a label name is always confined to function scope. (For more information on labels and label names, see the chapter on "Statements.") The scope of any other item is determined by the level at which its declaration occurs. An item declared at the external level has file scope and is visible everywhere within the file. If its declaration occurs within a block (including the list of formal parameters in a function definition), the item's scope is limited to that block and blocks nested within that block. Formal parameter names declared in the parameter list of a function prototype have scope only from the completion of the parameter declaration to the end of the function declarator.

Note

Although an item with a global lifetime *exists* throughout the execution of the source program (for example, an externally declared variable or a local variable declared with the **static** keyword), it may not be visible in all parts of the program.

An item is said to be "globally visible" if it is visible, or if you can use appropriate declarations to make it visible, in all the source files making up the program. (For more information on visibility between source files, also known as "linkage," see the chapter on "Declarations.")

The following rules govern the visibility of variables and functions within a program:

- Variables declared or defined at the global level (that is, outside all blocks in the program) are visible from their point of definition or declaration to the end of the source file. You can use appropriate declarations to make such variables visible in other source files, as described in "Storage Classes." However, variables declared at the global level with the **static** storage-class specifier are visible only within the source file in which they are defined.

- In general, variables declared or defined at the local level (that is, within a block) are visible only from their point of declaration or definition to the end of the block actually containing the definition or declaration.

- Variables from outer blocks (including those declared at the global level) are visible in all inner blocks. However, the visibility of variables is said to "nest" within blocks. For instance, a block within another block can contain declarations for variables whose identifiers (names) are the same as variables in enclosing blocks. Such redefinitions prevail only within the inner block, however. Outer-block definitions are restored as the inner blocks are exited.

- Functions with **static** storage class are visible only in the source file in which they are defined. All other functions are globally visible. (For more information on function declarations, see "Function Definitions (Prototypes)."

Summary

Table 3.1 summarizes the main factors determining lifetime and visibility of variables and functions. However, the table does not cover all possible cases. For more information, see the "Declarations" chapter.

Note

A Microsoft extension to the ANSI C standard provides that functions declared at an internal level may have global visibility. This feature should not be relied upon where portability of source code is a consideration. See your compiler guide for information on enabling Microsoft extensions.

Table 3.1
Summary of Lifetime and Visibility

Level	Item	Storage Class Specifier	Lifetime	Visibility
External	Variable definition	**static**	Global	Restricted to source file in which it occurs
	Variable declaration	**extern**	Global	Remainder of source file
	Function prototype or definition	**static**	Global	Restricted to single source file
	Function prototype	**extern**	Global	Remainder of source file
Internal	Variable declaration	**extern**	Global	Block
	Variable definition	**static**	Global	Block
	Variable definition	**auto** or **register**	Local	Block

Example

The following program example illustrates blocks, nesting, and visibility of variables. In the example, there are four levels of visibility: the external level and three block levels. Assuming that the function *printf* is defined elsewhere in the program, the values will be printed to the screen as noted in the comments preceding each statement.

```
#include <stdio.h>

/* i defined at external level: */
int i = 1;

/* main function defined at external level: */
main ()
{

    /* prints 1 (value of external level i): */
    printf("%d\n", i);

    /* begin first nested block: */
    {

        /* i and j defined at internal level: */
        int i = 2, j = 3;

        /* prints 2, 3: */
        printf("%d\n%d\n", i, j);

        /* begin second nested block: */
        {

            /* i is redefined: */
            int i = 0;

            /* prints 0, 3: */
            printf("%d\n%d\n", i, j);

        /* end of second nested block: */
        }

        /* prints 2 (outer definition restored): */
        printf("%d\n", i);

    /* end of first nested block: */
    }

    /* prints 1 (external level definition restored): */
    printf("%d\n", i);
}
```

Naming Classes

In any C program, identifiers are used to refer to many different kinds of items. When you write a C program, you provide identifiers for the functions, variables, formal parameters, union members, and other items the program uses. C lets you use the same identifier for more than one program item, as long as you follow the rules outlined in this section. (For a definition of an identifier, see the "Elements of C" chapter.)

The compiler sets up "naming classes" to distinguish between the identifiers used for different kinds of items. The names within each class must be unique to avoid conflict, but an identical name can appear in more than one naming class. This means that you can use the same identifier for two or more different items, provided that the items are in different naming classes. The compiler can resolve references based on the context of the identifier in the program.

The following list describes the kinds of items you can name in C programs and the rules for naming them:

Variables and functions
: The names of variables and functions are in a naming class with formal parameters, **typedef** names and enumeration constants. Therefore, variable and function names must be distinct from other names in this class that have the same visibility.

  However, you can redefine variable and function names within program blocks, as described in "Lifetime and Visibility."

Formal parameters
: The names of formal parameters to a function are grouped with the names of the function's variables, so the formal parameter names should be distinct from the variable names. You cannot redeclare the formal parameters at the top level of the function. However, the names of the formal parameters may be redefined (that is, used to refer to different items) within subsequent blocks nested within the function body.

Enumeration constants

Enumeration constants are in the same naming class as variable and function names. This means that the names of enumeration constants must be distinct from all variable and function names with the same visibility, and distinct from the names of other enumeration constants with the same visibility. However, like variable names, the names of enumeration constants have nested visibility, so you can redefine them within blocks. (Nested visibility is discussed in "Lifetime and Visibility.")

typedef names

The names of types defined with the **typedef** keyword are in a naming class with variable and function names. Therefore, **typedef** names must be distinct from all variable and function names with the same visibility, as well as from the names of formal parameters and enumeration constants. Like variable names, names used for **typedef** types can be redefined within program blocks. See "Lifetime and Visibility."

Tags

Enumeration, structure, and union tags are grouped in a single naming class. These tags must be distinct from other tags with the same visibility. Tags do not conflict with any other names.

Members

The members of each structure and union form a naming class. The name of a member must, therefore, be unique within the structure or union, but it does not have to be distinct from other names in the program, including the names of members of different structures and unions.

Statement labels

Statement labels form a separate naming class. Each statement label must be distinct from all other statement labels in the same function. Statement labels do not have to be distinct from other names or from label names in other functions.

Example

Since structure tags, structure members, and variable names are in three different naming classes, the three items named *student* in the following example do not conflict. The context of each item allows correct interpretation of each occurrence of *student* in the program.

For example, when *student* appears after the **struct** keyword, the compiler recognizes it as a structure tag. When *student* appears after a member-selection operator (-> or .), the name refers to the structure member. In other contexts, *student* refers to the structure variable.


```
struct student {
        char student[20];
        int class;
        int id;
        } student;
```

Chapter 4

Declarations

Introduction 4-1

Type Specifiers 4-2
- Storage for Fundamental Types 4-5
- Range of Values 4-7
- Data-Type Categories 4-7

Declarators 4-9
- Array, Pointer, and Function Declarators 4-9
- Complex Declarators 4-10
- Declarators with Special Keywords 4-14

Variable Declarations 4-17
- Simple Variable Declarations 4-18
- Enumeration Declarations 4-19
- Structure Declarations 4-21
- Union Declarations 4-25
- Array Declarations 4-26
- Pointer Declarations 4-28

Function Declarations (Prototypes) 4-33
- Formal Parameters 4-34
- Return Type 4-34
- The List of Formal Parameters 4-35
- Summary 4-36

Storage Classes 4-40
- Variable Declarations at the Global Level 4-41
- Variable Declarations at the Local Level 4-44
- Function Declarations at the Global and Local Levels 4-46

Initialization 4-48
- Fundamental and Pointer Types 4-49
- Aggregate Types 4-50
- String Initializers 4-54

Type Declarations 4-55
Structure, Union, and Enumeration Types 4-55
Using typedef Declarations 4-56

Type Names 4-58

Introduction

This chapter describes the form and constituents of C declarations for variables, functions, and types. C declarations have the form

[*sc-specifier*] [*type-specifier*] *declarator*[=*initializer*] [,*declarator*[=*initializer*]]...

where *sc-specifier* is a storage-class specifier; *type-specifier* is the name of a defined type; and *initializer* gives the value or sequence of values to be assigned to the variable being declared. The *declarator* is an identifier that can be modified with brackets ([ ]), asterisks (*), or parentheses (( )).

You must explicitly declare all C variables before using them. You can declare a C function explicitly with a function prototype. If you do not provide a prototype, one is created automatically from whatever information is included in the first reference to the function, whether that reference is a definition or a call.

The C language includes a standard set of data types. You can add your own data types by declaring new ones based on types already defined. You can declare arrays, data structures, and pointers to both variables and functions.

C declarations require one or more "declarators." A declarator is an identifier that can be modified with brackets ([ ]), asterisks (*), or parentheses (( )) to declare an array, pointer, or function type, respectively. When you declare simple variables (such as character, integer, and floating-point items), or structures and unions of simple variables, the declarator is just an identifier.

Four storage-class specifiers are defined in C: **auto, extern, register**, and **static**. The storage-class specifier of a declaration affects how the declared item is stored and initialized and which parts of a program can reference the item. Location of the declaration within the source program and the presence or absence of other declarations of the variable are also important factors in determining the visibility of variables.

Function prototype declarations are presented in "Function Declarations (Prototypes)" in this chapter and in the "Functions" chapter of this guide. For information on function definitions, see the "Functions" chapter.

Type Specifiers

The C language provides definitions for a set of basic data types, called "fundamental" types. Their names are listed in Table 4.1.

Table 4.1
Fundamental Types

Integral Types[a]	Floating-Point Types	Other
char	**float**	**void**[c]
int	**double**	**const**
short	**long double**[b]	**volatile**[d]
long		
signed		
unsigned		
enum		

[a] The optional keywords **signed** and **unsigned** can precede any of the integral types, except **enum**, and can also be used alone as type specifiers, in which case they are understood as **signed int** and **unsigned int**, respectively. When used alone, the keyword **int** is assumed to be **signed**. When used alone, the keywords **long** and **short** are understood as **long int** and **short int**.

[b] The **long double** type is semantically equivalent to **double**, but is syntactically distinct.

[c] The keyword **void** has three uses: as a function return type, as an argument-type list for a function that will take no arguments, and to modify a pointer.

[d] The **volatile** keyword is implemented syntactically, but not semantically.

Enumeration types are considered fundamental types.

Note

The **long float** type is no longer supported, and occurrences of it in old code should be changed to **double**.

The **signed char**, **signed int**, **signed short int**, and **signed long int** types, together with their **unsigned** counterparts and **enum**, are called "integral" types. The **float**, **double**, and **long double** type specifiers are referred to as "floating" or "floating-point" types. You can use any integral or floating-point type specifier in a variable or function declaration.

You can use the **void** type to declare functions that return no value or to declare a pointer to an unspecified type. When the keyword **void** occurs alone within the parentheses following a function name, it is not interpreted as a type specifier. In that context **void** indicates only that the function accepts no arguments. Function types are discussed in "Function Declarations (Prototypes)."

The **const** type specifier declares an object as nonmodifiable. The **const** keyword can be a modifier for any fundamental or aggregate type, or to modify a pointer to an object of any type. A **const** type specifier can modify a **typedef**. A declaration that includes the keyword **const** as a modifier of an aggregate type declarator indicates that each element of the aggregate type is unmodifiable. If an item is declared with only the **const** type specifier, its type is taken to be **const int**. A **const** object may be placed in a read-only region of storage.

The **volatile** type specifier declares an item whose value may legitimately be changed by something beyond the control of the program in which it appears. The **volatile** keyword can be used in the same circumstances as **const** (previously described). An item can be both **const** and **volatile**, in which case the item could not be legitimately modified by its own program, but could be modified by some asynchronous process. The **volatile** keyword is implemented syntactically, but not semantically.

You can create additional type specifiers with **typedef** declarations (see "Type Declarations"). When used in a declaration, such specifiers may only be modified by the **const** and **volatile** modifiers.

Type specifiers are commonly abbreviated, as shown in Table 4.2. Integral types are signed by default. Thus, if you omit the **unsigned** keyword from the type specifier, the integral type is signed, even if you do not specify the **signed** keyword.

In some implementations, you can specify a compiler option that changes the default **char** type from signed to unsigned. When this option is in effect, the abbreviation **char** means the same as **unsigned char**, and you must use the **signed** keyword to declare a signed character value. Compiler options are described in your compiler guide.

Note

This manual generally uses the abbreviated forms of the type specifiers listed in Table 4.2 rather than the long forms, and it assumes that the **char** type is signed by default. Therefore, throughout this manual, **char** stands for **signed char**.

Table 4.2
Type Specifiers and Abbreviations

Type Specifier	Abbreviations
signed char[a]	**char**
signed int	**signed, int**
signed short int	**short, signed short**
signed long int	**long, signed long**
unsigned char[b]	--
unsigned int	**unsigned**
unsigned short int	**unsigned short**
unsigned long int	**unsigned long**
float	--
const int	**const**
volatile int	**volatile**
const volatile int	**const volatile**

[a] When you make the **char** type unsigned by default (by specifying the appropriate compiler option), you cannot abbreviate **signed char**.

[b] When you make the **char** type unsigned by default (by specifying the appropriate compiler option), you can abbreviate **unsigned char** as **char**.

Storage for Fundamental Types

Table 4.3 summarizes the storage associated with each fundamental type and gives the range of values that can be stored in a variable of each type. Since the **void** type specifier is only used to denote a function with no return value or a pointer to an unspecified type, it is not included in the table. Similarly, the table does not include **const** or **volatile** because a variable type modified by **const** or **volatile** retains its storage size and can contain any value within range for its fundamental type.

Table 4.3
Storage and Range of Values for Fundamental Types

Type	Storage	Range of Values (Internal)
char	1 byte	–128 to 127
int	implementation defined	
short	2 bytes	–32,768 to 32,767
long	4 bytes	–2,147,483,648 to 2,147,483,647
unsigned char	1 byte	0 to 255
unsigned	implementation defined	
unsigned short	2 bytes	0 to 65,535
unsigned long	4 bytes	0 to 4,294,967,295
float	4 bytes	IEEE-standard notation; discussed below
double	8 bytes	IEEE-standard notation; discussed below
long double	8 bytes	IEEE-standard notation; discussed below

The **char** type stores the integer value of a member of the representable character set. That integer value is the ASCII code corresponding to the specified character. Since the **char** type is interpreted as a signed, 1-byte integer, a **char** variable can store values in the range -128 to 127, although only the values from 0 to 127 have character equivalents. Similarly, an **unsigned char** variable can store values in the range 0-255.

Note that the C language does not define the storage and range associated with the **int** and **unsigned int** types. Instead, the size of a signed or unsigned **int** item is the standard size of an integer on a particular ma-

chine. For example, on a 16-bit machine the **int** type is usually 16 bits, or 2 bytes. On a 32-bit machine the **int** type is usually 32 bits, or 4 bytes. Thus, the **int** type is equivalent to either the **short int** or the **long int** type, and the **unsigned int** type is equivalent to either the **unsigned short** or the **unsigned long** type, depending on the implementation.

The type specifiers **int** and **unsigned int** (or simply **unsigned**) define certain features of the C language (for instance, the **enum** type discussed later in "Type Declarations"). In these cases, the definitions of **int** and **unsigned int** for a particular implementation determine the actual storage.

Note

The **int** and **unsigned int** type specifiers are widely used in C programs because they let a particular machine handle integer values in the most efficient way for that machine. However, since the sizes of the **int** and **unsigned int** types vary, programs that depend on a specific **int** size may not be portable to other machines. To make programs more portable, you can use expressions with the **sizeof** operator instead of hard-coded data sizes. The actual sizes of **int** and **unsigned int** are discussed in your compiler guide.

Floating-point numbers use the IEEE (Institute of Electrical and Electronics Engineers, Inc.) format. Values with **float** type have 4 bytes, consisting of a sign bit, an 8-bit excess-127 binary exponent, and a 23-bit mantissa. The mantissa represents a number between 1.0 and 2.0. Since the high-order bit of the mantissa is always 1, it is not stored in the number. This representation gives a range of approximately 3.4E-38 to 3.4E+38 for type **float**.

Values with **double** type have 8 bytes. The format is similar to the **float** format except that it has an 11-bit excess-1023 exponent and a 52-bit mantissa, plus the implied high-order 1 bit. This format gives a range of approximately 1.7E-308 to 1.7E+308 for type **double**.

Range of Values

The range of values for a variable is bounded by the minimum and maximum values that can be represented *internally* in a given number of bits. However, because of C's conversion rules (discussed in detail in the "Expressions and Assignments" chapter), you cannot always use the maximum or minimum value for a constant of a particular type in an expression.

For example, the constant expression *-32768* consists of the arithmetic negation operator (**-**) applied to the constant value 32,768. Since 32,768 is too large to represent as a **short int**, it is given the **long** type. Consequently, the constant expression *-32768* has **long** type. You can only represent -32,768 as a **short int** by type-casting it to the **short** type. No information is lost in the type cast, since -32,768 can be represented internally in 2 bytes.

Similarly, a value such as 65,000 can only be represented as an **unsigned short** by type-casting the value to **unsigned short** type or by giving the value in octal or hexadecimal notation. The value 65,000 in decimal notation is considered a signed constant. It is given the **long** type because 65,000 does not fit into a **short**. You can cast this **long** value to the **unsigned short** type without loss of information, since 65,000 can fit in 2 bytes when it is stored as an unsigned number.

Octal and hexadecimal constants may have either **signed** or **unsigned** type, depending on their size (see "Integer Constants," for more information). However, the method used to assign types to octal and hexadecimal constants ensures that they always behave like unsigned integers in type conversions.

Data-Type Categories

The C data types fall into two general categories, called scalar and aggregate. Scalar types include pointers and arithmetic types. Arithmetic types include all floating and integral types, as described in this section. Aggregate types include arrays and structures. Table 4.4 illustrates the categories of C data types.

Table 4.4
C Data-Type Categories

Data Types	Categories		
char			
int			
short			
long	*Integral*		
signed	*Types*		
unsigned		*Arithmetic*	
enum		*Types*	*Scalar Types*
float			
double	*Floating*		
long double	*Types*		
Pointers			
Arrays			*Aggregate*
Structures			*Types*

Declarators

Syntax

identifier
declarator[[*constant-expression*]]
**declarator*
(*declarator*)

The C language lets you declare "arrays" of values, "pointers" to values, and "functions returning" values of specified types. You must use a "declarator" to declare these items.

A "declarator" is an identifier that may be modified by brackets ([ ]), asterisks (*), or parentheses (( )) to declare an array, pointer, or function type, respectively. Declarators appear in the array, pointer, and function declarations described later in this chapter. The following section discusses the rules for forming and interpreting declarators.

Array, Pointer, and Function Declarators

When a declarator consists of an unmodified identifier, the item being declared has a base type. If the identifier is followed by brackets ([ ]), the type is modified to an *array* type. If asterisks (*) appear to the left of an identifier, the type is modified to a *pointer* type. If the identifier is followed by parentheses, the type is modified to a *function returning* type.

A declarator must include a type specifier to be a complete declaration. The type specifier gives the type of the elements of an array type, the type of object addressed by a pointer type, or the return type of a function.

The sections on array, pointer, and function declarations later in this chapter discuss each type of declaration in detail.

The following examples illustrate the simplest forms of declarators:

Example 1

This example declares an array of **int** values named *list*:

```
int list[20];
```

Example 2

The following example declares a pointer named *cp* to a **char** value:

```
char *cp;
```

Example 3

The following declares a function named *func*, with no arguments, that returns a **double** value:

```
double func(void);
```

4 Complex Declarators

You can enclose any declarator in parentheses to specify a particular interpretation of a complex declarator.

A "complex" declarator is an identifier qualified by more than one array, pointer, or function modifier. You can apply various combinations of array, pointer, and function modifiers to a single identifier. However, a declarator may not have the following illegal combinations:

- An array cannot have functions as its elements.
- A function cannot return an array or a function.

In interpreting complex declarators, brackets and parentheses (that is, modifiers to the right of the identifier) take precedence over asterisks (that is, modifiers to the left of the identifier). Brackets and parentheses have the same precedence and associate from left to right. After the declarator has been fully interpreted, the type specifier is applied as the last step. By using parentheses you can override the default association order and force a particular interpretation.

A simple way to interpret complex declarators is to read them from the inside out, using the following four steps:

1. Start with the identifier and look to the right for brackets or parentheses (if any).
2. Interpret these brackets or parentheses, then look to the left for asterisks.

3. For each right parenthesis you encounter, apply rules 1 and 2 to everything within the parentheses.

4. Apply the type specifier.

Example 1

In the following example, the steps are labeled in order and can be interpreted as follows:

1. The identifier *var* is declared as

2. a pointer to

3. a function returning

4. a pointer to

5. an array of 10 elements, which are

6. pointers to

7. **char** values.

```
char *(*(*var)())[10];
 ^    ^ ^ ^ ^   ^  ^
 7    6 4 2 1   3  5
```

Examples 2 through 9 illustrate complex declarations further and show how parentheses can affect the meaning of a declaration.

Example 2

In the following example, the array modifier has higher priority than the pointer modifier, so *var* is declared to be an array. The pointer modifier applies to the type of the array elements; therefore, the array elements are pointers to **int** values.

```
        /* array of pointers to int values */

int *var[5];
```

Example 3

In the following example, parentheses give the pointer modifier higher priority than the array modifier, and *var* is declared to be a pointer to an array of five **int** values.

```
        /* pointer to array of int values */

int (*var)[5];
```

Example 4

Function modifiers also have higher priority than pointer modifiers, so this example declares *var* to be a function returning a pointer to a **long** value. The function is declared to take two **long** values as arguments.


```
        /* function returning pointer to a long */

long *var(long,long);
```

Example 5

This example is similar to Example 3. Parentheses give the pointer modifier higher priority than the function modifier, and *var* is declared to be a pointer to a function that returns a **long** value. Again, the function takes two **long** arguments.

```
        /* pointer to function returning long */

long (*var)(long,long);
```

Example 6

The elements of an array cannot be functions, but this example demonstrates how to declare an array of pointers to functions instead. In this example, *var* is declared to be an array of five pointers to functions that return structures with two members. The arguments to the functions are declared to be two structures with the same structure type, *both*. Note that the parentheses surrounding **var[5]* are required. Without them, the declaration is an illegal attempt to declare an array of functions, as shown here:

```
                /* ILLEGAL */
struct both *var[5]( struct both, struct both );


      /* array of pointers to functions
         returning structures */

struct both {
     int a;
     char b;
     } ( *var[5] )( struct both, struct both );
```

Example 7

This example shows how to declare a function returning a pointer to an array, since functions returning arrays are illegal. Here *var* is declared to be a function returning a pointer to an array of three **double** values. The function *var* takes one argument. The argument, like the return value, is a pointer to an array of three **double** values. The argument type is given by a complex abstract declarator. The parentheses around the asterisk in the argument type are required; without them, the argument type would be an array of three pointers to **double** values. For a discussion and examples of abstract declarators, see "Type Names."


```
          /* function returning pointer
             to an array of 3 double values */

double ( *var( double (*)[3] ) )[3];
```

Example 8

As this example shows, a pointer can point to another pointer, and an array can contain arrays as elements. Here *var* is an array of five elements. Each element is a five-element array of pointers that point to unions, each of which have two members.

```
          /* array of arrays of pointers
             to pointers to unions */

union sign {
      int x;
      unsigned y;
      } **var[5][5];
```

Example 9

This example shows how the placement of parentheses changes the meaning of the declaration. In this example, *var* is a five-element array of pointers to five-element arrays of pointers to unions.

```
        /* array of pointers to arrays
           of pointers to unions */

union sign *(*var[5])[5];
```

Declarators with Special Keywords

Your implementation of Microsoft C may include the following special keywords:

1. **cdecl**
2. **far**
3. **fortran**
4. **huge**
5. **near**
6. **pascal**

These keywords modify the meaning of variable and function declarations. See your compiler guide for a full discussion of the effects of these special keywords.

When a special keyword appears in a declarator, it modifies the item immediately to the right of the keyword. You can apply more than one special keyword to the same item. For example, you might modify a function identifier with both the **far** keyword and the **pascal** keyword. In this case, the order of the keywords does not matter (that is, **far pascal** and **pascal far** have the same effect). Thus the "binding" characteristics of the special keywords are the same as those of the type specifiers **const** and **volatile**. (The section "Type Specifiers," contains descriptions of the **const** and **volatile** keywords.)

You can also use two or more special keywords in different parts of a declaration to modify the meaning of the declaration. For example, the following declaration contains two occurrences of the **far** keyword:

```
int far * pascal far func(void);
```

In this example, the **pascal** and **far** keywords modify the function identifier *func*. The return value of *func* is declared to be a **far** pointer to an **int** value.

As in any C declaration, you can use parentheses to override the default interpretation of the declaration. The rules governing complex declarators also apply to declarations that use the special keywords.

The following examples show the use of special keywords in declarations.

Example 1

This example declares a **huge** array named *database* with 65,000 **int** elements. The **huge** keyword modifies the array declarator.

```
int huge database[65000];
```

Example 2

In this example, the **far** keyword modifies the asterisk to its right, making *x* a **far** pointer to a pointer to **char**.

```
char * far * x;
```

This declaration is equivalent to the following declaration:

```
char * (far *x);
```

Example 3

This example shows two equivalent declarations. Both declare *calc* as a function with the **near** and **cdecl** attributes.

```
double near cdecl calc(double,double);

double cdecl near calc(double,double);
```

Example 4

Example 4 also shows two declarations. The first declares a **far fortran** array of characters named *initlist*, and the second declares three **far** pointers named *nextchar*, *prevchar*, and *currentchar*. These pointers might be used to store the addresses of characters in the *initlist* array. Note that the **far** keyword must be repeated before each declarator.

```
char far fortran initlist[INITSIZE];

char far *nextchar, far *prevchar, far *currentchar;
```

Example 5

Example 5 shows a more complex declaration with several occurrences of the **far** keyword.


```
char far *(far *getint)(int far *);
 ^    ^      ^       ^    ^     ^
 6    5      2       1    3     4
```

The following procedure would be used to interpret this declaration:

1. The identifier *getint* is declared as a
2. **far** pointer to
3. a function taking
4. a single argument that is a **far** pointer to an **int** value
5. and returning a **far** pointer to a
6. **char** value.

Note that the **far** keyword always modifies the item immediately to its right.

Variable Declarations

Syntax

[*sc-specifier*] *type-specifier declarator* [, *declarator*]...

This section describes the form and meaning of variable declarations. In particular, it explains how to declare the following:

Simple variables	Single-value variables with integral or floating-point type
Enumeration variables	Simple variables with integral type that hold one value from a set of named integer constants
Structures	Variables composed of a collection of values that may have different types
Unions	Variables composed of several values of different types, which occupy the same storage space
Arrays	Variables composed of a collection of elements with the same type
Pointers	Variables that point to other variables and contain variable locations (in the form of addresses) instead of values

In the general form of a variable declaration, *type-specifier* gives the data type of the variable and *declarator* gives the name of the variable, possibly modified to declare an array or a pointer type. The *type-specifier* can be a compound, as when the type is modified by **const**, **volatile**, or one of the special keywords described in "Declarators with Special Keywords." You can define more than one variable in a declaration by using multiple declarators, separated by commas. For example, *int const far *fp* declares a variable named *fp* as a far pointer to a nonmodifiable **int** value.

The *sc-specifier* gives the storage class of the variable. In some contexts, you can initialize variables at the time you declare them. For information about storage classes and initialization, see the sections on "Storage Classes" and "Initialization," respectively.

Simple Variable Declarations

Syntax

[*sc-specifier*] *type-specifier identifier* [, *identifier*]...;

The declaration of a simple variable specifies the variable's name and type. It can also specify the variable's storage class, as described in "Storage Classes." The *identifier* in the declaration is the variable's name. The *type-specifier* is the name of a defined data type.

You can use a list of identifiers separated by commas (,) to specify several variables in the same declaration. Each identifier in the list names a variable. All variables defined in the declaration have the same type.

Example 1

Example 1 declares a simple variable named *x*. This variable can hold any value in the set defined by the **int** type for a particular implementation. The simple object *y* is declared as a constant value of type **int**. It is initialized to the value 1, and is not modifiable. If the declaration of *y* was for an uninitialized external, it would receive an initial value of 0, and that value would be unmodifiable.

```
int x;
int const y=1;
```

Example 2

This example declares two variables named *reply* and *flag*. Both variables have **unsigned long** type and hold unsigned integral values.

```
unsigned long reply, flag;
```

Example 3

The following example declares a variable named *order* that has **double** type and can hold floating-point values.

```
double order;
```

Enumeration Declarations

Syntax

enum [*tag*] {*enum-list*} [*declarator* [, *declarator*]...];

enum *tag* [*identifier* [, *declarator*]...];

An "enumeration declaration" gives the name of an enumeration variable and defines a set of named integer constants (the "enumeration set"). A variable with enumeration type stores one of the values of the enumeration set defined by that type. The integer constants of the enumeration set have **int** type; thus, the storage associated with an enumeration variable is the storage required for a single **int** value.

Variables of **enum** type are treated as if they are of type **int** in all cases. They may be used in indexing expressions and as operands of all arithmetic and relational operators.

Enumeration declarations begin with the **enum** keyword and have the two forms shown at the beginning of this section and described below:

- In the first form, *enum-list* specifies the values and names of the enumeration set. (The *enum-list* is described in detail below.) The optional *tag* is an identifier that names the enumeration type defined by *enum-list*. The *declarator* names the enumeration variable. You can specify zero or more enumeration variables in a single enumeration declaration.

- The second form of the enumeration declaration uses a previously defined enumeration *tag* to refer to an enumeration type defined elsewhere. The *tag* must refer to a defined enumeration type, and that enumeration type must be currently visible. Since the enumeration type is defined elsewhere, *enum-list* does not appear in this type of declaration. Declarations of pointers to enumerations and **typedef** declarations for enumeration types can use the enumeration *tag* before the enumeration type is defined. However, the enumeration definition must be encountered prior to any actual use of the **typedef** declaration or pointer.

If a *tag* argument appears, but no *declarator* is given, the declaration constitutes a declaration for an enumeration tag.

An *enum-list* has the following form:

identifier [= *constant-expression*]
[, *identifier* [= *constant-expression*] ...]

Each *identifier* in an enumeration list names a value of the enumeration set. By default, the first identifier is associated with the value 0, the next identifier is associated with the value 1, and so on through the last identifier in the declaration. The name of an enumeration constant is equivalent to its value.

The optional phrase = *constant-expression* overrides the default sequence of values. Thus, if *identifier* = *constant-expression* appears in *enum-list*, the identifier is associated with the value given by *constant-expression*. The *constant-expression* must have **int** type and can be negative. The next identifier in the list is associated with the value of *constant-expression* + 1, unless you explicitly associate it with another value.

The following rules apply to the members of an enumeration set:

- An enumeration set can contain duplicate constant values. For example, you could associate the value 0 with two different identifiers named *null* and *zero* in the same set.
- The identifiers in the enumeration list must be distinct from other identifiers with the same visibility, including ordinary variable names and identifiers in other enumeration lists.
- Enumeration tags must be distinct from other enumeration, structure, and union tags with the same visibility.
- A comma is allowed following the last item in the enumeration list.

Example 1

This example defines an enumeration type named *day* and declares a variable named *workday* with that enumeration type. The value 0 is associated with *saturday* by default. The identifier *sunday* is explicitly set to 0. The remaining identifiers are given the values 1 through 5 by default.

```
enum day {
        saturday,
        sunday = 0,
        monday,
        tuesday,
        wednesday,
        thursday,
        friday
        } workday;
```

Example 2

In this example, a value from the set defined in Example 1 is assigned to the variable *today*. Note that the name of the enumeration constant is used to assign the value. Since the *day* enumeration type was previously declared, only the enumeration tag is necessary.

```
enum day today = wednesday;
```

Structure Declarations

Syntax

struct [*tag*] {*member-declaration-list*} [*declarator* [, *declarator*]...];

struct *tag*[*declarator* [, *declarator*]...];

A "structure declaration" names a structure variable and specifies a sequence of variable values (called "members" of the structure) that can have different types. A variable of that structure type holds the entire sequence defined by that type.

Structure declarations begin with the **struct** keyword and have two forms:

- In the first form, a *member-declaration-list* specifies the types and names of the structure members. The optional *tag* is an identifier that names the structure type defined by *member-declaration-list*.

- The second form uses a previously defined structure *tag* to refer to a structure type defined elsewhere. Thus, *member-declaration-list* is not needed as long as the definition is visible. Declarations of pointers to structures and **typedefs** for structure types can use the structure tag before the structure type is defined. However, the structure definition must be encountered prior to any actual use of the **typedef** or pointer.

In both forms, each *declarator* specifies a structure variable. A *declarator* can also modify the type of the variable to a pointer to the structure type, an array of structures, or a function returning a structure. If *tag* is given, but *declarator* does not appear, the declaration constitutes a type declaration for a structure tag.

Structure tags must be distinct from other structure, union, and enumeration tags with the same visibility.

A *member-declaration-list* argument contains one or more variable or bitfield declarations.

Each variable declared in the member-declaration list is defined as a member of the structure type. Variable declarations within the member-declaration list have the same form as other variable declarations discussed in this chapter, except that the declarations cannot contain storage-class specifiers or initializers. The structure members can have any variable type: fundamental, array, pointer, union, or structure.

A member cannot be declared to have the type of the structure in which it appears. However, a member can be declared as a pointer to the structure type in which it appears as long as the structure type has a tag. This lets you create linked lists of structures.

A bitfield declaration has the following form:

type-specifier [*identifier*] **:** *constant-expression***;**

The *constant-expression* specifies the number of bits in the bitfield. The *type-specifier* has type **int** (**signed** or **unsigned**) and *constant-expression* must be a non-negative integer value. Arrays of bitfields, pointers to bitfields, and functions returning bitfields are not allowed. The optional *identifier* names the bitfield. Unnamed bitfields can be used as "dummy" fields, for alignment purposes. An unnamed bitfield whose width is specified as 0 guarantees that storage for the member following it in the member-declaration list begins on an **int** boundary.

Each *identifier* in a member-declaration list must be unique within the list. However, they do not have to be distinct from ordinary variable names or from identifiers in other member-declaration lists.

Note

A Microsoft extension to the ANSI C standard allows **char** and **long** types (both **signed** and **unsigned**) for bitfields. Unnamed bitfields with base type **long** or **char** (**signed** or **unsigned**) force alignment to a boundary appropriate to the base type.

Microsoft C does not implement **signed** bitfields. The syntax is allowed, but a bitfield specified as **signed** is treated as **unsigned** in all conversions.

Storage

Structure members are stored sequentially in the order in which they are declared: the first member has the lowest memory address and the last member the highest. Storage for each member begins on a memory boundary appropriate to its type. Therefore, unnamed spaces (''holes'') may appear between structure members in memory.

Bitfields are not stored across boundaries of their declared type. For example, a bitfield declared with **unsigned int** type is packed into the space remaining (if any) if the previous bitfield was of type **unsigned int**. Otherwise, it begins a new object on an **int** boundary.

Example 1

This example defines a structure variable named *complex*. This structure has two members with **float** type, *x* and *y*. The structure type has no tag and is therefore unnamed.

```
struct {
          float x,y;
    } complex;
```

Example 2

This example defines a structure variable named *temp*. The structure has three members: *name*, *id*, and *class*. The *name* member is a 20-element array, and *id* and *class* are simple members with **int** and **long** type, respectively. The identifier *employee* is the structure tag.

```
struct employee {
            char name[20];
            int id;
            long class;
    } temp;
```

Example 3

This example defines three structure variables: *student*, *faculty*, and *staff*. Each structure has the same list of three members. The members are declared to have the structure type *employee*, defined in Example 2.


```
struct employee student, faculty, staff;
```

Example 4

This example defines a structure variable named *x*. The first two members of the structure are a **char** variable and a pointer to a **float** value. The third member, *next*, is declared as a pointer to the structure type being defined (*sample*).

```
struct sample {
            char c;
            float *pf;
            struct sample *next;
    } x;
```

Example 5

This example defines a two-dimensional array of structures named *screen*. The array contains 2000 elements. Each element is an individual structure containing four bitfield members: *icon*, *color*, *underline*, and *blink*.

```
struct {
            unsigned icon : 8;
            unsigned color : 4;
            unsigned underline : 1;
            unsigned blink : 1;
    } screen[25][80];
```

Union Declarations

Syntax

union [*tag*] {*member-declaration-list*} [*declarator* [**,** *declarator*.]..];

union *tag*[*declarator*[**,** *declarator*]...];

A ''union declaration'' names a union variable and specifies a set of variable values, called ''members'' of the union, that can have different types. A variable with **union** type stores one of the values defined by that type.

Union declarations have the same form as structure declarations, except that they begin with the **union** keyword instead of the **struct** keyword. The same rules govern structure and union declarations, except that bitfield members are not allowed in unions.

Storage

The storage associated with a union variable is the storage required for the largest member of the union. When a smaller member is stored, the union variable may contain unused memory space. All members are stored in the same memory space and start at the same address. The stored value is overwritten each time a value is assigned to a different member.

Example 1

This example defines a union variable with *sign* type and declares a variable named *number* that has two members: *svar*, a signed integer, and *uvar*, an unsigned integer. This declaration allows the current value of *number* to be stored as either a signed or an unsigned value. The tag associated with this union type is *sign*.

```
union sign {
        int svar;
        unsigned uvar;
    } number;
```

Example 2

This example defines a union variable named *jack*. The members of the union are, in order of their declaration, a pointer to a **char** value, a **char** value, and an array of **float** values. The storage allocated for *jack* is the storage required for the 20-element array *f*, since *f* is the longest member

of the union. Because there is no tag associated with the union, its type is unnamed.

```
union {
        char *a, b;
        float f[20];
    } jack;
```

Example 3

This example defines a two-dimensional array of unions named *screen*. The array contains 2000 elements. Each element of the array is an individual union with two members: *window1* and *screenval*. The *window1* member is a structure with two bitfield members, *icon* and *color*. The *screenval* member is an **int**. At any given time, each union element holds either the **int** represented by *screenval* or the structure represented by *window1*.


```
union {
        struct {
                unsigned int icon : 8;
                unsigned color : 4;
        } window1;
        int screenval;
    } screen[25][80];
```

Array Declarations

Syntax

type-specifier declarator [*constant-expression*];
type-specifier declarator [ ];

An ''array declaration'' names the array and specifies the type of its elements. It may also define the number of elements in the array. A variable with array type is considered a pointer to the type of the array elements, as described in the section on ''Identifiers.''

Array declarations have the two forms shown at the beginning of this section. Their syntax differs as follows:

- In the first form, the *constant-expression* argument within the brackets specifies the number of elements in the array. Each element has the type given by *type-specifier*, which can be any type except **void**. An array element cannot be a function type.

- The second form omits the *constant-expression* argument in brackets. You can use this form only if you have initialized the array, declared it as a formal parameter, or declared it as a reference to an array explicitly defined elsewhere in the program.

In both forms, *declarator* names the variable and may modify the variable's type. The brackets ([ ]) following *declarator* modify the declarator to array type. You can declare an array of arrays (a ''multidimensional'' array) by following the array declarator with a list of bracketed constant expressions, as shown:

type-specifier declarator[*constant-expression*] [*constant-expression*] ...

Each *constant-expression* in brackets defines the number of elements in a given dimension: two-dimensional arrays have two bracketed expressions, three-dimensional arrays have three, and so on. When you declare a multidimensional array within a function, you can omit the first constant expression if you have initialized the array, declared it as a formal parameter, or declared it as a reference to an array explicitly defined elsewhere in the program.

You can define arrays of pointers to various types of objects by using complex declarators, as described in ''Complex Declarators.''

Storage

The storage associated with an array type is the storage required for all of its elements. The elements of an array are stored in contiguous and increasing memory locations, from the first element to the last. No blanks separate the array elements in storage.

Arrays are stored by row. For example, the following array consists of two rows with three columns each:

```
char A[2][3];
```

The three columns of the first row are stored first, followed by the three columns of the second row. This means that the last subscript varies most quickly.

To refer to an individual element of an array, use a subscript expression, as described in ''Subscript Expressions.''

Example 1

This example declares an array variable named *scores* with 10 elements, each of which has **int** type. The variable named *game* is declared as a simple variable with **int** type.

```
int scores[10], game;
```

Example 2

This example declares a two-dimensional array named *matrix*. The array has 150 elements, each having **float** type.

```
float matrix[10][15];
```


Example 3

This example declares an array of structures. This array has 100 elements; each element is a structure containing two members.

```
struct {
            float x,y;
            } complex[100];
```

Example 4

This example declares the type and name of an array of pointers to **char**. The actual definition of *name* occurs elsewhere.

```
extern char *name[];
```

Pointer Declarations

Syntax

type-specifier * [*modification-spec*] *declarator*;
    extern char *name [ ];

A "pointer declaration" names a pointer variable and specifies the type of the object to which the variable points. A variable declared as a pointer holds a memory address.

The *type-specifier* gives the type of the object, which can be any fundamental, structure, or union type. Pointer variables can also point to functions, arrays, and other pointers. (For information on declaring more complex pointer types, refer to the section on "Complex Declarators.")

By making *type-specifier* **void**, you can delay specification of the type to which the pointer refers. Such an item is referred to as a "pointer to **void**" (**void** *). A variable declared as a pointer to **void** can be used to point to an object of any type. However, in order to perform operations on the pointer or on the object to which it points, the type to which it points must be explicitly specified for each operation. Such conversion can be accomplished with a type cast.

The *modification-spec* can be either **const** or **volatile**, or both. These specify, respectively, that the pointer will not be modified by the program itself (**const**), or that the pointer may legitimately be modified by some process beyond the control of the program (**volatile**). (For more information on **const** and **volatile**, see "Type Specifiers.")

The *declarator* names the variable and can include a type modifier. For example, if *declarator* represents an array, the type of the pointer is modified to pointer to array.

You can declare a pointer to a structure, union, or enumeration type before you define the structure, union, or enumeration type. However, the definition must appear before the pointer can be used as an operand in an expression. You declare the pointer by using the structure or union tag (see Example 7 in this section). Such declarations are allowed because the compiler does not need to know the size of the structure or union to allocate space for the pointer variable.

Storage

The amount of storage required for an address and the meaning of the address depend on the implementation of the compiler. Pointers to different types are not guaranteed to have the same length.

In some implementations, you can use the special keywords **near**, **far**, and **huge** to modify the size of a pointer. Declarations using special keywords are described in "Declarators with Special Keywords." For more information on the meaning and use of these keywords, see your compiler guide.

Example 1

This example declares a pointer variable named *message*. It points to a variable with **char** type.

```
char *message;
```

Example 2

Example 2 declares an array of pointers named *pointers*. The array has 10 elements; each element is a pointer to a variable with **int** type.

```
int *pointers[10];
```


Example 3

This example declares a pointer variable named *pointer*; it points to an array with 10 elements. Each element in this array has **int** type.

```
int (*pointer)[10];
```

Example 4

This example declares a pointer variable, *x*, to a constant value. The pointer may be modified to point to a different **int** value, but the value to which it points may not be modified.

```
int const *x;
```

Example 5

The variable *y* in Example 5 is declared as a constant pointer to an **int** value. The value it points to may be modified, but the pointer itself must always point to the same location: the address of *fixed_object*. Similarly, *z* is a constant pointer, but it is also declared to point to an **int** whose value will not be modified by the program. The additional specifier *volatile* indicates that although the value of the **const int** pointed to by *z* cannot be modified by the program, it could legitimately be modified by a process outside the program. The declaration of *w* specifies that the value

pointed to will not be changed and that the program itself will not modify the pointer. However, some outside process could legitimately modify the pointer.

```
const int some_object = 5 ;
int other_object = 37;
int *const y = &fixed_object;
const volatile *const z = &some_object;
*const volatile w = &some_object;
```

Example 6

This example declares two pointer variables that point to the structure type *list*. This declaration can appear before the definition of the *list* structure type (see Example 7), as long as the *list* type definition has the same visibility as the declaration.

```
struct list *next, *previous;
```

Example 7

This example defines the variable *line* to have the structure type named *list*. The *list* structure type has three members: the first member is a pointer to a **char** value, the second is an **int** value, and the third is a pointer to another *list* structure.

```
struct list {
            char *token;
            int count;
            struct list *next;
    } line;
```

Example 8

This example declares the variable *record* to have the structure type *id*. Note that *pname* is declared as a pointer to another structure type named *name*. This declaration can appear before the *name* type is defined.

```
struct id {
     unsigned int id_no;
     struct name *pname;
    } record;
```

Example 9

In this example, the pointer variable *p* is declared, but the **void** * preceding the identifier *p* in the declaration means that *p* can be used later to point to any type object. The address of an **int** value is assigned to *p*, but no operations on the pointer itself are permitted unless it is explicitly converted to the type to which it points. Similarly, indirect operations on the object pointed to by *p* are not permitted unless *p* is converted to a specific type. Finally, a cast is used to convert *p* to a pointer to **int**, and *p* is then incremented.

```
int i;
void *p;        /* p declared as pointer to an object
                   whose type is not specified        */
p = &i;         /* address of integer i assigned to p
                   but type of p itself is still not
                   specified. An operation like p++
                   would not be permitted yet         */
(int *)p++;     /* incrementing p permitted when the
                   cast converts it to pointer to int */
```

Function Declarations (Prototypes)

Syntax

[*sc-spec*] [*type-spec*] *declarator*([*formal-parameter-list*]) [, *declarator-list*]...;

A "function declaration," also called a "function prototype," establishes the name and return type of a function and may specify the types, formal parameter names, and number of arguments to the function. A function declaration does not define the function body. It simply makes information about the function known to the compiler. This information enables the compiler to check the types of the actual arguments in ensuing calls to the function.

If you do not provide a function prototype, the compiler constructs one from the first reference to the function it encounters, whether a call or a function definition. Whether such a prototype reflects the correct parameter types can only be assured if the function definition occurs in the same source file. If the definition occurs in a different module, argument mismatch errors may not be detected. Function definitions are described in detail in "Function Prototypes (Declarations)."

The *sc-spec* represents a storage-class specifier; it can be either **extern** or **static**. Storage-class specifiers are discussed in "Storage Classes."

The *type-spec* gives the function's return type, and *declarator* names the function. If you omit *type-spec* from a function declaration, the function is assumed to return a value of type **int**.

The *formal-parameter-list* is described in the next section.

The final *declarator-list* in the syntax line represents further declarations on the same line. These may be other functions returning values of the same type as the first function, or declarations of any variables whose type is the same as the first function's return type. Each such declaration must be separated from its predecessors and successors by a comma.

Formal Parameters

"Formal parameters" describe the actual arguments that can be passed to a function. In a function declaration, the parameter declarations establish the number and types of the actual arguments. They may also include identifiers of the formal parameters. Though the parameters may be omitted from a function declaration, their inclusion is recommended, and they are mandatory in a true prototype. The extent of the information in the declaration influences the argument checking done on function calls that appear before the compiler has processed the function definition.

Note

Identifiers used to name the formal parameters in the prototype declaration are descriptive only. They go out of scope at the end of the declaration. Therefore, they need not be identical to the identifiers used in the declaration portion of the function definition. Using the same names may enhance readability, but this use has no other significance.

Return Type

Functions can return values of any type except arrays and functions. Therefore, the *type-specifier* argument of a function declaration can specify any fundamental, structure, or union type. You can modify the function identifier with one or more asterisks (*) to declare a pointer return type.

Although functions cannot return arrays and functions, they can return pointers to arrays and functions. You can declare a function that returns a pointer to an array or function type by modifying the function identifier with asterisks (*), brackets ([ ]), and parentheses (( )). Such a function identifier is known as a "complex declarator." Rules for forming and interpreting complex declarators are discussed in "Complex Declarators."

The List of Formal Parameters

All elements of the *formal-parameter-list* argument appearing within the parentheses following the function declarator are optional. The two following syntax variations illustrate the possibilities:

[void]
[register] [*type-spec*] [*declarator*[[, ...][,...]]]

If formal parameters are omitted from the function declaration, the parentheses should contain the keyword **void** to specify that no arguments will ever be passed to the function. If the parentheses are left entirely empty, no information is conveyed about whether arguments will be passed to the function and no checking of argument types is performed.

Note

Empty parentheses in a function declaration or definition represent an obsolete form not recommended for new code. Functions accepting no arguments should be declared with the **void** keyword replacing the list of formal parameters. This use of **void** is interpreted by context, and is distinct from uses of **void** as a type specifier.

A declaration in the list of formal parameters can contain the **register** storage-class specifier, either alone or combined with a type specifier and an identifier. If **register** is not specified, the storage class is **auto**. The only explicit storage-class specifier permitted is **register**. If the parentheses contain only the **register** keyword, the formal parameter is considered to represent an unnamed **int** for which **register** storage is being requested.

If *type-spec* is included, it can specify the type name for any fundamental, structure, or union type (such as **int**). A *declarator* for a fundamental, structure, or union type is simply an identifier of a variable having that type.

The *declarator* for a pointer, array, or function can be formed by combining a type specifier, plus the appropriate modifier, with an identifier. Alternatively, an "abstract declarator" (that is, a declarator without a specified identifier) can be used. The section "Type Names" explains how to form and interpret abstract declarators.

A full, partial, or empty list of formal parameters can be declared. If the list contains at least one declarator, a variable number of parameters can be specified by ending the list with a comma followed by three periods (,...), referred to as the "ellipsis notation." A function is expected to have at least as many arguments as there are declarators or type specifiers preceding the last comma.

Note

To maintain compatibility with previous versions, the compiler accepts a comma without trailing periods at the end of a declarator list to indicate a variable number of arguments. However, this is a Microsoft extension to the ANSI C standard. New code should use the comma followed by three periods. For information on enabling and disabling extensions, see your compiler guide.

One other special construction is permitted as a formal parameter: **void *** represents a pointer to an object of unspecified type. Thus, in a call, the pointer can refer to any type of object after you convert the pointer (for example, with a cast) to a pointer to the desired type. Note that before operations can be performed on the pointer or the object it addresses, the pointer must be explicitly converted. For more information on **void ***, see "Pointer Declarations."

Summary

Function prototypes are optional, but strongly recommended. If included, the only elements absolutely required are the name of the function, the opening and closing parentheses following the name, and the final semicolon. If no return type is included, as in the following example, the function is assumed to return an **int**:

```
/***** Obsolete form of function declaration *****/

minimal_declaration();      /* may or may not
                           accept arguments */
```

A full function prototype is the same as a function definition, except that instead of having a function "body," it is terminated by a semicolon (;) immediately following the closing parenthesis.

Any appropriate combination of elements is permitted among the parameter declarations, from no information (as in the obsolete form in the example above) to a full prototype of the function. If no prototype at all is given, a *de facto* prototype is constructed from information in the first reference to the function encountered in the source file.

Example 1

In this example, any information included in the formal parameter list is used to check actual arguments appearing in calls to the function that occur before the compiler has processed the function definition.

```
double func(void);       /* returns a double, but
                          * accepts no arguments
                         */
fun (void *);            /* takes a pointer to an
                          * unspecified type;
                          * returns an int
                         */
char *true(long, long);    /* takes two longs;
                          * returns pointer to char
                         */
new (register a, char *);  /* takes an int with request
                          * for register storage, and
                          * a pointer to char;
                          * returns an int
                         */
void go(int *[], char *b); /* takes an array of pointers
                          * to int using an abstract
                          * declarator, and a pointer
                          * to char; there is no return
                         */
void *tu(double v,...);        /* takes at least one double;
                          * other arguments may also be
                           * given; returns a pointer
                          * to an unspecified type
                         */
```

Example 2

This example is a prototype for a function named *add* that takes two **int** arguments, represented by the identifiers *num1* and *num2*, and returns an **int** value.

```
int add(int num1, int num2);
```

Example 3

This example declares a function named *calc* that returns a **double** value. The obsolete empty parentheses leave the issue of possible arguments to the function undefined.

```
double calc();
```

Example 4

This example is a prototype for a function named *strfind* that returns a pointer to **char**. The function accepts at least one argument, declared by the formal parameter *char *ptr*, to be a pointer to a **char** value. The formal parameter list has one entry and ends with a comma followed by three periods, indicating that the function may take more arguments.


```
char *strfind(char *ptr,...);
```

Example 5

This example declares a function with **void** return type (returning no value). The **void** keyword also replaces the list of formal parameters, so no arguments are expected for this function.

```
void draw(void);
```

Example 6

In this example, *sum* is declared as a function returning a pointer to an array of three **double** values. The *sum* function takes two **double** values as arguments.

```
double (*sum(double, double))[3];
```

Example 7

In this example, the function named *select* is declared to take no arguments and to return a pointer to a function. The pointer return value points to a function taking one **int** argument, represented by the identifier *number*, and returning an **int** value.

```
int (*select(void))(int number);
```

Example 8

In this example, the function *prt* is declared to take a pointer argument of any type and return an **int** value. A pointer to any type could be passed as an argument to *prt* without producing a type-mismatch warning.

```
int prt(void *);
```

Example 9

This example shows the declaration of an array, named *rainbow*, of an unspecified number of constant pointers to functions. Each of these takes at least one parameter of type **int**, as well as an unspecified number of other parameters. Each of the functions pointed to returns a **long** value.

```
long (*const rainbow[]) (int, ...) ;
```

Storage Classes

The "storage class" of a variable determines whether the item has a "local" or "global" lifetime. Variables with local lifetimes are allocated new storage each time execution control passes to the block in which they are defined. When execution control passes out of the block, the variables no longer have meaningful values.

An item with a global lifetime exists and has a value throughout the execution of the program. All functions have global lifetimes.

Although C defines only two types of storage classes, it provides the following four storage-class specifiers:

Table 4.5
Storage-Class Specifiers

Items declared with	Have a
auto	local lifetime
register	local lifetime
static	global lifetime
extern	global lifetime

The four storage-class specifiers have distinct meanings because they affect the visibility of functions and variables, as well as their storage class. The term "visibility" refers to the portion of the source program in which the variable or function can be referenced by name. An item with a global lifetime exists throughout the execution of the source program, but it may not be "visible" in all parts of the program. (Visibility and the related concept of lifetime are discussed in the chapter on "Program Structure.")

The placement of variable and function declarations within source files also affects storage class and visibility. Declarations outside all function definitions are said to appear at the "external level"; declarations within function definitions appear at the "internal level."

The exact meaning of each storage-class specifier depends on two factors:

- Whether the declaration appears at the external or internal level
- Whether the item being declared is a variable or a function

The sections that follow describe the meanings of storage-class specifiers in each kind of declaration and explain the default behavior when the storage-class specifier is omitted from a variable or function declaration.

Variable Declarations at the Global Level

In variable declarations at the global level (that is, outside all functions), you can use the **static** or **extern** storage-class specifier or omit the storage-class specifier entirely. You cannot use the **auto** and **register** storage-class specifiers at the global level.

Variable declarations at the global level are either *definitions* of variables (''defining declarations''), or *references* to variables defined elsewhere (''referencing declarations'').

A global variable declaration that also initializes the variable (implicitly or explicitly) is a defining declaration of the variable. A definition at the global level can take several forms:

- A variable that you declare with the **static** storage-class specifier. You can explicitly initialize the **static** variable with a constant expression, as described in ''Initialization.'' If you omit the initializer, the variable is initialized to 0 by default. For example, *static int k = 16;* and *static int k;* are both considered definitions of the variable *k*.
- A variable that you explicitly initialize at the global level. For example, *int j = 3;* is a definition of the variable *j*.

Once a variable is defined at the global level, it is visible throughout the rest of the source file in which it appears. The variable is not visible prior to its definition in the same source file. Also, it is not visible in other source files of the program, unless a referencing declaration makes it visible, as described later in this section.

You can define a variable at the global level only once within a source file. If you give the **static** storage-class specifier, you can define another variable with the same name and the **static** storage-class specifier in a different source file. Since each **static** definition is visible only within its own source file, no conflict occurs.

The **extern** storage-class specifier declares a *reference* to a variable defined elsewhere. You can use an **extern** declaration to make a definition in another source file visible, or to make a variable visible above its definition in the same source file. Once you have declared a reference to the variable at the global level, the variable is visible throughout the remainder of the source file in which the declared reference occurs.

Declarations that use the **extern** storage-class specifier cannot contain initializers, since these declarations refer to variables whose values are defined elsewhere.

For an **extern** reference to be valid, the variable it refers to must be defined once, and only once, at the global level. The definition can be in any of the source files that form the program.

One special case is not covered by the rules outlined above. You can omit both the storage-class specifier and the initializer from a variable declaration at the global level; for example, the declaration *int n;* is a valid global declaration. This declaration can have one of two different meanings, depending on the context:

1. If there is a global defining declaration of a variable with the same name elsewhere in the program, the current declaration is assumed to be a reference to the variable in the defining declaration, exactly as if the **extern** storage-class specifier had been used in the declaration.

2. If there is no global declaration of a variable with the same name elsewhere in the program, the declared variable is allocated storage at link time and initialized to 0. This kind of variable is known as a ''communal'' variable. If more than one such declaration appears in the program, storage is allocated for the largest size declared for the variable. For example, if a program contains two uninitialized declarations of *i* at the global level, *int i;* and *char i;*, storage space for an **int** value is allocated for *i* at link time.

Uninitialized variable declarations at the global level are not recommended for any file that might be placed in a library.

Example

The two source files in this example contain a total of three global declarations of *i*. Only one declaration contains an initialization; that declaration, *int i = 3;* , defines the global variable *i* with initial value 3. The **extern** declaration of *i* at the top of the first source file makes the global variable visible above its definition in the file. Without the **extern** declaration, the *main* function could not reference the global variable *i*. The **extern** declaration of *i* in the second source file also makes the global variable visible in that source file.

Assuming that the *printf* function is defined elsewhere in the program, all three functions perform the same task: they increase *i* and print it. The values 4, 5, and 6 are printed.

If the variable *i* had not been initialized, it would have been set to 0 automatically at link time. In this case, the values 1, 2, and 3 would have been printed.

Source File One

```
extern int i;                   /* reference to i,
                                   defined below */

main()
{
        i++;
        printf("%d\n", i);      /* i equals 4 */
        next();
}

int i = 3;                      /* definition of i */

next()
{
        i++;
        printf("%d\n", i);      /* i equals 5 */
        other();
}
```

Source File Two

```
extern int i;                /* reference to i in
                                first source file */

other()
{
        i++;
        printf("%d\n", i);   /* i equals 6 */
}
```

Variable Declarations at the Local Level

You can use any of the four storage-class specifiers for variable declarations at the local level. When you omit the storage-class specifier from such a declaration, the default storage class is **auto**.

The **auto** storage-class specifier declares a variable with a local lifetime. An **auto** variable is visible only in the block in which it is declared. Declarations of **auto** variables can include initializers, as discussed in "Initialization." Since variables with **auto** storage class are not initialized automatically, you should either explicitly initialize them when you declare them, or assign them initial values in statements within the block. The values of uninitialized **auto** variables are undefined.

A **static auto** variable can be initialized with the address of any global or **static** item, but not with the address of another **auto** item, because the address of an **auto** item is not a constant.

The **register** storage-class specifier tells the compiler to give the variable storage in a register, if possible. Register storage usually speeds access time and reduces code size. Variables declared with **register** storage class have the same visibility as **auto** variables. The number of registers that can be used for variable storage is machine-dependent. If no registers are available when the compiler encounters a **register** declaration, the variable is given **auto** storage class and stored in memory. The compiler assigns register storage to variables in the order in which the declarations appear in the source file. Register storage, if available, is only guaranteed for **int** and pointer types that are the same size as an **int**.

A variable declared at the local level with the **static** storage-class specifier has a global lifetime but is visible only within the block in which it is declared. Unlike **auto** variables, **static** variables keep their values when the block is exited. You can initialize a **static** variable with a constant expression. A **static** variable is initialized only once, when program execution begins; it is *not* reinitialized each time the block is entered. If you do not explicitly initialize a **static** variable, it is initialized to 0 by default.

A variable declared with the **extern** storage-class specifier is a reference to a variable with the same name defined at the global level in any of the source files of the program. The local **extern** declaration is used to make the global-level variable definition visible within the block. Unless otherwise declared at the global level, a variable declared with the **extern** keyword is visible only in the block in which it is declared.

Example

In the following example, the variable *i* is defined at the global level with initial value 1. An **extern** declaration in the *main* function is used to declare a reference to the global-level *i*. The **static** variable *a* is initialized to 0 by default, since the initializer is omitted. The call to *printf* (assuming the *printf* function is defined elsewhere in the source program) prints the values 1, 0, 0, and 0.

In the *other* function, the address of the global variable *i* is used to initialize the **static** pointer variable *external_i*. This works because the global variable has **static** lifetime, meaning its address will always be the same. Next, the variable *i* is redefined as a local variable with initial value 16. This redefinition does not affect the value of the global-level *i*, which is hidden by the use of its name for the local variable. The value of the global *i* is now accessible only indirectly within this block, through the pointer *external_i*. Attempting to assign the address of the **auto** variable *i* to a pointer would not work, since it may be different each time the block is entered. The variable *a* is declared as a **static** variable and initialized to 2. This *a* does not conflict with the *a* in *main*, since **static** variables at the local level are visible only within the block in which they are declared.

The variable *a* is increased by 2, giving 4 as the result. If the *other* function were called again in the same program, the initial value of *a* would be 4, since local **static** variables keep their values when the program exits and then re-enters the block in which they are declared.

```
int i = 1;

main()
{       /* reference to i, defined above: */
        extern int i;

        /* initial value is zero; a is
           visible only within main: */
        static int a;

        /* b is stored in a register, if possible: */
        register int b = 0;

        /* default storage class is auto: */
        int c = 0;

        /* values printed are 1, 0, 0, 0: */
        printf("%d\n%d\n%d\n%d\n", i, a, b, c);
        other();
}

other()
{
       /* address of global i assigned to pointer variable */
       static int *external_i = &i;

        /* i is redefined; global i no longer visible: */
        int i = 16;

        /* this a is visible only within other: */
        static int a = 2;

        a += 2;
        /* values printed are 16, 4, and 1: */
        printf("%d\n%d\n%d\n", i, a, *external_i);
}
```

Function Declarations at the Global and Local Levels

You can use either the **static** or the **extern** storage-class specifier in function declarations. Functions always have global lifetimes.

The visibility rules for functions vary slightly from the rules for variables, as follows:

- A function declared to be **static** is visible only within the source file in which it is defined. Functions in the same source file can call the **static** function, but functions in other source files cannot. You can declare another **static** function with the same name in a different source file without conflict.

- Functions declared as **extern** are visible throughout all the source files that make up the program (unless you later redeclare such a function as **static**). Any function can call an **extern** function.

- Function declarations that omit the storage-class specifier are **extern** by default.

Note

A Microsoft extension to the ANSI C standard provides that function declarations at the local level have the same meaning as function declarations at the global level. This means that a function is visible from its point of declaration through the rest of the source file.

Initialization

Syntax

declarator = initializer

You can set a variable to an initial value by applying an initializer to the declarator in the variable declaration. The value or values of the initializer are assigned to the variable. An equal sign (=) precedes the initializer.

You can initialize variables of any type, provided that you obey the following rules:

- Declarations that use the **extern** storage-class specifier cannot include initializers.
- Variables declared at the global level can be initialized. If you do not explicitly initialize a variable at the global level, it is initialized to 0 by default.
- A constant expression can be used to initialize any variable declared with the **static** storage-class specifier. Variables declared to be **static** are initialized when program execution begins. If you do not explicitly initialize a **static** variable, it is initialized to 0 by default.
- Variables declared with the **auto** and **register** storage-class specifiers are initialized each time execution control passes to the block in which they are declared. If you omit an initializer from the declaration of an **auto** or **register** variable, the initial value of the variable is undefined.
- Aggregate types with **auto** storage class (arrays, structures, and unions) cannot be initialized. Only **static** aggregates and aggregates declared at the global level can be initialized.
- The initial values for global variable declarations and for all **static** variables, whether global or local, must be constant expressions. You can use either constant or variable values to initialize **auto** and **register** variables.

The sections that follow describe how to initialize variables of fundamental, pointer, and aggregate types.

Fundamental and Pointer Types

Syntax

declarator = *expression*

The value of *expression* is assigned to the variable. The conversion rules for assignment apply.

A locally declared static variable can only be initialized with a constant value. Since the address of any globally declared or static variable is constant, it may be used to initialize an local declared **static** pointer variable. However, the address of an **auto** variable cannot be used as an initializer because it may be different for each execution of the block.

Example 1

In this example, *x* is initialized to the constant expression 10.

```
int x = 10;
```

Example 2

In this example, the pointer *px* is initialized to 0, producing a "null" pointer.

```
register int *px = 0;
```

Example 3

This example uses a constant expression to initialize *c* to a constant value that cannot be modified.

```
const int c = (3 * 1024);
```

Example 4

This example initializes the pointer *b* with the address of another variable, *x*. The pointer *a* is initialized with the address of a variable named *z*. However, since it is specified to be a **const**, the variable *a* can only be initialized, never modified. It always points to the same location.

```
int *b = &x;
int *const a = &z;
```

Example 5

The global variable *GLOBAL* is declared in Example 5 at the global level, so it has global lifetime. The local variable *LOCAL* has **auto** storage class and only has an address during the execution of the function in which it is declared. Therefore, attempting to initialize the **static** pointer variable *lp* with the address of *LOCAL* is not permitted. The **static** pointer variable *gp* can be initialized to the address of *GLOBAL* because that address is always the same. Similarly, **rp* can be initialized because *rp* is a local variable and can have a nonconstant initializer. Each time the block is entered, *LOCAL* will have a new address, which will then be assigned to *rp*.

```
int GLOBAL ;

int function(void)
  {
     int LOCAL ;
     static int *lp = &LOCAL;    /* Illegal declaration */
     static int *gp = &GLOBAL;   /* Legal declaration   */
     register int *rp = &LOCAL; /* Legal declaration   */
  }
```


Aggregate Types

Syntax

declarator = {*initializer-list*}

The *initializer-list* is a list of initializers separated by commas. Each initializer in the list is either a constant expression or an initializer list. Therefore, an initializer list enclosed in braces can appear within another initializer list. This form is useful for initializing aggregate members of an aggregate type, as shown in the in this section.

For each *initializer-list*, the values of the constant expressions are assigned, in order, to the corresponding members of the aggregate variable. When a union is initialized, *initializer-list* must be a single constant expression. The value of the constant expression is assigned to the first member of the union.

If *initializer-list* has fewer values than an aggregate type, the remaining members or elements of the aggregate type are initialized to 0. If *initializer-list* has more values than an aggregate type, an error results.

These rules apply to each embedded initializer list, as well as to the aggregate as a whole.

The following example, declares *P* as a 4-by-3 array and initializes the elements of its first row to 1, the elements of its second row to 2, and so on through the fourth row:

```
int P[4][3] = {
        { 1, 1, 1 },
        { 2, 2, 2 },
        { 3, 3, 3,},
        { 4, 4, 4,},
};
```

Note that the initializer list for the third and fourth rows contains commas after the last constant expression. The last initializer list *({4, 4, 4,})* is also followed by a comma. These extra commas are permitted but not required; only commas that separate constant expressions from one another, and those that separate one initializer list from another, are required.

If there is no embedded initializer list for an aggregate member, values are simply assigned, in order, to each member of the subaggregate. Therefore, the initialization in the previous example is equivalent to the following:

```
int P[4][3] = {
        1, 1, 1, 2, 2, 2, 3, 3, 3, 4, 4, 4
};
```

Braces can also appear around individual initializers in the list.

When you initialize an aggregate variable, you must be careful to use braces and initializer lists properly. The following example illustrates the compiler's interpretation of braces in more detail:

```
typedef struct {
    int n1, n2, n3;
} triplet;

triplet nlist[2][3] = {
    { {  1, 2, 3 }, {  4, 5, 6 }, {  7, 8, 9 } },  /* Line 1 */
    { { 10,11,12 }, { 13,14,15 }, { 16,17,18 } }    /* Line 2 */
};
```

In this example, *nlist* is declared as a 2-by-3 array of structures, each structure having three members. Line 1 of the initialization assigns values to the first row of *nlist*, as follows:

1. The first left brace on Line 1 signals the compiler that the first aggregate member of *nlist* (that is, *nlist[0]*) is initializing.

2. The second left brace indicates that the first aggregate member of *nlist[0]* (that is, the structure at *nlist[0][0]*) is initializing.

3. The first right brace ends initialization of the structure *nlist[0][0]*; the next left brace starts initializing *nlist[0][1]*.

4. The process continues until the end of the line, where the closing right brace ends initialization of *nlist[0]*.

Line 2 assigns values to the second row of *nlist* in a similar way.

Note that the outer sets of braces enclosing the initializers on lines 1 and 2 are required. The following construction, which omits the outer braces, would cause an error:


```
triplet nlist[2][3] = {
     {  1, 2, 3 },{  4, 5, 6 },{  7, 8, 9 },   /* Line 1 */
     { 10,11,12 },{ 13,14,15 },{ 16,17,18 }    /* Line 2 */
};
```

In this construction, the first left brace on line 1 initializes *nlist[0]*, which is an array of three structures. The values 1, 2, and 3 are assigned to the three members of the first structure. When the next right brace is encountered (after the value 3), initialization of *nlist[0]* is complete, and the two remaining structures in the three-structure array are automatically initialized to 0. Similarly, *{ 4,5,6 }* initializes the first structure in the second row of *nlist*. The remaining two structures of *nlist[1]* are set to 0. When the compiler encounters the next initializer list (*{ 7,8,9 }*), it tries to initialize *nlist[2]*. Since *nlist* has only two rows, this attempt causes an error.

Example 1

In this example, the three **int** members of *x* are initialized to 1, 2, and 3, respectively. The three elements in the first row of *m* are initialized to 4.0; the elements of the remaining row of *m* are initialized to 0.0 by default.

```
struct list {
        int i, j, k;
        float m[2][3];
        } x = {
                1,
                2,
                3,
                {4.0, 4.0, 4.0}
        };
```


Example 2

In this example, the union variable *y* is initialized. The first element of the union is an array, so the initializer is an aggregate initializer. The initializer list *{'1'}* assigns values to the first row of the array. Since only one value appears in the list, the element in the first column is initialized to the character *1*, and the remaining two elements in the row are initialized to the value zero by default. Similarly, the first element of the second row of *x* is initialized to the character *4*, and the remaining two elements in the row are initialized to the value 0.

```
union
 {
        char x[2][3];
        int i, j, k;
        } y = { {
                  {'1'},
                  {'4'} }
        };
```

String Initializers

Syntax

declarators = "*characters*"

You can initialize an array of characters with a string literal. The following example, initializes *code* as a four-element array of characters. The fourth element is the null character, which terminates all string literals.

```
char code[ ] = "abc";
```

If you specify the array size and the string is longer than the specified array size, the extra characters are simply ignored. For example, the following declaration initializes *code* as a three-element character array:


```
char code[3] = "abcd";
```

Only the first three characters of the initializer are assigned to *code*. The character *d* and the string-terminating null character are discarded. Beware that this creates an unterminated string (that is, one without a 0 value to mark its end) and generates a diagnostic message indicating the condition.

If the string is shorter than the specified array size, the remaining elements of the array are initialized to 0 values.

Type Declarations

A type declaration defines the name and members of a structure or union type, or the name and enumeration set of an enumeration type. You can use the name of a declared type in variable or function declarations to refer to that type. This is useful if many variables and functions have the same type.

A **typedef** declaration defines a type specifier for a type. You can use **typedef** declarations to construct shorter or more meaningful names for types already defined by C or for types that you have declared.

Structure, Union, and Enumeration Types

Declarations of structure, union, and enumeration types have the same general form as variable declarations of those types. However, type declarations and variable declarations differ in the following ways:

- In type declarations the variable identifier is omitted, since no variable is declared.
- In type declarations *tag* is required; it names the structure, union, or enumeration type.
- The *member-declaration-list* or *enum-list* defining the type must appear in the type declaration; the abbreviated form of variable declarations, in which *tag* refers to a type defined elsewhere, is not legal for type declarations.

Example 1

This example declares an enumeration type named *status*. The name of the type can be used in declarations of enumeration variables. The identifier *loss* is explicitly set to -1. Both *bye* and *tie* are associated with the value 0, and *win* is given the value 1.

```
enum status {
        loss = -1,
        bye,
        tie = 0,
        win
        };
```

Example 2

This example declares a structure type named *student.* A declaration such as *struct student employee;* can be used to define a structure variable with *student* type.

```
struct student {
        char name[20];
        int id, class;
        };
```

Using typedef Declarations

Syntax

typedef *type-specifier declarator* [, *declarator*]...;

A **typedef** declaration is analogous to a variable declaration except that the **typedef** keyword replaces a storage-class specifier. A **typedef** declaration is interpreted in the same way as a variable or function declaration, but the identifier, instead of assuming the type specified by the declaration, becomes a synonym for the type.

Note that a **typedef** declaration does not create types. It creates synonyms for existing types, or names for types that could be specified in other ways. When a **typedef** name is used as a type specifier, it can be combined with certain type specifiers, but not others. Acceptable modifiers include **const** and **volatile**. In some implementations there are additional special keywords that can be used to modify a **typedef**.

You can declare any type with **typedef**, including pointer, function, and array types. You can declare a **typedef** name for a pointer to a structure or union type before you define the structure or union type, as long as the definition has the same visibility as the declaration.

Example 1

This example declares *WHOLE* to be a synonym for **int**. Note that *WHOLE* could now be used in a variable declaration such as *WHOLE i;* or *const WHOLE i;*. However, the declaration *long WHOLE i;* would be illegal.

```
typedef int WHOLE;
```

Example 2

This example declares *GROUP* as a structure type with three members. Since a structure tag, *club*, is also specified, either the **typedef** name (*GROUP*) or the structure tag can be used in declarations.

```
typedef struct club {
        char name[30];
        int size, year;
        } GROUP ;
```

Example 3

This example uses the previous **typedef** name to declare a pointer type. The type *PG* is declared as a pointer to the *GROUP* type, which in turn is defined as a structure type.


```
typedef GROUP *PG;
```

Example 4

Example 4 provides the type *DRAWF* for a function returning no value and taking two **int** arguments. This means, for example, that the declaration *DRAWF box;* is equivalent to the declaration *void box(int, int);*.

```
typedef void DRAWF(int, int);
```

Type Names

A "type name" specifies a particular data type. In addition to ordinary variable declarations and defined-type declarations, type names are used in three other contexts: in the formal-parameter lists of function declarations, in type casts, and in **sizeof** operations. Formal-parameter lists are discussed in "Function Declarations." Type casts and **sizeof** operations are discussed in Chapter 5 in the sections entitled "Type Conversions" and "C Operators", respectively.

The type names for fundamental, enumeration, structure, and union types are simply the type specifiers for those types.

A type name for a pointer, array, or function type has the following form:

type-specifier abstract-declarator

An *abstract-declarator* is a declarator without an identifier, consisting of one or more pointer, array, or function modifiers. The pointer modifier (*) always precedes the identifier in a declarator; array ([ ]) and function (( )) modifiers follow the identifier. Knowing this, you can determine where the identifier would appear in an abstract declarator and interpret the declarator accordingly.

Abstract declarators can be complex. Parentheses in a complex abstract declarator specify a particular interpretation, just as they do for the complex declarators in declarations.

Note

The abstract declarator consisting of a set of empty parentheses, ( ), is not allowed because it is ambiguous. It is impossible to determine whether the implied identifier belongs inside the parentheses (in which case it is an unmodified type) or before the parentheses (in which case it is a function type).

The type specifiers established by **typedef** declarations also qualify as type names.

Example 1

This example gives the type name for "pointer to **long**" type.

```
long *
```

Example 2

Examples 2 and 3 show how parentheses modify complex abstract declarators. Example 2 gives the type name for a pointer to an array of five **int** values.

```
int (*)[5]
```


Example 3

Example 3 specifies a pointer to a function taking no arguments and returning an **int** value.

```
int (*)(void)
```

Chapter 5

Expressions and Assignments

Introduction 5-1
- Constants 5-2
- Identifiers 5-2
- Strings 5-3
- Function Calls 5-3
- Subscript Expressions 5-4
- Member-Selection Expressions 5-7
- Expressions with Operators 5-9
- Expressions in Parentheses 5-10
- Type-Cast Expressions 5-10
- Constant Expressions 5-11
- Side Effects 5-12
- Sequence Points 5-12

C Operators 5-14
- Usual Arithmetic Conversions 5-15
- Complement and Unary Plus Operators 5-16
- Indirection and Address-of Operators 5-17
- The sizeof Operator 5-19
- Multiplicative Operators 5-20
- Additive Operators 5-22
- Shift Operators 5-24
- Relational Operators 5-25
- Bitwise Operators 5-27
- Logical Operators 5-28
- Sequential-Evaluation Operator 5-29
- Conditional Operator 5-30

Assignment Operators 5-32
- Lvalue Expressions 5-33
- Unary Increment and Decrement 5-34
- Simple Assignment 5-35
- Compound Assignment 5-36

Precedence and Order of Evaluation 5-37

Type Conversions 5-41
- Assignment Conversions 5-41

Type-Cast Conversions 5-50
Operator Conversions 5-50
Function-Call Conversions 5-50

Introduction

This chapter describes how to form expressions and make assignments in the C language. An "expression" is a combination of operands and operators that yields ("expresses") a single value.

An "operand" is a constant or variable value that is manipulated in the expression. Each operand of an expression is also an expression, since it represents a single value. When an expression is evaluated, the resulting value depends on the relative precedence of operators in the expression and on "sequence points" and "side effects," if any. The precedence of operators determines how operands are grouped for evaluation. Side effects are changes caused by the evaluation of an expression. In an expression with side effects, the evaluation of one operand can affect the value of another. With some operators, the order in which operands are evaluated also affects the result of the expression. The section entitled "C Operands" describes the formats and evaluation rules for C operands, including discussions of side effects and sequence points.

"Operators" specify how the operand or operands of the expression are manipulated. C operators are described later in this chapter in the section entitled "C Operators".

In C, assignments are considered expressions because an assignment yields a value. Its value is the value being assigned. In addition to the simple-assignment operator (=), C offers complex-assignment operators that both transform and assign their operands. Assignment operators are described later in this chapter in the section entitled "Assignment Operators".

The value represented by each operand in an expression has a type that may be converted to a different type in certain contexts. Type conversions occur in assignments, type casts, function calls, and operations. (The section entitled "Precedence and Order of Evaluation" gives the precedence rules for C operators; side effects are discussed in the "Introduction" section of this chapter under "Side Effects"; and type conversions are covered in the section entitled "Type Conversions" all elsewhere in this Chapter.)

Operands in C include constants, identifiers, strings, function calls, subscript expressions, member-selection expressions, or more complex expressions formed by combining operands with operators or enclosing operands in parentheses. Any operand that yields a constant value is called a "constant expression."

Every operand has a type. The following sections discuss the type of value each kind of operand represents. An operand can be "cast" (or

temporarily converted) from its original type to another type by means of a ''type-cast'' operation. A type-cast expression can also form an operand of an expression.

Constants

A constant operand has the value and type of the constant value it represents. A character constant has **int** type. An integer constant has **int**, **long**, **unsigned int**, or **unsigned long** type, depending on the integer's size and how the value is specified. Floating-point constants always have **double** type. String literals are considered arrays of characters and are discussed earlier in this section under the subheading ''Strings''.

Identifiers

An ''identifier'' names a variable or function. Every identifier has a type that is established when the identifier is declared. The value of an identifier depends on its type, as follows:

- Identifiers of integral and floating types represent values of the corresponding type.
- An identifier of **enum** type represents one constant value among a set of constant values. The value of the identifier is the constant value. Its type is **int**, by definition of the **enum** type.
- An identifier of **struct** or **union** type represents a value of the specified **struct** or **union** type.
- An identifier declared as a pointer represents a pointer to a value of the type specified in the pointer's declaration.
- An identifier declared as an array represents a pointer whose value is the address of the first array element. The pointer addresses the type of the array elements. For if *series* is declared to be a 10-element integer array, the identifier *series* represents the address of the array, and the subscript expression *series[5]* refers to an integer value which is the sixth element of *series*. Subscript expressions are discussed later in this section under the subheading ''Subscript Expressions''. The address of an array does not change during program execution, although the values of the individual elements can change. The pointer value represented by an array identifier is not a variable, so an array identifier cannot form the left-hand operand of an assignment operation.

- An identifier declared as a function represents a pointer whose value is the address of the function. The pointer addresses a function returning a value of a specified type. The address of a function does not change during program execution; only the return value varies. Thus, function identifiers cannot be left-hand operands in assignment operations.

Strings

Syntax

"string" [*"string"*]

A ''string literal'' is a character or sequence of adjacent characters enclosed in double quotation marks. Two or more adjacent string literals separated only by white space are concatenated into a single string literal. A string literal is stored as an array of elements with **char** type and initialized with the quoted sequence of characters. The string literal is represented by a pointer whose value is the address of the first array element. The address of the string's first element is a constant, so the value represented by a string expression is a constant.

Since string literals are effectively pointers, they can be used in the same contexts as pointers, and have the same restrictions as pointers. However, since they are not variables, neither string literals nor any of their elements can be the left-hand operand in an assignment operation.

The last character of a string is always the null character. Though the null character is not visible in the string expression, it is added automatically as the last element when the string is stored. For example, the string *"abc"* actually has four characters rather than three.

Function Calls

Syntax

expression ([*expression-list*])

A ''function call'' consists of an *expression* followed by an optional *expression-list* in parentheses, where

- *expression* must evaluate to a function address (for example, a function identifier), and

- *expression-list* is a list of expressions (separated by commas) whose values (the "actual arguments") are passed to the function. The *expression-list* argument can be empty.

A function-call expression has the value and type of the function's return value. If the function's return type is **void** (that is, the function has been declared never to return a value), the function-call expression also has **void** type. If the called function returns control without executing a **return** statement, the value of the function-call expression is undefined. (See the chapter on "Functions," for more information about function calls.)

Subscript Expressions

Syntax

expression1 [*expression2*]

A subscript expression represents the value at the address that is *expression2* positions beyond *expression1*. Usually, the value represented by *expression1* is a pointer value, such as an array identifier, and *expression2* is an integral value. However, all that is required syntactically is that one of the expressions be of pointer type and the other be of integral type. Thus the integral value could be in the *expression1* position and the pointer value could be in the brackets in the *expression2*, or "subscript," position. Whatever the order of values, *expression2* must be enclosed in brackets ([ ]).

Subscript expressions are generally used to refer to array elements, but you can apply a subscript to any pointer.

Unidimensional-Array References

The subscript expression is evaluated by adding the integral value to the pointer value, then applying the indirection operator (*) to the result. (For a discussion of the indirection operator see the "Indirection and Address-of Operators" subsection of the section entitled "C Operators" later in this chapter.) In effect, for a one-dimensional array, the following four expressions are equivalent, assuming that *a* is a pointer and *b* is an integer:

```
a[b]
*(a + b)
*(b + a)
b[a]
```

According to the conversion rules for the addition operator (see "Additive Operators" in the "C Operators" section), the integral value is converted to an address offset by multiplying it by the length of the type addressed by the pointer.

For example, suppose the identifier *line* refers to an array of **int** values. The following procedure is used to evaluate the subscript expression *line*[*i*]:

1. The integer value *i* is multiplied by the number of bytes defined as the length of an **int** item. The converted value of *i* represents *i* **int** positions.
2. This converted value is added to the original pointer value (*line*) to yield an address that is offset *i* **int** positions from *line*.
3. The indirection operator is applied to the new address. The result is the value of the array element at that position (intuitively, *line*[*i*]).

Note

The following subscript expression represents the value of the first element of *line*, since the offset from the address represented by *line* is 0:

```
line[0]
```

Similarly, an expression such as the following refers to the element offset five positions from *line* or the sixth element of the array:

```
line[5]
```

Multidimensional-Array Reference

A subscript expression can be subscripted, as follows:

expression1 [*expression2*] [*expression3*]...

Subscript expressions associate from left to right. The left-most subscript expression, *expression1*[*expression2*], is evaluated first. The address that results from adding *expression1* and *expression2* forms a pointer expression; then *expression3* is added to this pointer expression to form a new pointer expression, and so on until the last subscript expression has been added. The indirection operator (*) is applied after the last subscripted expression is evaluated, unless the final pointer value addresses an array type (see Example 3).

Expressions with multiple subscripts refer to elements of "multidimensional arrays." A multidimensional array is an array whose elements are arrays. For example, the first element of a three-dimensional array is an array with two dimensions.

For the following examples, an array named *prop* is declared with three elements, each of which is a 4-by-6 array of **int** values.

```
int prop[3][4][6];
int i, *ip, (*ipp)[6];
```

Example 1

This example shows how to refer to the second individual **int** element of *prop*. Arrays are stored by row, so the last subscript varies the most quickly; the expression *prop[0][0][2]* refers to the next (third) element of the array, and so on.

```
i = prop[0][0][1];
```

Example 2

This example shows a more complex reference to an individual element of *prop*. The expression is evaluated as follows:

1. The first subscript, *2*, is multiplied by the size of a 4-by-6 **int** array and added to the pointer value *prop*. The result points to the third 4-by-6 array of *prop*.

2. The second subscript, *1*, is multiplied by the size of the 6-element **int** array and added to the address represented by *prop[2]*.

3. Each element of the 6-element array is an **int** value, so the final subscript, *3*, is multiplied by the size of an **int** before it is added to *prop[2][1]*. The resulting pointer addresses the fourth element of the 6-element array.

4. The indirection operator is applied to the pointer value. The result is the **int** element at that address.

```
i = prop[2][1][3];
```

Example 3

Examples 3 and 4 show cases where the indirection operator is not applied.

In Example 3, the expression *prop[2][1]* is a valid reference to the three-dimensional array *prop*; it refers to a 6-element array (declared above Example 1). Since the pointer value addresses an array, the indirection operator is not applied.


```
ip = prop[2][1];
```

Example 4

As in example 3, the result of the expression *prop[2]* in Example 4 is a pointer value addressing a two-dimensional array.

```
ipp = prop[2];
```

Member-Selection Expressions

Syntax

expression.identifier
expression->identifier

A ''member-selection expression'' refers to members of structures and unions. Such an expression has the value and type of the selected member. As shown in the syntax line, a member-selection expression can have one of the two following forms:

1. In the first form, *expression.identifier*, *expression* represents a value of **struct** or **union** type, and *identifier* names a member of the specified structure or union.

2. In the second form, *expression–>identifier*, *expression* represents a pointer to a structure or union, and *identifier* names a member of the specified structure or union.

The two forms of member-selection expressions have similar effects. In fact, an expression involving the pointer selection operator (–>) is a shorthand version of an expression using the period (.) if the expression before the period consists of the indirection operator (*) applied to a pointer value. (See the ''Indirection and Address-of Operators'' section in the ''C Operators'' section.) Therefore,

expression->identifier

is equivalent to

(**expression*).*identifier*

when *expression* is a pointer value.

Examples 1 through 3 refer to the following structure declaration:

```
struct pair {
        int a;
        int b;
        struct pair *sp;
        } item, list[10];
```

Example 1

In this example, the address of the *item* structure is assigned to the *sp* member of the structure. This means that *item* contains a pointer to itself.

```
item.sp = &item;
```

Example 2

In this example, the pointer expression *item.sp* is used with the pointer selection operator (–>) to assign a value to the member *a*.

```
(item.sp)->a = 24;
```

Example 3

This example shows how to select an individual structure member from an array of structures.

```
list[8].b = 12;
```

Expressions with Operators

Expressions with operators can be "unary," "binary," or "ternary" expressions. A unary expression consists of either a unary operator ("unop") prepended to an operand, or the **sizeof** keyword followed by an *expression*. The *expression* can be either the name of a variable or a cast expression. If *expression* is a cast expression it must be enclosed in parentheses.

unop operand
sizeof *expression*

A binary expression consists of two operands joined by a binary operator ("binop"):

operand binop operand

A ternary expression consists of three operands joined by the ternary operator (**? :**):

operand **?** *operand* **:** *operand*

The section later in this chapter entitled "C Operators" describes the operators used in unary, binary, and ternary expressions.

Expressions with operators also include assignment expressions that use unary or binary assignment operators. The unary assignment operators are the increment (++) and decrement (--) operators; the binary assignment operators are the simple-assignment operator (=) and the compound-assignment operators (referred to as "compound-assign-ops"). Each compound-assignment operator is a combination of another binary operator with the simple-assignment operator. Assignment expressions have the following forms:

operand++
operand– –
++*operand*
– –*operand*
operand = *operand*
operand compound-assign-op operand

The section later in this chapter entitled "Assignment Operators" describes the assignment operators in detail.

Expressions in Parentheses

You can enclose any operand in parentheses without changing the type or value of the enclosed expression. For example, in the the following expression, the parentheses around *10 + 5* mean that the value of *10 + 5* is the left operand of the division (/) operator.

```
(10 + 5) / 5
```

The result of *(10 + 5) / 5* is 3. Without the parentheses, *10 + 5 / 5* would evaluate to 11.

Although parentheses affect the way operands are grouped in an expression, they cannot guarantee a particular order of evaluation in all cases. Exceptions resulting from "side effects" are discussed in the section entitled "Precedence and Order of Evaluation" later in this chapter.

Type-Cast Expressions

A type cast provides a method for explicit conversion of the type of an object in a specific situation. Type-cast expressions have the following form:

(*type-name*) *operand*

Casts can be used to convert objects of any scalar type to or from any other scalar type. Explicit type casts are constrained by the same rules that determine the effects of implicit conversions, discussed in "Assignment Conversions." Additional restraints on casts may result from the actual sizes or representation of specific types on specific implementations. Representation is discussed in the "Declarations" chapter. For information on actual sizes of integral types and pointers, see your compiler guide.

Any object may be cast to **void** type. However, if the *type-name* in a type-cast expression is not **void**, then *operand* cannot be a **void**

expression. Any expression can be cast to **void**, but an expression of type **void** cannot be cast to any other type. For example, a function with **void** return type cannot have its return cast to another type. Note that a **void *** expression has a type pointer to **void**, not type **void**. If an object is cast to **void** type, the resulting expression cannot be assigned to any item. Similarly, a type-cast object is not an acceptable lvalue, so no assignment can be made to a type-cast object. See the section on "Lvalue Expressions" in the section entitled "Assignment Operators" for a discussion of Lvalues, and the section on "Type-Cast Conversions" in the section entitled "Type Conversions" for a discussion of type conversions later in this chapter.

Constant Expressions

A constant expression is any expression that evaluates to a constant. The operands of a constant expression can be integer constants, character constants, floating type constants, enumeration constants, type casts, **sizeof** expressions, and other constant expressions. You can use operators to combine and modify operands as described in the section entitled "Expressions with Operators" with the following restrictions:

- You cannot use assignment operators (see "Assignment Operators" later in this chapter) or the binary sequential-evaluation operator (,) in constant expressions.

- You can use the unary address-of operator (**&**) only in certain initializations (as described in the last paragraph of this section).

Constant expressions used in preprocessor directives are subject to additional restrictions. Consequently, they are known as "restricted constant expressions." A restricted constant expression cannot contain **sizeof** expressions, enumeration constants, type casts to any type, or floating-type constants. It can, however, contain the special constant expression **defined**(*identifier*).

Constant expressions involving floating constants, casts to nonarithmetic types, and address-of expressions can only appear in initializers. The unary address-of operator (**&**) can only be applied to variables with fundamental, structure, or union types that are declared at the global level, or to subscripted array references. In these expressions, a constant expression that does not include the address-of operator can be added to or subtracted from the address expression.

Side Effects

"Side effects" occur whenever the value of a variable is changed by expression evaluation. All assignment operations have side effects. Function calls may also have side effects if they change the value of an externally visible item, either by direct assignment or by indirect assignment through a pointer.

The order of evaluation of expressions is defined by the specific implementation, except when the language guarantees a particular order of evaluation (as outlined in the section entitled "Precedence and Order of Evaluation" later in this chapter).

For example, side effects occur in the following function call:

```
add (i + 1, i = j + 2)
```

The arguments of a function call can be evaluated in any order. The expression *i + 1* can be evaluated before *i = j + 2*, or *i = j + 2* can be evaluated before *i + 1*. The result is different in each case.

Sequence Points

Expressions involving assignment, unary "increment," unary "decrement," or calling a function may have consequences incidental to their evaluation (side effects). When a "sequence point" is reached, everything preceding the sequence point, including any side effects, is guaranteed to have been evaluated before evaluation begins on anything following the sequence point.

Certain operators act as sequence points, including the following:

- The logical-AND operator (**&&**)
- The logical-OR operator (||)
- The ternary operator (**?:**)
- The sequential-evaluation operator (**,**)
- The function-call operator (that is, the parentheses following a function name)

Other sequence points include

- the end of a full expression (that is, an expression that is not part of another expression)
- any initializer
- an expression in an expression statement
- the control expressions in selection statements (**if** or **switch**) and iteration statements (**do**, **while**, or **for**)
- the expression in a **return** statement

C Operators

C operators take one operand (unary operators), two operands (binary operators), or three operands (the ternary operator). Assignment operators include both unary or binary operators; the section entitled "Assignment Operators" describes the assignment operators.

Unary operators appear before their operand and associate from right to left. C includes the following unary operators:

- ~ !	Negation and complement operators
* &	Indirection and address-of operators
sizeof	Size operator
+	Unary plus operator

Binary operators associate from left to right. C provides the following binary operators:

* / %	Multiplicative operators
+ –	Additive operators
<< >>	Shift operators
< > <= >= == !=	Relational operators
& | ^	Bitwise operators
&& ||	Logical operators
,	Sequential-evaluation operator

C has one ternary operator: the conditional operator (**? :**). It associates from right to left.

Usual Arithmetic Conversions

Most C operators perform type conversions to bring the operands of an expression to a common type or to extend short values to the integer size used in machine operations. The conversions performed by C operators depend on the specific operator and the type of the operand or operands. However, many operators perform similar conversions on operands of integral and floating types. These conversions are known as "arithmetic conversions" because they apply to the types of values ordinarily used in arithmetic.

The arithmetic conversions summarized in this section are called "usual arithmetic conversions." The discussion of each operator in the following sections specifies whether or not the operator performs the usual arithmetic conversions. It also specifies the additional conversions, if any, the operator performs. This is not a precedence order. It is an outline of an algorithm that is applied to each binary operator in the expression.

The section entitled "Type Conversions" outlines the specific path of each type of conversion. In determining which conversions will actually take place, the following algorithm is applied to each binary operation in the expression:

1. Any operands of **float** type are converted to **double** type.

2. If one operand has **long double** type, the other operand is converted to **long double** type.

3. If one operand has **double** type, the other operand is converted to **double** type.

4. Any operands of **char** or **short** type are converted to **int** type.

5. Any operands of **unsigned char** or **unsigned short** type are converted to **unsigned int** type.

6. If one operand is of **unsigned long** type, the other operand is converted to **unsigned long** type.

7. If one operand is of **long** type, the other operand is converted to **long** type.

8. If one operand is of **unsigned int** type, the other operand is converted to **unsigned int** type.

The following example illustrates the application of the preceding algorithm:

```
long l;
unsigned char uc;
int i;
f( l + uc * i);
```

The preceding example would be converted as follows:

1. *uc* is converted to an **unsigned int** (step 5).
2. *i* is converted to an **unsigned int** (step 8). The multiplication is performed and the result is an **unsigned int.**
3. *uc* * *i* is converted to a **long** (step 7).

The addition is performed and the result is type **long.**

Complement and Unary Plus Operators

The C complement operators are discussed in the following list:

- The arithmetic-negation operator produces the negative (two's complement) of its operand. The operand must be an integral or floating value. This operator performs the usual arithmetic conversions.

~ The bitwise-complement operator produces the bitwise complement of its operand. The operand must be of integral type. This operator performs usual arithmetic conversions; the result has the type of the operand after conversion.

! The logical-NOT operator produces the value 0 if its operand is true (nonzero) and the value 1 if its operand is false (0). The result has **int** type. The operand must be an integral, floating, or pointer value.

+ The unary plus operator preceding a parenthesized expression forces the grouping of the enclosed operations. It is used with expressions involving more than one associative or commutative binary operator.

Note

The unary plus operator (+) is implemented syntactically in Microsoft C, but has no semantics of any type associated with it.

Example 1

In this example, the new value of *x* is the negative of 987, or –987.

```
short x = 987;
    x = -x;
```

Example 2

In this example, the new value assigned to *y* is the one's complement of the unsigned value 0xaaaa, or 0x5555.

```
unsigned short y = 0xaaaa;
    y = ~y;
```

Example 3

In this example, if *x* is greater than or equal to *y*, the result of the expression is 1 (true). If *x* is less than *y*, the result is 0 (false).

```
if ( !(x < y));
```

Indirection and Address-of Operators

The C indirection and address-of operators are discussed in the following list:

- The indirection operator accesses a value indirectly, through a pointer. The operand must be a pointer value. The result of the operation is the value addressed by the operand; that is, the value at the address specified by the operand. The type of the result is the type that the operand addresses. If the pointer value is invalid, the result is undefined. The specific conditions that invalidate a pointer value are implementation-defined. The following list includes some of the most common:

— The pointer is a null pointer.

— The pointer specifies the address of a local item that is not active at the time of the reference.

— The pointer specifies an address that is inappropriately aligned for the type of the object pointed to.

— The pointer specifies an address not used by the executing program.

- The address-of operator gives the address of its operand. The operand can be any value that is a valid left-hand value of an assignment operation. A function designator or array name can also be the operand of the address-of operator, although in these cases the operator is superfluous since function designators and array names are addresses. (Assignment operations are discussed in the section entitled "Assignment Operators" later in this chapter.) The result of the address operation is a pointer to the operand. The type addressed by the pointer is the type of the operand.

You cannot apply the address-of operator to a bitfield member of a structure (described in the section entitled "Structure Declarations" in Chapter 4) or to an identifier declared with the **register** storage-class specifier.

Examples 1 through 4 use the following declarations:

```
int *pa, x;
int a[20];
double d;
```

Example 1

In this example, the address-of operator (**&**) takes the address of the sixth element of the array *a*. The result is stored in the pointer variable *pa*.

```
pa = &a[5];
```

Example 2

In this example the indirection operator (*) is used to access the **int** value at the address stored in *pa*. The value is assigned to the integer variable *x*.

```
x = *pa;
```

Example 3

In this example , the word *True* would be printed. This example demonstrates that the result of applying the indirection operator to the address of *x* is the same as *x*.

```
if (x == *&x)
    printf("True\n");
```

Example 4

This example demonstrates an appropriate application of the rule shown in Example 3. First the address of *x* is converted by a type cast to a pointer to a **double** type; then the indirection operator is applied to give a result of type **double**.

```
d = *(double *)(&x);
```

Example 5

In this example, the function *roundup* is declared, and then two pointers to *roundup* are declared and initialized. The first pointer *proundup* is initialized using only the name of the function, while the second, *pround*, uses the address-of operator in the initialization. The initializations are equal.


```
int roundup() ;

int (*proundup) = roundup;
int (*pround) = &roundup;
```

The sizeof Operator

The **sizeof** operator gives the amount of storage, in bytes, associated with an identifier or a type. This operator lets you avoid specifying machine-dependent data sizes in your programs.

A **sizeof** expression has the form

sizeof *expression*

An *expression* is either an identifier or a type-cast expression (that is, a type specifier enclosed in parentheses). If *expression* is a type-cast expression, it cannot be **void**. If it is an identifier, it cannot represent a bitfield object or a function designator.

When you apply the **sizeof** operator to an array identifier, the result is the size of the entire array rather than the size of the pointer represented by the array identifier.

When you apply the **sizeof** operator to a structure or union type name, or to an identifier of structure or union type, the result is the actual size of the structure or union. This size may include internal and trailing padding used to align the members of the structure or union on memory boundaries. Thus, the result may not correspond to the size calculated by adding up the storage requirements of the individual members.

Example 1

This example uses the **sizeof** operator to pass the size of an **int**, which varies among machines, as an argument to a function named *calloc*. The *buffer* stores the value returned by the function.

```
buffer = calloc(100, sizeof (int) );
```

Example 2

In this example, *strings* is an array of pointers to **char**. The number of pointers is the number of elements in the array, but is not specified. It is easy to determine the number of pointers by using the **sizeof** operator to calculate the number of elements in the array. The **const** integer value *string_no* is initialized to this number. Because it is a **const** value, *string_no* cannot be modified.

```
static char *strings[] ={
                        "this is string one",
                        "this is string two",
                        "this is string three",
                       };
const int string_no = (sizeof strings)/(sizeof strings[0]);
```

Multiplicative Operators

The multiplicative operators perform multiplication (*), division (/), and remainder (%) operations. The operands of the remainder operator (%) must be integral. The multiplication (*) and division (/) operators can take integral- or floating-type operands; the types of the operands can be different.

The multiplicative operators perform the usual arithmetic conversions on the operands. The type of the result is the type of the operands after conversion.

Note

Since the conversions performed by the multiplicative operators do not provide for overflow or underflow conditions, information may be lost if the result of a multiplicative operation cannot be represented in the type of the operands after conversion.

The C multiplicative operators are described as follows:

* The multiplication operator causes its two operands to be multiplied.

/ The division operator causes the first operand to be divided by the second. If two integer operands are divided and the result is not an integer, it is truncated according to the following rules:

- If both operands are positive or unsigned, the result is truncated toward 0.
- If either operand is negative, the direction of truncation of the result (either toward 0 or away from 0) is defined by the implementation. For more information, see your compiler guide.

The result of division by 0 is undefined.

% The result of the remainder operator is the remainder when the first operand is divided by the second. If either or both operands are positive or unsigned, the result is positive. If either operand is negative the sign of the result is defined by the implementation. (For more information, see your compiler guide.) If the right operand is zero, the result is undefined.

These declarations are used for all of the following examples:

```
int i = 10, j = 3, n;
double x = 2.0, y;
```

Example 1

In this example, *x* is multiplied by *i* to give the value 20.0. The result has **double** type.

```
y = x * i;
```

Example 2

In this example, 10 is divided by 3. The result is truncated toward 0, yielding the integer value 3.

```
n = i / j;
```

Example 3

In this example, *n* is assigned the integer remainder, 1, when 10 is divided by 3.

```
n = i % j;
```


Additive Operators

The additive operators perform addition (+) and subtraction (-). The operands can be integral or floating values. Some additive operations can also be performed on pointer values, as outlined under the discussion of each operator.

The additive operators perform the usual arithmetic conversions on integral and floating operands. The type of the result is the type of the operands after conversion. Since the conversions performed by the additive operators do not provide for overflow or underflow conditions, information may be lost if the result of an additive operation cannot be represented in the type of the operands after conversion.

Addition (+)

The addition operator (+) causes its two operands to be added. Both operands can have integral or floating types, or one operand can be a pointer and the other an integer.

When an integer is added to a pointer, the integer value (i) is converted by multiplying it by the size of the value that the pointer addresses. After conversion, the integer value represents i memory positions, where each position has the length specified by the pointer type. When the converted integer value is added to the pointer value, the result is a new pointer value representing the address i positions from the original address. The new pointer value addresses a value of the same type as the original pointer value.

Subtraction (-)

The subtraction operator (-) subtracts the second operand from the first. The following combinations of operands can be used with this operator:

- Both operands integral or floating type values
- Both operands pointer values to the same type
- The first operand a pointer value and the second operand an integer

When two pointers are subtracted, the difference is converted to a signed integral value by dividing the difference by the size of a value of the type that the pointers address. The result represents the number of memory positions of that type between the two addresses. The result is only guaranteed to be meaningful for two elements of the same array, as discussed in "Pointer Arithmetic," later in this section.

When an integer value is subtracted from a pointer value, the subtraction operator converts the integer value (i) by multiplying it by the size of the value that the pointer addresses. After conversion, the integer value represents i memory positions, where each position has the length specified by the pointer type. When the converted integer value is subtracted from the pointer value, the result is the memory address i positions before the original address. The new pointer points to a value of the type addressed by the original pointer value.

Pointer Arithmetic

Additive operations involving a pointer and an integer give meaningful results only if the pointer operand addresses an array member and the integer value produces an offset within the bounds of the same array. When the integer value is converted to an address offset, the compiler assumes that only memory positions of the same size lie between the original address and the address plus the offset.

This assumption is valid for array members. By definition, an array is a series of values of the same type; its elements reside in contiguous memory locations. However, storage for any types except array elements is not

guaranteed to be completely filled. That is, blanks may appear between memory positions, even positions of the same type. Therefore, the results of adding to or subtracting from the addresses of any values but array elements are undefined.

Similarly, when two pointer values are subtracted, the conversion assumes that only values of the same type, with no blanks, lie between the addresses given by the operands.

On machines with segmented architecture (such as the 8086/8088), additive operations between pointer and integer values may not be valid in some cases. For example, an operation may result in an address that is outside the bounds of an array. See your compiler guide for more information on memory models.

The following declarations are used for both examples:

```
int i = 4, j;
float x[10];
float *px;
```

Example 1

In this example, the value of *i* is multiplied by the length of a **float** and added to *&x[4]*. The resulting pointer value is the address of *x[8]*.

```
px = &x[4] + i;  /* equivalent to px = &x[4+i]; */
```

Example 2

In this example, the address of the third element of *x* (given by *x[i–2]*) is subtracted from the address of the fifth element of *x* (given by *x[i]*). The difference is divided by the length of a **float**; the result is the integer value 2.

```
j = &x[i] - &x[i-2];
```

Shift Operators

The shift operators shift their first operand left (<<) or right (>>) by the number of positions the second operand specifies. Both operands must be integral values. These operators perform the usual arithmetic conversions; the type of the result is the type of the left operand after conversion.

For leftward shifts, the vacated right bits are set to 0. For rightward shifts, the vacated left bits are filled based on the type of the first operand after

conversion. If the type is **unsigned**, they are set to 0. Otherwise, they are filled with copies of the sign bit.

The result of a shift operation is undefined if the second operand is negative.

Since the conversions performed by the shift operators do not provide for overflow or underflow conditions, information may be lost if the result of a shift operation cannot be represented in the type of the first operand after conversion.

Example

```
unsigned int x, y, z;

x = 0x00aa;
y = 0x5500;

z = (x << 8) + (y >> 8);
```

In this example, *x* is shifted left eight positions and *y* is shifted right eight positions. The shifted values are added, giving *0xaa55*, and assigned to *z*.

Relational Operators

The binary relational operators compare their first operand to their second operand to test the validity of the specified relationship. The result of a relational expression is 1 if the tested relationship is true and 0 if it is false. The type of the result is **int**.

The relational operators test the following relationships:

<	First operand less than second operand
>	First operand greater than second operand
<=	First operand less than or equal to second operand
>=	First operand greater than or equal to second operand
==	First operand equal to second operand
!=	First operand not equal to second operand

The operands can have integral, floating, or pointer type. The types of the operands can be different. Relational operators perform the usual

arithmetic conversions on integral and floating type operands. In addition, you can use the following combinations of operand types with relational operators:

- Both operands of any relational operator can be pointers to the same type. For the equality (==) and inequality (!=) operators, the result of the comparison indicates whether or not the two pointers address the same memory location. For the other relational operators (<, >, <=, and >=), the result of the comparison indicates the relative position of two memory addresses.

  Since the address of a given value is arbitrary, comparisons between the addresses of two unrelated values are generally meaningless. However, comparisons between the addresses of different elements of the same array can be useful, since array elements are guaranteed to be stored in order from the first element to the last. The address of the first array element is "less than" the address of the last element.

- A pointer value can be compared to the constant value 0 for equality (==) or inequality (!=). A pointer with a value of 0, called a "null" pointer, does not point to a memory location.

Example 1

Because *x* and *y* are equal, the expression in Example 1 yields the value 0.

```
int x = 0, y = 0;
x < y
```

Example 2

The fragment in Example 2 initializes each element of *array* to a null character constant.

```
char array[10] ;
char *p ;

  for (p = array; p < &array[10]; p++)
      *p = '\0' ;
```

Example 3

Example 3 declares an enumeration variable named *col* with the tag *color*. At any time, the variable may contain an integer value of 0, 1, or 2, which represents one of the elements of the enumeration set *color*: the color red, white, or green, respectively. If *col* contains 0 when the **if** statement is executed, any statements depending on the **if** will be executed.

```
enum color {red, white, green} col;
      .
      .
      .
      if (col == red)
      .
      .
      .
```

Bitwise Operators

The bitwise operators perform bitwise-AND (&), inclusive-OR (/), and exclusive-OR (^) operations. The operands of bitwise operators must have integral types, but their types can be different. These operators perform the usual arithmetic conversions; the type of the result is the type of the operands after conversion.

The C bitwise operators are described as follows:

&	The bitwise-AND operator compares each bit of its first operand to the corresponding bit of its second operand. If both bits are 1, the corresponding result bit is set to 1. Otherwise, the corresponding result bit is set to 0.
|	The bitwise-inclusive-OR operator compares each bit of its first operand to the corresponding bit of its second operand. If either bit is 1, the corresponding result bit is set to 1. Otherwise, the corresponding result bit is set to 0.
^	The bitwise-exclusive-OR operator compares each bit of its first operand to the corresponding bit of its second operand. If one bit is 0 and the other bit is 1, the corresponding result bit is set to 1. Otherwise, the corresponding result bit is set to 0.

The following declarations are used for these examples:

```
short i = 0xab00;
short j = 0xabcd;
short n;
```

Example 1

The result assigned to *n* in Example 1 is the same as *i* (0xab00 hexadecimal).

```
n = i & j;
```

Example 2

The bitwise-inclusive OR in Example 2 results in the value 0xabcd (hexadecimal).

```
n = i | j;
```

Example 3

The bitwise-exclusive OR in Example 3 produces 0xcd (hexadecimal).

```
n = i ^ j;
```

Logical Operators

The logical operators perform logical-AND (**&&**) and logical-OR (//) operations. The operands of the logical operators must have integral, floating, or pointer type. The types of the operands can be different.

The operands of logical-AND and logical-OR expressions are evaluated from left to right. If the value of the first operand is sufficient to determine the result of the operation, the second operand is not evaluated. There is a sequence point after the first operand.

Logical operators do not perform the usual arithmetic conversions. Instead, they evaluate each operand in terms of its equivalence to 0.

The result of a logical operation is either 0 or 1. The result's type is **int**.

The C logical operators are described as follows:

&& The logical-AND operator produces the value 1 if both operands have nonzero values. If either operand is equal to 0, the result is 0. If the first operand of a logical-AND operation is equal to 0, the second operand is not evaluated.

|| The logical-OR operator performs an inclusive-OR operation on its operands. The result is 0 if both operands have 0 values. If either operand has a nonzero value, the result is 1. If the first operand of a logical-OR operation has a nonzero value, the second operand is not evaluated.

The following examples use these declarations:

```
int w, x, y, z;
```

Example 1

In this example, the *printf* function is called to print a message if *x* is less than *y* and *y* is less than *z*. If *x* is greater than *y*, the second operand (*y* < *z*) is not evaluated and nothing is printed. Note that this could cause problems in cases where the second operand has side effects that are being relied on for some other reason.

```
if (x < y && y < z)
        printf ("x is less than z\n");
```

Example 2

In this example, if *x* is equal to either *w*, *y*, or *z*, the second argument to the *printf* function evaluates to true and the value 1 is printed. Otherwise, it evaluates to false and the value 0 is printed. As soon as one of the conditions evaluates to true, evaluation ceases.

```
printf ("%d" , (x==w || x==y || x==z));
```


Sequential-Evaluation Operator

The sequential-evaluation operator evaluates its two operands sequentially from left to right. There is a sequence point after the first operand. The result of the operation has the same value and type as the right operand. Each operand can be of any type. The sequential-evaluation operator does not perform type conversions between its operands.

The sequential-evaluation operator, also called the "comma operator," is typically used to evaluate two or more expressions in contexts where only one expression is allowed.

Commas can be used as separators in some contexts. However, you must be careful not to confuse the use of the comma as a separator with its use as an operator; the two uses are completely different.

Example 1

In this example, each operand of the **for** statement's third expression is evaluated independently. The left operand, *i* += *i*, is evaluated first; then the right operand, *j*– –, is evaluated.

```
for ( i = j = 1; i + j < 20; i += i, j--);
```

Example 2

In the function call to *func_one*, three arguments, separated by commas, are passed: *x*, *y* + 2, and *z*.

In the function call to *func_two*, parentheses force the compiler to interpret the first comma as the sequential-evaluation operator. This function call passes two arguments to *func_two*. The first argument is the result of the sequential-evaluation operation *(x--, y + 2)*, which has the value and type of the expression *y* + 2; the second argument is *z*.

```
func_one(x, y + 2, z);
func_two((x--, y + 2), z);
```

Conditional Operator

C has one ternary operator: the conditional operator (**? :**). It has the following form:

operand1 **?** *operand2* **:** *operand3*

The expression *operand1* must have integral, floating, or pointer type. It is evaluated in terms of its equivalence to 0. A sequence point follows *operand1*. Evaluation proceeds as follows:

- If *operand1* does not evaluate to 0, *operand2* is evaluated, and the result of the expression is the value of *operand2*.
- If *operand1* evaluates to 0, *operand3* is evaluated, and the result of the expression is the value of *operand3*.

Note that either *operand2* or *operand3* is evaluated, but not both.

The type of the result of a conditional operation depends on the type of *operand2* or *operand3*, as follows:

- If *operand2* or *operand3* has integral or floating type (their types can be different), the operator performs the usual arithmetic conversions. The type of the result is the type of the operands after conversion.
- If both *operand2* and *operand3* have the same structure, union, or pointer type, the type of the result is the same structure, union, or pointer type.

- If both operands have type **void**, the result has type **void**.
- If either operand is a pointer to an object of any type, and the other operand is a pointer to **void**, the pointer to the object is converted to a pointer to **void** and the result is a pointer to **void**.
- If either *operand2* or *operand3* is a pointer and the other operand is a constant expression with the value 0, the type of the result is the pointer type.

Example 1

This example assigns the absolute value of *i* to *j*. If *i* is less than 0, *-i* is assigned to *j*. If *i* is greater than or equal to 0, *i* is assigned to *j*.

```
j = (i < 0) ? (-i) : (i);
```

Example 2

In this example, two functions, *f1* and *f2*, and two variables, *x* and *y*, are declared. Later in the program, if the two variables have the same value, the function *f1* is called. Otherwise, *f2* is called.

```
void f1(void) ;
void f2(void) ;
int x ;
int y ;
    .
    .
    .
(x==y) ? (f1()) : (f2()) ;
```

Assignment Operators

The assignment operators in C can both transform and assign values in a single operation. Using a compound-assignment operator to replace two separate operations can make your programs smaller and more efficient.

C provides the following assignment operators:

++	Unary increment
—	Unary decrement
=	Simple assignment
*=	Multiplication assignment
/=	Division assignment
%=	Remainder assignment
+=	Addition assignment
–=	Subtraction assignment
<<=	Left-shift assignment
>>=	Right-shift assignment
&=	Bitwise-AND assignment
|=	Bitwise-inclusive-OR assignment
^=	Bitwise-exclusive-OR assignment

In assignment, the type of the right-hand value is converted to the type of the left-hand value. The specific conversion path, which depends on the two types, is outlined in detail in the section entitled "Assignment Conversions" to be found in the section entitled "Type Conversions" later in this chapter.

Lvalue Expressions

An assignment operation assigns the value of the right-hand operand to the storage location named by the left-hand operand. Therefore, the left-hand operand of an assignment operation (or the single operand of a unary assignment expression) must be an expression that refers to a modifiable memory location.

Expressions that refer to memory locations are called "lvalue expressions." Expressions referring to modifiable locations are "modifiable lvalues." One example of a modifiable lvalue expression is a variable name declared without the **const** specifier (non-**const**). The name of the variable denotes a storage location, while the value of the variable is the value stored at that location.

The following C expressions may be lvalue expressions:

- An identifier of integral, floating, pointer, structure, or union type
- A subscript ([ ]) expression that does not evaluate to an array or a function
- A member-selection expression (–> or .), if the selected member is one of the aforementioned expressions
- A unary-indirection (*) expression that does not refer to an array or function
- An lvalue expression in parentheses
- A **const** object (a nonmodifiable lvalue)

Note

Microsoft C includes an extension to the ANSI C standard allowing a type cast to a pointer type as an lvalue expression, as long as the size of the object does not change. The following example illustrates this feature:

```
char *p ;
int  i;
long l;

(long *) p = &l ;          /* legal cast */
(long) i = l ;             /* illegal cast */
```

See your compiler guide for information on enabling and disabling the Microsoft extensions.

5

Unary Increment and Decrement

The unary assignment operators (++ and --) increment and decrement their operand, respectively. The operand must have integral, floating, or pointer type and must be a modifiable (non-**const**) lvalue expression.

An operand of integral or floating type is incremented or decremented by the integer value 1. The type of the result is the same as the operand type. An operand of pointer type is incremented or decremented by the size of the object it addresses.
An incremented pointer points to the next object; a decremented pointer points to the previous object.

An increment (++) or decrement (--) operator can appear either before or after its operand, with the following results:

- When the operator appears before its operand, the operand is incremented or decremented and its new value is the result of the expression.

- When the operator appears after its operand, the immediate result of the expression is the value of the operand *before* it is incremented or decremented. After that result is applied in context, the operand is incremented or decremented.

Example 1

In this example, the variable *pos* is compared to 0, then incremented. If *pos* was positive before being incremented, the next statement is executed. First, the value of *q* is assigned to *p*. Then *q* and *p* are incremented.

```
if (pos++ > 0)
        *p++ = *q++;
```

Example 2

In this example, the variable *i* is decremented before it is used as a subscript to *line*.

```
if (line[--i] != '\n')
        return;
```

Simple Assignment

The simple-assignment operator assigns its right operand to its left operand. The conversion rules for assignment apply

Example

In this example, the value of *y* is converted to **double** type and assigned to *x*:

```
double x;
int y;

x = y;
```

Compound Assignment

The compound-assignment operators combine the simple-assignment operator with another binary operator. Compound-assignment operators perform the operation specified by the additional operator, then assign the result to the left operand. For example, a compound-assignment expression such as

expression1 += *expression2*

can be understood as

expression1 = *expression1* + *expression2*

However, the compound-assignment expression is not equivalent to the expanded version because the compound-assignment expression evaluates *expression1* only once, while the expanded version evaluates *expression1* twice: in the addition operation and in the assignment operation.

The operands of a compound-assignment operator must be of integral or floating type. Each compound-assignment operator performs the conversions that the corresponding binary operator performs and restricts the types of its operands accordingly. The addition-assignment (+=) and subtraction-assignment (-=) operators may also have a left operand of pointer type, in which case the right-hand operand must be of integral type. The result of a compound-assignment operation has the value and type of the left operand.

Example

In this example, a bitwise-inclusive-AND operation is performed on *n* and *MASK*, and the result is assigned to *n*. The manifest constant *MASK* is defined with a **#define** preprocessor directive (this directive is discussed in the section entitled "Manifest Constants and Macros" in Chapter 8).

```
#define MASK   0xff00

n &= MASK;
```

Precedence and Order of Evaluation

The precedence and associativity of C operators affect the grouping and evaluation of operands in expressions. An operator's precedence is meaningful only if other operators with higher or lower precedence are present. Expressions with higher-precedence operators are evaluated first.

Table 5.1 summarizes the precedence and associativity of C operators, listing them in order of precedence from highest to lowest. Where several operators appear together in a line or large brace, they have equal precedence and are evaluated according to their associativity.

Table 5.1

Precedence and Associativity of C Operators

Symbol[a]	Type of Operation	Associativity
( ) [ ] . –>	Expression	Left to right
– ~ ! * & ++ -- **sizeof** *casts*	Unary[b]	Right to left
* / %	Multiplicative	Left to right
+ –	Additive	Left to right
<< >>	Shift	Left to right
< > <= >=	Relational (inequality)	Left to right
== !=	Relational (equality)	Left to right
&	Bitwise AND	Left to right
^	Bitwise-exclusive OR	Left to right
|	Bitwise-inclusive OR	Left to right
&&	Logical AND	Left to right
||	Logical OR	Left to right
? :	Conditional	Right to left

(*Continued on next page*)

Table 5.1
Precedence and Associativity of C Operators (*Continued*)

Symbol[a]	Type of Operation	Associativity
= *= /= %= += -= <<= >>= &= |= ^=	Simple and compound assignment[c]	Right to left
,	Sequential evaluation	Left to right

[a] Operators are listed in descending order of precedence. If several operators appear in the same line or in a large brace, they have equal precedence.

[b] All unary operators have equal precedence.

[c] All simple and compound-assignment operators have equal precedence.

5

As Table 5.1 shows, operands consisting of a constant, an identifier, a string, a function call, a subscript expression, a member-selection expression, or a parenthetical expression have the highest precedence and associate from left to right. Type-cast conversions have the same precedence and associativity as the unary operators.

An expression can contain several operators with equal precedence. When several such operators appear at the same level in an expression, evaluation proceeds according to the associativity of the operator, either from right to left or from left to right. The direction of evaluation does not affect the results of expressions that include more than one multiplication (*), addition (+), or binary-bitwise (& | ^) operator at the same level. The compiler is free to evaluate such expressions in any order, even when parentheses in the expression appear to specify a particular order. Only the sequential-evaluation (,), logical-AND (&&), logical-OR (||), ternary (?:) and function-call operators constitute sequence points, and therefore guarantee a particular order of evaluation for their operands. The function-call operator is the set of parentheses following the function identifier. The sequential-evaluation operator (,) is guaranteed to evaluate its operands from left to right. (Note that the comma separating arguments in a function call is not the same as the sequential-evaluation operator and does not provide any such guarantee.) Sequence points are discussed in the section entitled "Precedence and Order of Evaluation" later in this chapter.

The unary plus operator (+) is intended to force specific groupings in certain situations. It is implemented syntactically, but not semantically. For further information on unary operators, see the section earlier in this chapter entitled "Complement and Unary Plus Operators".

Logical operators also guarantee evaluation of their operands from left to right. However, they evaluate the smallest number of operands needed to determine the result of the expression. Thus, some operands of the expression may not be evaluated. For example, in the expression *x && y++*, the second operand, *y++*, is evaluated only if *x* is true (nonzero). Thus, *y* is not incremented if *x* is false (0).

The following list shows the default groupings for several sample expressions:

a & b || c *(a & b) || c*

a = b || c *a = (b || c)*

q && r || s-- *(q && r) || s--*

In the first expression, the bitwise-AND operator (**&**) has higher precedence than the logical-OR operator (||), so *a & b* forms the first operand of the logical-OR operation.

In the second expression, the logical-OR operator (||) has higher precedence than the simple-assignment operator (=), so *b || c* is grouped as the right-hand operand in the assignment. Note that the value assigned to *a* is either 0 or 1.

The third expression shows a correctly formed expression that may produce an unexpected result. The logical-AND operator (**&&**) has higher precedence than the logical-OR operator (||), so *q && r* is grouped as an operand. Since the logical operators guarantee evaluation of operands from left to right, *q && r* is evaluated before *s--*. However, if *q && r* evaluates to a nonzero value, *s--* is not evaluated, and *s* is not decremented. To correct this problem, *s--* should appear as the first operand of the expression, or *s* should be decremented in a separate operation.

The following expression is illegal and produces a diagnostic message at compile time:

p == 0 ? p += 1 : p += 2 *(p == 0 ? p += 1 : p) += 2*

In this expression, the equality operator (==) has the highest precedence, so *p == 0* is grouped as an operand. The ternary operator (**? :**) has the next-highest precedence. Its first operand is *p == 0*, and its second operand is *p += 1*. However, the last operand of the ternary operator is

considered to be *p* rather than *p += 2*, since this occurrence of *p* binds more closely to the ternary operator than it does to the compound assignment operator. A syntax error occurs because *+= 2* does not have a left-hand operand. You should use parentheses to prevent errors of this kind and produce more readable code. For example, you could use parentheses as shown to correct and clarify the preceding example:

```
(p == 0) ? (p += 1) : (p += 2)
```

Type Conversions

Type conversions are performed in the following cases:

- When a value of one type is assigned to a variable of a different type
- When a value of one type is explicitly cast to a different type
- When an operator converts the type of its operand or operands before performing an operation
- When a value is passed as an argument to a function

The rules for each kind of conversion are outlined later in this section.

Assignment Conversions

In assignment operations, the type of the value being assigned is converted to the type of the variable that receives the assignment. C allows conversions by assignment between integral and floating types, even if information is lost in the conversion. The conversion methods used depend on the types involved in the assignment, as described elsewhere in this section as well as in the section named "Usual Arithmetic Conversion" to be found in the section entitled "C Operators" earlier in this chapter.

Conversions from Signed Integral Types

A signed integer is converted to a shorter signed integer by truncating the high-order bits, and to a longer signed integer by sign extension.

When a signed integer is converted to an unsigned integer, the signed integer is converted to the size of the unsigned integer, and the result is interpreted as an unsigned value.

No information is lost when a signed integer is converted to a floating value, except that some precision may be lost when a **long int** or **unsigned long int** value is converted to a **float** value.

Table 5.2 summarizes conversions from signed integral types. This table assumes that the **char** type is signed by default. If you use a compile-time option to change the default for the **char** type to unsigned, the conversions given in Table 5.3 for the **unsigned char** type apply instead of the conversions in Table 5.2.

Table 5.2

Conversions from Signed Integral Types

From	To	Method
char[a]	**short**	Sign extend
char	**long**	Sign extend
char	**unsigned char**	Preserve pattern; high-order bit loses function as sign bit
char	**unsigned short**	Sign extend to **short**; convert **short** to **unsigned short**
char	**unsigned long**	Sign extend to **long**; convert **long** to **unsigned long**
char	**float**	Sign extend to **long**; convert **long** to **float**
char	**double**	Sign extend to **long**; convert **long** to **double**
char	**long double**	Sign extend to **long**; convert **long** to **double**
short	**char**	Preserve low-order byte
short	**long**	Sign extend
short	**unsigned char**	Preserve low-order byte
short	**unsigned short**	Preserve bit pattern; high-order bit loses function as sign bit
short	**unsigned long**	Sign extend to **long**; convert **long** to **unsigned long**
short	**float**	Sign extend to **long**; convert **long** to **float**

(*Continued on next page*)

Table 5.2
Conversions from Signed Integral Types (*Continued*)

From	To	Method
short	**double**	Sign extend to **long**; convert **long** to **double**
short	**long double**	Sign extend to **long**; convert **long** to **double**
long	**char**	Preserve low-order byte
long	**short**	Preserve low-order word
long	**unsigned char**	Preserve low-order byte
long	**unsigned short**	Preserve low-order word
long	**unsigned long**	Preserve bit pattern; high-order bit loses function as sign bit
long	**float**	Represent as **float**. If **long** cannot be represented exactly, some precision is lost.
long	**double**	Represent as **double**. If **long** cannot be represented exactly as a **double**, some precision is lost.
long	**long double**	Represent as **double**. If **long** cannot be represented exactly as a **double**, some precision is lost.

[a] All **char** entries assume that the **char** type is signed by default.

Note

The **int** type is equivalent to either the **short** type or the **long** type, depending on the implementation. Conversion of an **int** value proceeds the same as for a **short** or a **long**, whichever is appropriate.

Conversions from Unsigned Integral Types

An unsigned integer is converted to a shorter unsigned or signed integer by truncating the high-order bits, or to a longer unsigned or signed integer by zero extending.

When an unsigned integer is converted to a signed integer of the same size, the bit pattern does not change. However, the value it represents changes if the sign bit is set.

Unsigned integer values are converted to floating values by first converting the unsigned integer value to a signed **long** value, then converting that signed **long** value to a floating value.

Table 5.3 summarizes conversions from unsigned integral types.

Table 5.3
Conversions from Unsigned Integral Types

From	To	Method
unsigned char	**char**	Preserve bit pattern; high-order bi becomes sign bit
unsigned char	**short**	Zero extend
unsigned char	**long**	Zero extend
unsigned char	**unsigned short**	Zero extend
unsigned char	**unsigned long**	Zero extend
unsigned char	**float**	Convert to **long**; convert **long** t **float**
unsigned char	**double**	Convert to **long**; convert **long** t **double**
unsigned char	**long double**	Convert to **long**; convert **long** t **double**
unsigned short	**char**	Preserve low-order byte
unsigned short	**short**	Preserve bit pattern; high-order bi becomes sign bit

(*Continued on next page*

Table 5.3
Conversions from Unsigned Integral Types *(Continued)*

From	To	Method
unsigned short	**long**	Zero extend
unsigned short	**unsigned char**	Preserve low-order byte
unsigned short	**unsigned long**	Zero extend
unsigned short	**float**	Convert to **long**; convert **long** to **float**
unsigned short	**double**	Convert to **long**; convert **long** to **double**
unsigned short	**long double**	Convert to **long**; convert **long** to **double**
unsigned long	**char**	Preserve low-order byte
unsigned long	**short**	Preserve low-order word
unsigned long	**long**	Preserve bit pattern; high-order bit becomes sign bit
unsigned long	**unsigned char**	Preserve low-order byte
unsigned long	**unsigned short**	Preserve low-order word
unsigned long	**float**	Convert to **long**; convert **long** to **float**
unsigned long	**double**	Convert to **long**; convert **long** to **double**
unsigned long	**long double**	Convert to **long**; convert **long** to **double**

Note

The **unsigned int** type is equivalent either to the **unsigned short** type or to the **unsigned long** type, depending on the implementation. Conversion of an **unsigned int** value proceeds in the same way as conversion of an **unsigned short** or an **unsigned long**, whichever is appropriate.

Conversions from **unsigned long** values to **float**, **double**, or **long double** are not accurate if the value being converted is larger than the maximum positive **long** value.

Conversions from Floating-Point Types

A **float** value converted to a **double** value undergoes no change in value A **double** value converted to a **float** value is represented exactly, if possible. Precision may be lost if the value cannot be represented exactly.

A floating value is converted to an integral value by first converting to a **long**, then from the **long** value to the specific integral value, as described in Table 5.4. The decimal portion of the floating value is discarded in the conversion to a **long**; if the result is still too large to fit into a **long**, the result of the conversion is undefined.

Table 5.4 summarizes conversions from floating types.

Table 5.4

Conversions from Floating-Point Types

From	To	Method
float	**char**	Convert to **long**; convert **long** to **char**
float	**short**	Convert to **long**; convert **long** to **short**
float	**long**	Truncate at decimal point. If result is too large to be represented as **long**, result is undefined.

(*Continued on next page*)

Table 5.4
Conversions from Floating-Point Types (*Continued*)

From	To	Method
float	**unsigned short**	Convert to **long**; convert **long** to **unsigned short**
float	**unsigned long**	Convert to **long**; convert **long** to **unsigned long**
float	**double**	Change internal representation
float	**long double**	Change internal representation
double	**char**	Convert to **float**; convert **float** to **char**
double	**short**	Convert to **float**; convert **float** to **short**
double	**long**	Truncate at decimal point. If result is too large to be represented as **long**, result is undefined.
double	**unsigned short**	Convert to **long**; convert **long** to **unsigned short**
double	**unsigned long**	Convert to **long**; convert **long** to **unsigned long**
double	**float**	Represent as a **float.** If **double** value cannot be represented exactly as **float**, loss of precision occurs. If value is too large to be represented as **float**, the result is undefined.
long double	**char**	Convert to **float**; convert **float** to **char**
long double	**short**	Convert to **float**; convert **float** to **short**
long double	**long**	Truncate at decimal point. If result is too large to be represented as **long**, result is undefined.
long double	**unsigned short**	Convert to **long**; convert **long** to **unsigned short**

(*Continued on next page*)

Table 5.4
Conversions from Floating-Point Types (*Continued*)

From	To	Method
long double	**unsigned long**	Convert to **long**; convert **long** to **unsigned long**
long double	**float**	Represent as a **float**. If **double** value cannot be represented exactly as **float**, loss of precision occurs. If value is too large to be represented as **float**, the result is undefined.
long double	**double**	The **long double** value is treated as **double**.

Note

Conversions from **float**, **double**, or **long double** values to **unsigned long** are not accurate if the value being converted is larger than the maximum positive **long** value.

Conversions to and from Pointer Types

A pointer to one type of value can be converted to a pointer to a different type. However, the result may be undefined because of the alignment requirements and sizes of different types in storage.

A pointer to **void** may be converted to or from a pointer to any type, without restriction.

In some implementations, you can use the special keywords **near**, **far**, and **huge** to change the size of pointers within a program. The conversion path depends on your implementation. For example, on an 8086 processor, the compiler might use a segment-register value to convert a 16-bit pointer to a 32-bit pointer. For information about pointer conversions, see your compiler guide.

A pointer value can also be converted to an integral value. The conversion path depends on the size of the pointer and the size of the integral type, according to the following rules:

- If the size of the pointer is greater than or equal to the size of the integral type, the pointer behaves like an unsigned value in the conversion, except that it cannot be converted to a floating value.

- If the pointer is smaller than the integral type, the pointer is first converted to a pointer with the same size as the integral type, then converted to the integral type. The implementation determines how a pointer is converted to a longer pointer; for information about pointer conversions, see your compiler guide.

Conversely, an integral type can be converted to a pointer type according to the following rules:

- If the integral type is the same size as the pointer type, the conversion simply causes the integral value to be treated as a pointer (an unsigned integer).

- If the size of the integral type is different from the size of the pointer type, the integral type is first converted to the size of the pointer, using the conversion paths given in Tables 5.2 and 5.3. It is then treated as a pointer value.

If the special keywords **near**, **far**, and **huge** are implemented, implicit conversions may be made on pointer values. In particular, the compiler may make assumptions about the default size of pointers and convert passed pointer values accordingly, unless a forward declaration is present to override the implicit conversion. For information about pointer conversions, see your compiler guide.

Conversions from Other Types

Since an **enum** value is an **int** value by definition, conversions to and from an **enum** value are the same as those for the **int** type. An **int** is equivalent to either a **short** or a **long**, depending on the implementation.

No conversions between structure or union types are allowed.

The **void** type has no value, by definition. Therefore, it cannot be converted to any other type, and other types cannot be converted to **void** by assignment. However, you can explicitly cast a value to **void** type, as discussed in the next section, "Type-Cast Conversions".

Type-Cast Conversions

You can use type casts to explicitly convert types. A type cast has the form

(type-name)operand

where *type-name* is a type and *operand* is a value to be converted to that type.

The operand is converted as though it had been assigned to a variable of *type-name* type. The conversion rules for assignments (outlined in the section entitled "Assignment Conversions") apply to type casts as well.

You can use the type name **void** in a cast operation, but you cannot assign the resulting expression to any item.

Operator Conversions

The conversions performed by C operators depend on the operator and on the type of the operand or operands. Many operators perform the usual arithmetic conversions, outlined in the section entitled "Usual Arithmetic Conversions" earlier in this chapter.

C permits some arithmetic with pointers. In pointer arithmetic, integer values are converted to express memory positions. (For more information, see the discussion of additive operators in the section entitled "C Operators" and the discussion of subscript expressions in the section entitled "Introduction" earlier in this chapter.)

Function-Call Conversions

The type of conversion performed on the arguments in a function call depends on the presence of a function prototype (forward declaration) with declared argument types for the called function.

If a function prototype is present and includes declared argument types, the compiler performs type checking. The type-checking process is outlined in detail in the chapter on "Functions."

If no function prototype is present, or if an old-style forward declaration omits the argument-type list, only the usual arithmetic conversions are performed on the arguments in the function call. These conversions are performed independently on each argument in the call. This means that a

float value is converted to a **double**; a **char** or **short** value is converted to an **int**; and an **unsigned char** or **unsigned short** is converted to an **unsigned int**.

If the special keywords **near**, **far**, and **huge** are implemented, implicit conversions can also be made on pointer values passed to functions. You can override these implicit conversions by providing function prototypes to let the compiler perform type checking. For information about pointer conversions, see your compiler guide.

Chapter 6

Statements

Introduction 6-1

The break Statement 6-3

The Compound Statement 6-4

The continue Statement 6-5

The do Statement 6-6

The Expression Statement 6-7

The for Statement 6-9

The goto and Labeled Statements 6-11

The if Statement 6-13

The Null Statement 6-15

The return Statement 6-16

The switch Statement 6-18

The while Statement 6-21

Introduction

The statements of a C program control the flow of program execution. In C, as in other programming languages, several kinds of statements are available to perform loops, to select other statements to be executed, and to transfer control. This chapter describes C statements in alphabetical order, as follows:

break statement	**goto** and labeled statements
compound statement	**if** statement
continue statement	null statement
do statement	**return** statement
expression statement	**switch** statement
for statement	**while** statement

C statements consist of keywords, expressions, and other statements. The following keywords appear in C statements:

break	**default**	**for**	**return**
case	**do**	**goto**	**switch**
continue	**else**	**if**	**while**

The expressions in C statements are the expressions discussed in the "Expressions and Assignments" chapter. Statements appearing within C statements may be any of the statements discussed in this chapter. A statement that forms a component of another statement is called the "body" of the enclosing statement. Frequently the statement body is a "compound" statement: a single statement composed of one or more statements.

The compound statement is delimited by braces ({ }); all other C statements end with a semicolon(;).

Any C statement may begin with an identifying label consisting of a name and a colon. Since only the **goto** statement recognizes statement labels, statement labels are described along with the **goto** statement in the section entitled "The goto and Labeled Statements".

When a C program is executed, its statements are executed in the order in which they appear in the program, except where a statement explicitly transfers control to another location.

The break Statement

Syntax

break;

Execution

The **break** statement terminates the execution of the smallest enclosing **do**, **for**, **switch**, or **while** statement in which it appears. Control passes to the statement that follows the terminated statement. A **break** statement can appear only within a **do**, **for**, **switch**, or **while** statement.

Within nested statements, the **break** statement terminates only the **do**, **for**, **switch**, or **while** statement that immediately encloses it. You can use a **return** or **goto** statement to transfer control out of the nested structure.

Example

This example processes an array of variable-length strings stored in *lines*. The **break** statement causes an exit from the interior **for** loop after the terminating null character (**'\0'**) of each string is found and its position is stored in *lengths[i]*. Control then returns to the outer **for** loop. The variable *i* is incremented and the process is repeated until *i* is greater than or equal to *LENGTH*.


```
for (i = 0; i < LENGTH; i++) {
     for (j = 0; j < WIDTH; j++) {
          if (lines[i][j] == '\0') {
               lengths[i] = j;
               break;
          }
     }
}
```

The Compound Statement

Syntax

{
[*declaration*]
.
.
.
statement
[*statement*]
.
.
.
}

Execution

A compound statement typically appears as the body of another statement, such as the **if** statement. When a compound statement is executed, its statements are executed in the order in which they appear, except where a statement explicitly transfers control to another location. The "Declarations" chapter describes the form and meaning of the declarations that can appear at the head of a compound statement.

Like other C statements, any of the statements in a compound statement can carry a label. Labeled statements are discussed in the section entitled "The goto and Labeled Statements" later in this chapter.

Example

In this example, if *i* is greater than 0, all of the statements in the compound statement are executed in order.

```
if (i > 0) {
     line[i] = x;
     x++;
     i--;
}
```

The continue Statement

Syntax

continue;

Execution

The **continue** statement passes control to the next iteration of the **do**, **for**, or **while** statement in which it appears, bypassing any remaining statements in the **do**, **for**, or **while** statement body. The next iteration of a **do**, **for**, or **while** statement is determined as follows:

- Within a **do** or a **while** statement, the next iteration starts by re-evaluating the expression of the **do** or **while** statement.
- Within a **for** statement, the next iteration starts by evaluating the loop expression of the **for** statement. Then it evaluates the conditional expression and, depending on the result, either terminates or iterates the statement body. (The **for** statement is discussed in the section entitled ''The for Statement'' later in this chaper.)

Example

In this example, the statement body is executed if *i* is greater than 0. First *f(i)* is assigned to *x*; then, if *x* is equal to 1, the **continue** statement is executed. The rest of the statements in the body are ignored, and execution resumes at the top of the loop with the evaluation of *i-- > 0*.

```
while (i-- > 0) {
     x = f(i);
     if (x == 1)
          continue;
     y += x * x;
}
```

The do Statement

Syntax

do
statement
while (*expression*);

Execution

The body of a **do** statement is executed one or more times until *expression* becomes false (0). Execution proceeds as follows:

1. The statement body is executed.

2. The *expression* is evaluated. If *expression* is false, the **do** statement terminates and control passes to the next statement in the program. If *expression* is true (nonzero), the process is repeated, beginning with step 1.

The **do** statement may also terminate when a **break**, **goto**, or **return** statement is executed within the statement body.

Example

In this **do** statement, the two statements *y = f(x);* and *x—;* are executed, regardless of the initial value of *x*. Then *x > 0* is evaluated. If *x* is greater than 0, the statement body is executed again and *x > 0* is reevaluated. The statement body is executed repeatedly as long as *x* remains greater than 0. Execution of the **do** statement terminates when *x* becomes 0 or negative. The body of the loop is executed at least once.

```
do {
      y = f(x);
      x--;
} while (x > 0);
```

The Expression Statement

Syntax

expression;

Execution

When an expression statement is executed, the expression is evaluated according to the rules outlined in the "Expressions and Assignments" chapter.

In C, assignments are expressions. The value of the expression is the value being assigned (sometimes called the "right-hand value").

Function calls are also considered expressions. The value of the expression is the value, if any, returned by the function. If a function returns a value, the expression statement usually includes an assignment to store the returned value when the function is called. The value returned by the function is usually used as an operand in another expression. If the value is to be used more than once, it can be assigned to another variable. If the value is neither used as an operand nor assigned, the function is called but the return value, if any, is not used.

Example 1

In this example, *x* is assigned the value of *y* + *3*.

```
x = (y + 3);
```

Example 2

In this example, *x* is incremented.

```
x++;
```

Example 3

This example shows a function-call expression. The value of the expression, which includes any value returned by the function, is assigned to the variable *z*.

```
z = f(x) + 3;
```

The for Statement

Syntax

for ([*init-expression*]; [*cond-expression*]; [*loop-expression*])
statement

Execution

The body of a **for** statement is executed zero or more times until the optional *cond-expression* becomes false. You can use the optional *init-expression* and *loop-expression* to initialize and change values during the **for** statement's execution.

Execution of a **for** statement proceeds as follows:

1. The *init-expression*, if any, is evaluated.

2. The *cond-expression*, if any, is evaluated. Three results are possible:

   - If *cond-expression* is true (nonzero), *statement* is executed; then *loop-expression*, if any, is evaluated. The process then begins again with the evaluation of *cond-expression*.

   - If *cond-expression* is omitted, *cond-expression* is considered true, and execution proceeds exactly as described for case *a*. A **for** statement without a *cond-expression* argument terminates only when a **break** or **return** statement within the statement body is executed, or when a **goto** (to a labeled statement outside the **for** statement body) is executed.

   - If *cond-expression* is false, execution of the **for** statement terminates and control passes to the next statement in the program.

A **for** statement also terminates when a **break, goto,** or **return** statement within the statement body is executed.

Example

This example counts space (**'\x20'**) and tab (**'\t'**) characters in the array of characters named *line* and replaces each tab character with a space. First *i*, *space*, and *tab* are initialized to 0. Then *i* is compared with the constant *MAX*; if *i* is less than *MAX*, the statement body is executed. Depending on the value of *line [i]*, the body of one or neither of the **if** statements is executed. Then *i* is incremented and tested against *MAX*; the statement body is executed repeatedly as long as *i* is less than *MAX*.

```
for (i = space = tab = 0; i < MAX; i++) {
     if (line[i] == ' ')
          space++;
     if (line[i] == '\t') {
          tab++;
          line[i] = ' ';
     }
}
```

The goto and Labeled Statements

Syntax

goto *name*;
.
.
.
name: *statement*

Execution

The **goto** statement transfers control directly to the statement that has *name* as its label. The labeled statement is executed immediately after the **goto** statement is executed. A statement with the given label must reside in the same function, and the given label can appear before only one statement in the same function.

A statement label is meaningful only to a **goto** statement; in any other context, a labeled statement is executed without regard to the label.

A label name is simply an identifier. (The section entitled "Identifiers" in Chapter 2 describes the rules that govern the construction of identifiers.) Each statement label must be distinct from other statement labels in the same function.

Like other C statements, any of the statements in a compound statement can carry a label. Thus, you can use a **goto** statement to transfer into a compound statement. However, transferring into a compound statement is dangerous when the compound statement includes declarations that initialize variables. Since declarations appear before the executable statements in a compound statement, transferring directly to an executable statement within the compound statement bypasses the initializations. The results are undefined.

Example

In this example, a **goto** statement transfers control to the point labeled *exit* if an error occurs.

```
if (errorcode > 0)
     goto exit;
     .
     .
     .
     exit:
     return (errorcode);
```

The if Statement

Syntax

if (*expression*)
  statement1
[**else**
  statement2]

Execution

The body of an **if** statement is executed selectively, depending on the value of *expression*, described as follows:

1. The *expression* is evaluated.
   - If *expression* is true (nonzero), *statement1* is executed.
   - If *expression* is false, *statement2* is executed.
   - If *expression* is false and the **else** clause is omitted, *statement1* is ignored.
2. Control passes from the **if** statement to the next statement in the program.

Example 1

In this example, the statement *y = x/i;* is executed if *i* is greater than 0. If *i* is less than or equal to 0, *i* is assigned to *x* and *f(x)* is assigned to *y*. Note that the statement forming the **if** clause ends with a semicolon.

```
if (i > 0)
     y = x/i;
else {
     x = i;
     y = f(x);
}
```

Note

C does not offer an "else if" statement, but you can achieve the same effect by nesting **if** statements. An **if** statement can be nested within either the **if** clause or the **else** clause of another **if** statement.

When nesting **if** statements and **else** clauses, use braces to group the statements and clauses into compound statements that clarify your intent. If no braces are present, the compiler resolves ambiguities by pairing each **else** with the most recent **if** lacking an **else**.

Example 2

In this example, the **else** clause is associated with the inner **if** statement. If *i* is less than or equal to 0, no value is assigned to *x*.

```
if (i > 0)              /* Without braces */
     if (j > i)
          x = j;
     else
          x = i;
```

Example 3

In this example, the braces surrounding the inner **if** statement make the **else** clause part of the outer **if** statement. If *i* is less than or equal to 0, *i* is assigned to *x*.

```
if (i > 0) {            /* With braces */
     if (j > i)
          x = j;
}
else
     x = i;
```

The Null Statement

Syntax

```
;
```

Execution

A ''null statement'' is a statement containing only a semicolon; it may appear wherever a statement is expected. Nothing happens when a null statement is executed.

Statements such as **do**, **for**, **if**, and **while** require that an executable statement appear as the statement body. The null statement satisfies the syntax requirement in cases that do not need a substantive statement body.

As with any other C statement, you can include a label before a null statement. To label an item that is not a statement, such as the closing brace of a compound statement, you can label a null statement and insert it immediately before the item to get the same effect.

Example

In this example, the loop expression of the **for** statement *line[i++]=0* initializes the first 10 elements of *line* to 0. The statement body is a null statement, since no further statements are necessary.

```
for (i = 0; i < 10; line[i++] = 0)
     ;
```

The return Statement

Syntax

return [*expression*];

Execution

The **return** statement terminates the execution of the function in which it appears and returns control to the calling function. Execution resumes in the calling function at the point immediately following the call. The value of *expression*, if present, is returned to the calling function. If *expression* is omitted, the return value of the function is undefined.

By convention, parentheses enclose the *expression* argument of the **return** statement. However, C does not require the parentheses.

If no **return** statement appears in a function definition, control automatically returns to the calling function after the last statement of the called function is executed. The return value of the called function is undefined. If a return value is not required, declare the function to have **void** return type.

Example

In this example, the *main* function calls two functions: *sq* and *draw*. The *sq* function returns the value of *x* * *x* to *main*, where the return value is assigned to *y*. The *draw* function is declared as a **void** function and does not return a value. An attempt to assign the return value of *draw* would cause a diagnostic message to be issued.

```
main()
{
     void draw(int,int);
     long sq(int);
     .
     .
     .
     y = sq(x);
     draw(x, y);
     .
     .
     .
}

long sq(x)
int x;
{
     return (x * x);
}

void draw(x,y)
int x, y;
{
     .
     .
     .
     return;
}
```

The switch Statement

Syntax

```
switch (expression) {
   [declaration]
   .
   .
   .
   [case constant-expression :]
   .
   .
   .
      [statement]
      .
      .
      .
   [default :
      [statement]]
}
```

Execution

The **switch** statement transfers control to a statement within its body. Control passes to the statement whose **case** *constant-expression* matches the value of **switch** *expression*. The **switch** statement may include any number of **case** instances. Execution of the statement body begins at the selected statement and proceeds until the end of the body or until a statement transfers control out of the body.

The **default** statement is executed if no **case** *constant-expression* is equal to the value of **switch** *expression*. If the **default** statement is omitted, and no **case** match is found, none of the statements in the **switch** body is executed. The **default** statement need not come at the end; it can appear anywhere in the body of the **switch** statement.

The type of **switch** *expression* must be integral, but the resulting value is converted to **int**. Each **case** *constant-expression* is then converted using the usual arithmetic conversions. The value of each **case** *constant-expression* must be unique within the statement body. If the type of **switch** *expression* is larger than **int**, a diagnostic message is issued.

The **case** and **default** labels of the **switch** statement body are significant only in the initial test that determines where execution starts in the statement body. All statements between the statement where execution starts and the end of the body are executed regardless of their labels, unless a statement transfers control out of the body entirely.

Note

Declarations can appear at the head of the compound statement forming the **switch** body, but initializations included in the declarations are not performed. The **switch** statement transfers control directly to an executable statement within the body, bypassing the lines that contain initializations.

Example 1

In this example, all three statements of the **switch** body are executed if *c* is equal to *'A'*. Execution control is transferred to the first statement (*capa++;*) and continues in order through the rest of the body. If *c* is equal to *lettera and total are incremented. Only total is incremented if c is not equal to or*

```
switch (c) {
        case 'A':
             capa++;
        case 'a':
             lettera++;
        default :
             total++;
      }
```

Example 2

In this example, a **break** statement follows each statement of the **switch** body. The **break** statement forces an exit from the statement body after one statement is executed. If *i* is equal to –1, only *n* is incremented. The **break** following the statement *n++;* causes execution control to pass out of the statement body, bypassing the remaining statements. Similarly, if *i* is equal to 0, only *z* is incremented; if *i* is equal to 1, only *p* is incremented. The final **break** statement is not strictly necessary, since control passes out of the body at the end of the compound statement, but it is included for consistency.

```
switch (i) {
        case -1:
            n++;
            break;
        case 0 :
            z++;
            break;
        case 1 :
            p++;
            break;
    }
```

Multiple Labels

A single statement can carry multiple **case** labels, as the following example shows:


```
case 'a' :
case 'b' :
case 'c' :
case 'd' :
case 'e' :
case 'f' :  hexcvt(c);
```

Although you can label any statement within the body of the **switch** statement, no statement is required to carry a label. You can freely intermingle statements with and without labels. Keep in mind, however, that once the **switch** statement passes control to a statement within the body, all following statements in the block are executed, regardless of their labels.

The while Statement

Syntax

while (*expression*)
statement

Execution

The body of a **while** statement is executed zero or more times until *expression* becomes false (0). Execution proceeds as follows:

1. The *expression* is evaluated.

2. If *expression* is initially false, the body of the **while** statement is never executed, and control passes from the **while** statement to the next statement in the program.

   If *expression* is true (nonzero), the body of the statement is executed and the process is repeated beginning at step 1.

The **while** statement may also terminate when a **break**, **goto**, or **return** within the statement body is executed.

Example

This example copies characters from *string2* to *string1*. If *i* is greater than or equal to 0, *string2[i]* is assigned to *string1[i]* and *i* is decremented. When *i* reaches or falls below 0, execution of the **while** statement terminates.

```
while (i >= 0) {
      string1[i] = string2[i];
      i--;
}
```

Chapter 7

Functions

ntroduction 7-1

unction Definitions 7-3
Storage Class 7-4
Return Type and Function Name 7-5
Formal Parameters 7-7
Function Body 7-11

unction Prototypes (Declarations) 7-13

unction Calls 7-16
Actual Arguments 7-19
Calls with a Variable Number of Arguments 7-22
Recursive Calls 7-23

Introduction

A function is an independent collection of declarations and statements, usually designed to perform a specific task. C programs have at least one function, the **main** function, and they may have other functions. This chapter describes how to define, declare, and call C functions.

A function *definition* specifies the name of the function, the types and number of its formal parameters, and the declarations and statements that determine what it does. These declarations and statements are called the "function body." The function definition also gives the function's return type and its storage class. If the return type and storage class are not stated explicitly, they default to **int** and **extern**, respectively.

A function *prototype* (or declaration) establishes the name, return type, and storage class of a function fully defined elsewhere in the program. It can also include declarations giving the types and number of the function's formal parameters. The formal parameter declarations can name the formal parameters, although such names go out of scope at the end of the declaration. The storage class **register** can also be specified for a formal parameter.

Example

This example contrasts the concise and clear prototype declaration and definition formats, and illustrates that the function prototype has the same form as the function definition except that the prototype ends with a semicolon instead of a function body.

The compiler uses the prototype or declaration to compare the types of actual arguments in subsequent calls to the function with the function's formal parameters, even in the absence of an explicit definition of the function. Explicit prototypes and declarations are optional for functions whose return type is **int**. However, to ensure correct behavior, you must declare or define functions with other return types before calling them. (Function prototype declarations are discussed further in "Function Definitions (Prototypes)" later in this chapter and in the "Declarations" chapter.)

If no prototype or declaration is provided, a default prototype is created from whatever information accompanies the first reference to the function name, whether that reference occurs in a call or a definition. However, such a default prototype may not adequately represent a subsequent definition of, or call to, the function.

A function "call" passes execution control from the calling function to the called function. The actual arguments, if any, are passed by value to the called function. Execution of a **return** statement in the called function returns control and possibly a value to the calling function.

Note

The use of function prototypes is strongly recommended. Sometimes they provide the only basis on which the compiler can enforce correct argument passing. Prototypes let the compiler either diagnose, or handle correctly, argument mismatches that would otherwise be undetectable until program execution.

The Microsoft C Compiler can generate function prototypes automatically from program source files. These can then be stored in a file that can be included in the compilation of the program. See your compiler guide for more information.

```
/** Prototype-Style Function Declarations and Definitions **/

double new_style(int a, double *x);     /* Function
                                        Prototype      */
double alt_style (int, double *);       /* Alternative
                                        Prototype form */
double old_style ();                  /* Obsolete
       .                               * form of function
       .                               * declaration
       .                                              */
double new_style(int a, double *real)   /* Prototype-style */
       {                                /* Function        */
         return (*real + a) ;           /* Definition        */
       }

double alt_style(a , real)            /* Old Form of     */
       double *real ;                 /* Function      */
       int a ;                        /* Definition    */
   {
       return (*real + a) ;
   }
```

Function Definitions

Syntax

[*sc-specifier*][*type-specifier*] *declarator* ([*formal-parameter-list*])
function-body

A "function definition" specifies the name, formal parameters, and body of a function. It can also stipulate the function's return type and storage class.

The optional *sc-specifier* gives the function's storage class, which must be either **static** or **extern**.

The optional *type-specifier* and mandatory *declarator* together specify the function's return type and name. The *declarator* is a combination of the identifier that names the function and the parentheses following the function name.

The *formal-parameter-list* is a sequence of formal parameter declarations separated by commas. The following syntax illustrates the form of each formal parameter in a formal parameter list.

[**register**] *type-specifier* [*declarator*]
[,...]

The formal parameter list contains declarations for the function's parameters. If no arguments are to be passed to the function, the list should contain the keyword **void**. The empty parentheses form (( )) can be used, but is obsolete and, if used, conveys no information about whether arguments will be passed. The formal parameter list can be full or partial. The second line of the syntax above shows the "ellipsis notation," a comma followed by three periods (,...). A partial formal parameter list can be terminated by the ellipsis notation to indicate that there may be more arguments passed to the function, but no more information is given about them. Type checking is not performed on such arguments. At least one formal parameter must precede the ellipsis notation and the ellipsis notation must be the last token in the formal parameter list. Without the ellipsis notation, the behavior of a function is undefined if it receives parameters in addition to those declared in the formal parameter list.

When a prototype is available, argument checking and conversion are automatically performed. If no information is given concerning the formal parameters, any undeclared arguments simply undergo the usual arithmetic conversions.

The *type-specifier* can be omitted only if **register** storage class is specified for a value of **int** type.

The *function-body* is a compound statement containing local variable declarations, references to externally declared items, and statements.

Note

The old forms for function declaration and definition are still supported, but considered obsolete. Use of the prototype form is recommended in new code. The old function-definition form is represented in the following syntax:

[*sc-specifier*][*type-specifier*] *declarator* ([*identifier-list*])
[*parameter-declarations*]
function-body

The *identifier-list* is an optional list of identifiers that the function will use as the names of formal parameters. The *parameter-declaration* arguments establish the types of the formal parameters.

The section entitled "Function Definitions" later in this chapter. describes the parts of a function definition in detail.

Storage Class

The storage-class specifier in a function definition gives the function either **extern** or **static** storage class. If a function definition does not include a storage-class specifier, the storage class defaults to **extern**. You can explicitly give the **extern** storage-class specifier in a function definition, but it is not required.

A function with **static** storage class is visible only in the source file in which it is defined. All other functions, whether they are given **extern** storage class explicitly or implicitly, are visible throughout all the source files that make up the program.

If **static** storage class is desired, it must be declared on the first occurrence of a declaration (if any) of the function, and on the definition of the function.

Note

A Microsoft extension to the ANSI C standard offers some latitude on functions declared without a storage-class specifier. When the extensions are enabled, a function originally declared without a storage class (or with **extern** storage class) is given **static** storage class if the function definition is in the same source file and explicitly specifies **static** storage class. For information on enabling and disabling extensions, see your compiler guide.

Return Type and Function Name

Syntax

[*sc-specifier*][*type-specifier*] *declarator* ([*formal-parameter-list*])

The return type of a function establishes the size and type of the value returned by the function and corresponds to *type-specifier* in the syntax above. The *type-specifier* can specify any fundamental, structure, or union type. If you do not include *type-specifier*, the return type **int** is assumed.

The *declarator* is the function identifier, which may be modified to a pointer type. The parentheses following the identifier establish the item as a function. Functions cannot return arrays or functions, but they can return pointers to any type, including arrays and functions.

The return type given in the function definition must match the return type in declarations of the function elsewhere in the program. You need not declare functions with **int** return type before you call them, although prototypes are recommended so that correct argument checking will be enabled. However, functions with other return types must be defined or declared before they are called.

A function's return type is used only when the function returns a value. A function returns a value when a **return** statement containing an expression is executed. The expression is evaluated, converted to the return value type if necessary, and returned to the point at which the function was called. If no **return** statement is executed, or if the **return** statement does not contain an expression, the return value is undefined. If the calling function expects a return value, the behavior of the program is also undefined.

Example 1

In this example, the return type of *add* is **int** by default. The function has **static** storage class, which means that only functions in the same source file can call it. The formal parameters declared in the header include one **int** value, *x*, for which register storage is requested, and a second **int** value, *y*. The second function, *subtract*, is defined in the old form. Its return type is **int** by default. The formal parameters are declared between the header and the opening brace.

```
 /* prototype-style definition: */

static add (register x, int y)
 {
    return (x+y);
 }

 /* old-style definition: */

subtract (x , y)
    int x, y;
 {
  return (x-y);
 }
```


Example 2

This example defines the *STUDENT* type with a **typedef** declaration and defines the function *sortstu* to have *STUDENT* return type. The function selects and returns one of its two structure arguments. This prototype-style definition has the formal parameters declared in the header. In subsequent calls to the function, the compiler checks to make sure the argument types are *STUDENT*. Efficiency would be enhanced by passing pointers to the structure, rather than the entire structure.

```
typedef struct  {
    char name[20];
    int id;
    long class;
} STUDENT;

      /* return type is STUDENT: */

STUDENT sortstu (STUDENT a, STUDENT b)
{
    return ( (a.id < b.id) ? a : b );
}
```

Example 3

This example uses the old form to define a function returning a pointer to an array of characters. The function takes two character arrays (strings) as arguments and returns a pointer to the shorter of the two strings. A pointer to an array points to the type of the array elements; thus, the return type of the function is pointer to **char**.

```
  /* return type is char pointer: */

char *smallstr(s1, s2)
char s1[], s2[];
{
    int i;

    i=0;
    while ( s1[i] != '\0' && s2[i] != '\0' )
                i++;
    if ( s1[i] == '\0' )
            return (s1);
    else
            return (s2);
}
```

Formal Parameters

"Formal parameters" are variables that receive values passed to a function by a function call. In a function prototype-style definition, the parentheses following the function name contain complete declarations of the function's formal parameters.

Note

In the old form of a function definition, the formal parameters were declared following the closing parenthesis, immediately before the beginning of the compound statement constituting the function body. In that form, an identifier list within the parentheses specifies the name of each of the formal parameters and the order in which they take on values in the function call. The identifier list consists of zero or more identifiers, separated by commas. The list must be enclosed in parentheses, even if it is empty. This form is obsolete and should not be used in new code.

If at least one formal parameter occurs in the formal parameter list, the list can end with a comma followed by three periods (,...). This construction, called the "ellipsis notation," indicates a variable number of arguments to the function. However, a call to the function is expected to have at least as many arguments as there are formal parameters before the last comma. In the obsolete definition form, the ellipsis notation can follow the last identifier in the identifier list.

If no arguments are to be passed to the function, the list of formal parameters is replaced by the keyword **void**. This use of **void** is distinct from its use as a type specifier.

Note

To maintain compatibility with previous versions, a Microsoft extension to the ANSI C standard allows a comma without trailing periods (,) at the end of the list of formal parameters to indicate a variable number of arguments. However, it is recommended that code be changed to incorporate the ellipsis notation. For information on enabling and disabling extensions, see your compiler guide.

Formal parameter declarations specify the types, sizes, and identifiers of values stored in the formal parameters. In the obsolete function definition form, these declarations have the same form as other variable declarations (see the "Declarations" chapter). However, in a function prototype-style definition, each identifier in the *formal-parameter-list* must be preceded by its appropriate type specifier. For example, in the

following (obsolete form) definition of the function *old*, *double x, y, z ;* can be declared simply by separating identifiers with commas:

```
void old(x, y, z)
    double z, y ;
    double x ;
      {
        ;
      }

void new(double x, double y, double z)
      {
        ;
      }
```

The function called *new* is defined in prototype format, with a list of formal parameters in the parentheses. In this form, the type specifier *double* must be repeated for each identifier.

The order and type of formal parameters, including any use of the ellipsis notation, must be the same in all the function declarations (if any) and in the function definition. The types of the actual arguments in calls to a function must be assignment compatible with the types of the corresponding formal parameters, up to the point of the ellipsis notation. Arguments following the ellipsis are not checked. A formal parameter can have any fundamental, structure, union, pointer, or array type.

The only storage class you can specify for a formal parameter is **register**. Undeclared identifiers in the parentheses following the function name are assumed to have **int** type. In the old function-definition form, formal parameter declarations can be in any order.

The identifiers of the formal parameters are used in the function body to refer to the values passed to the function. These identifiers cannot be redefined in the outermost block of the function body, but they can be redefined in inner, nested blocks.

In the obsolete form, only identifiers appearing in the identifier list can be declared as formal parameters. Functions having variable-length argument lists should use the new prototype form. You are responsible for determining the number of arguments passed, and for retrieving additional arguments from the stack within the body of the function. (For information about macros that let you do this in a portable way, see your compiler guide.)

The compiler performs the usual arithmetic conversions independently on each formal parameter and on each actual argument, if necessary. After conversion, no formal parameter is shorter than an **int**, and no formal parameter has **float** type. This means, for example, that declaring a formal parameter as a **char** has the same effect as declaring it as an **int**.

If the **near**, **far**, and **huge** keywords are implemented, the compiler can also convert pointer arguments to the function. The conversions performed depend on the default size of pointers in the program and the presence or absence of a list of argument types for the function. For specific information about pointer conversions, see your compiler guide.

The converted type of each formal parameter determines the interpretation of the arguments that the function call places on the stack. A type mismatch between an actual argument and a formal parameter can cause the arguments on the stack to be misinterpreted. For example, if a 16-bit pointer is passed as an actual argument, then declared as a **long** formal parameter, the first 32 bits on the stack are interpreted as a **long** formal parameter. This error creates problems not only with the **long** formal parameter, but with any formal parameters that follow it. You can detect errors of this kind by declaring function prototypes for all functions.

Example

This example contains a structure-type declaration, a prototype of the function *match*, a call to *match*, and a prototype-style definition of *match*. Note that the same name, *student*, can be used without conflict both for the structure tag and for the structure variable name.

The *match* function is declared to have two arguments: the first, represented by *r*, is a pointer to the *struct student* type; the second, represented by *n*, is a pointer to a value of type **char**.

In the definition, the two formal parameters of the *match* function are declared in the formal parameter list in the parentheses following the function name, with the identifiers *r* and *n*. The parameter *r* is declared as a pointer to the *struct student* type; the parameter *n* is declared as a pointer to a **char** type value.

The function is called with two arguments, both members of the *student* structure. Because there is a prototype of *match*, the compiler performs type checking between the actual arguments and the types specified in the prototype and between the actual arguments and the formal parameters in the definition. Since the types match, no warnings or conversions are necessary.

Note that the array name given as the second argument in the call evaluates to a **char** pointer. The corresponding formal parameter is also declared as a **char** pointer and is used in subscripted expressions as though it were an array identifier. Since an array identifier evaluates to a pointer expression, the effect of declaring the formal parameter as *char *n* is the same as declaring it *char n[]*.

Within the function, the local variable *i* is defined and used to monitor the current position in the array. The function returns the *id* structure member if the *name* member matches the array *n*; otherwise, it returns 0.

```
struct student {
        char name[20];
        int id;
        long class;
        struct student *nextstu;
} student;

main()
{
      /* declaration of function prototype: */

        int match ( struct student *r, char *n );
        .
        .
        .
        if (match (student.nextstu, student.name) > 0) {
        .
        .
        .
        }
}

/* prototype style function definition */

match ( struct student *r, char *n )
{
        int i = 0;

        while ( r->name[i] == n[i] )
                if ( r->name[i++] == '\0' )
                        return (r->id);
        return (0);
}
```

Function Body

A "function body" is a compound statement containing the statements that define what the function does. It can also contain declarations of variables used by these statements. (The section entitled "The Compound Statement" in Chapter 6 discusses compound statements.)

All variables declared in a function body have **auto** storage class unless otherwise specified. When the function is called, storage is created for the local variables and local initializations are performed. Execution control passes to the first statement in the compound statement and continues sequentially until a **return** statement is executed or the end of the function body is encountered. Control then returns to the point at which the function was called.

A **return** statement containing an expression must be executed if the function is to return a value. The return value of a function is undefined if no **return** statement is executed or if the **return** statement does not include an expression.

Function Prototypes (Declarations)

A "function prototype" declaration specifies the name, return type, and storage class of a function. It can also establish types and identifiers of some or all of the function's arguments. The prototype has the same format as the function definition, except that it is terminated by a semicolon immediately following the closing parenthesis and therefore has no body. (See the "Declarations" chapter for a detailed description of the syntax of function declarations.)

You can declare a function implicitly, or you can use a "function prototype" (sometimes called a "forward declaration") to declare it explicitly. A prototype is a declaration that precedes the function definition. In either case, the return type must agree with the return type specified in the function definition.

If a call to a function precedes its declaration or definition, a default prototype of the function is constructed, giving it **int** return type. The types and number of the actual arguments are used as the basis for declaring the formal parameters. Thus a call to the function is an implicit declaration, but the prototype generated may not adequately represent a subsequent definition of, or call to, the function.

A prototype establishes the attributes of a function so that calls to the function that precede its definition (or occur in other source files) can be checked for argument- and return-type mismatches. If you specify the **static** storage-class specifier in a prototype, you must also specify the **static** storage class in the function definition.

If you specify the **extern** storage-class specifier or omit the storage-class specifier entirely, the function has **extern** class. (For an explanation of the Microsoft extension that offers some latitude in function storage-class specification, see the *Note* in the section entitled "Storage Classes") in Chapter 4.

Function prototypes have the following important uses:

- They establish the return type for functions that return any type other than **int**. If you call such a function before you declare or define it, the results are undefined. Although functions that return **int** values do not require prototypes, they are recommended.

- If the prototype contains a full list of parameter types, the types of the arguments occurring in a function call or definition can be checked. The prototype can include both the type of, and an identifier for, each expression that will be passed as an actual argument. However, such identifiers have scope only until the end of the declaration. The prototype can also reflect the fact that the number of arguments will be variable, or that there will be no arguments passed.

  The parameter list in a prototype is a list of type names, separated by commas, corresponding to the actual arguments in the function call. The list is used for checking the correspondence of actual arguments in the function call with the formal parameters in the function definition. Without such a list, mismatches may not be revealed, so the compiler cannot generate diagnostic messages concerning them. (Type checking is further discussed in the subsection "Actual Arguments" of the section entitled "Function Calls" later in this chapter.)

- Prototypes are used to initialize pointers to functions before those functions are defined.

Example

In this example, the function *intadd* is implicitly declared to return an **int** value, since it is called before it is defined. The compiler creates a prototype using the information in the first call. Therefore, when the second call to *intadd* is encountered, the compiler sees the mismatch between *val1*, which is a **float**, and the **int** type of the first argument in its self-created prototype. The **float** is converted to an **int** and passed. Note that if the calls to *intadd* were reversed, the prototype created would expect a **float** as the first argument to *intadd*. When the second call is made, the variable *a* would be converted at the call, but when the value is actually passed to *intadd*, a diagnostic message would be issued because the **int** type specified in the definition does not match the **float** type in the compiler-created prototype.

The function *realadd* returns a **double** value instead of an **int** value. Therefore, the prototype of *realadd* in the *main* function is necessary because the *realadd* function is called before it is defined. Note that the definition of *realadd* matches the forward declaration by specifying the **double** return type.

The forward declaration of *realadd* also establishes the types of its two arguments. The actual argument types match the types given in the declaration and also match the types of the formal parameters in the definition.

```
main()
{
        int a = 0, b = 1;
        float val1= 2.0, val2 = 3.0;

       /* function prototype: */

        double realadd(double x, double y);

        a = intadd (a, b);      /* first call to intadd */
        val1 = realadd(val1, val2);
       a = intadd(val1,b);      /* second call to intadd */
}

/* functions defined with formal parameters in header: */

intadd(int a, int b)
{
        return (a + b);
}

double realadd(double x, double y)
{
        return (x + y);
}
```

Function Calls

Syntax

expression([*expression-list*])

A "function call" is an expression that passes control and actual arguments (if any) to a function. In a function call, *expression* evaluates to a function address and *expression-list* is a list of expressions (separated by commas). The values of these latter expressions are the actual arguments passed to the function. If the function takes no arguments, *expression-list* can be empty.

When the function call is executed:

1. The expressions in *expression-list* are evaluated and converted using the usual arithmetic conversions. If a function prototype is available, the results of these conversions may be further converted consistent with the formal parameter declarations.

2. The expressions in *expression-list* are passed to the formal parameters of the called function. The first expression in the list always corresponds to the first formal parameter of the function, the second expression corresponds to the second formal parameter, and so on through the list. Since the called function uses copies of the actual arguments, any changes it makes to the arguments do not affect the values of variables from which the copies may have been made.

3. Execution control passes to the first statement in the function.

4. The execution of a **return** statement in the body of the function returns control and possibly a value to the calling function. If no **return** statement is executed, control returns to the caller after the last statement of the called function is executed. In such cases, the return value is undefined.

Note

The expressions in the function argument list can be evaluated in any order, so arguments whose values may be changed by side effects from another argument have undefined values. The sequence point defined by the function-call operator guarantees only that all side effects in the argument list are evaluated before control passes to the called function. See the "Expressions and Assignments" chapter for more information on sequence points.

The only requirement in a function call is that the expression before the parentheses must evaluate to a function address. This means that a function can be called through any function-pointer expression.

A function is called in much the same way it is declared. For instance, when you declare a function, you specify the name of the function, followed by a list of formal parameters in parentheses. Similarly, when a function is called, you need only specify the name of the function, followed by an argument list in parentheses. The indirection operator (*) is not required to call the function because the name of the function evaluates to the function address.

The same principle applies when you call a function using a pointer. For example, suppose a function pointer has the following prototype:

```
int (*fpointer)(int num1, int num2);
```

The identifier *fpointer* is declared to point to a function taking two **int** arguments, represented by *num1 and num2*, respectively, and returning an **int** value. A function call using *fpointer* might look like this:

```
(*fpointer)(3,4)
```

The indirection operator (*) is used to obtain the address of the function to which *fpointer* points. The function address is then used to call the function. If a prototype of the pointer to the function precedes the call, the same checking will be performed as with any other function.

Example 1

In this example, the *realcomp* function is called in the statement *rp = realcomp(a, b);*. Two **double** arguments are passed to the function. The return value, a pointer to a **double** value, is assigned to *rp*.

```
double *realcomp(double value1, double value2);
double a, b, *rp;
.
.
.
rp = realcomp(a, b);
```

Example 2

In this example, the function call in *main* passes an integer variable and the address of the function *lift* to the function *work*:

```
work (count, lift);
```

Note that the function address is passed simply by giving the function identifier, since a function identifier evaluates to a pointer expression. To use a function identifier in this way, the function must be declared or defined before the identifier is used; otherwise, the identifier is not recognized. In this case, a prototype for *work* is given at the beginning of the *main* function.

The formal parameter *function* in *work* is declared to be a pointer to a function taking one **int** argument and returning a **long** value. The parentheses around the parameter name are required; without them, the declaration would specify a function returning a pointer to a **long** value.

The function *work* calls the selected function by using the following function call:

```
(*function)(i);
```

One argument, *i*, is passed to the called function.

```
main ()
{
    /* function prototypes: */

    long lift(int), step(int), drop(int);
    void work (int number, long (*function)(int i));

    int select, count;
    .
    .
    .
    select = 1;
    switch ( select ) {
           case 1: work(count, lift);
                   break;

           case 2: work(count, step);
                   break;

           case 3: work(count, drop);

           default:
                   break;
     }
}

/* function definition with formal parameters in header: */

void work ( int number, long (*function)(int i) )
{
    int i;
    long j;

    for (i = j = 0; i < number; i++)
            j += (*function)(i);
}
```


Actual Arguments

An actual argument can be any value with fundamental, structure, union, or pointer type. Although you cannot pass arrays or functions as parameters, you can pass pointers to these items.

All actual arguments are passed by value. A copy of the actual argument is assigned to the corresponding formal parameter. The function uses this copy without affecting the variable from which it was originally derived.

Pointers provide a way for a function to access a value by reference. Since a pointer to a variable holds the address of the variable, the function can use this address to access the value of the variable. Pointer arguments allow a function to access arrays and functions, even though arrays and functions cannot be passed as arguments.

The expressions in a function call are evaluated and converted as follows:

- The usual arithmetic conversions are performed on each actual argument in the function call. If a prototype is available, the resulting argument type is compared to the prototype's corresponding formal parameter. If they do not match, either a conversion is performed, or a diagnostic message is issued. The formal parameters also undergo the usual arithmetic conversions.

- If no prototype is available, the usual arithmetic conversions are performed on each actual argument before it is passed to the function. A prototype is created whose formal parameter types correspond to the types of the actual arguments after conversion.

If the **near**, **far**, and **huge** keywords are implemented, implementation-dependent conversions on pointer arguments can also be performed. For information about pointer conversions, see your compiler guide.

The number of expressions in the expression list must match the number of formal parameters, unless the function's prototype or definition explicitly specifies a variable number of arguments. In this case, the compiler checks as many arguments as there are type names in the list of formal parameters and converts them, if necessary, as described above.

If the prototype's formal parameter list contains only the keyword **void**, the compiler expects zero actual arguments in the function call and zero formal parameters in the definition. A diagnostic message is issued if it finds otherwise.

The type of each formal parameter also undergoes the usual arithmetic conversions. The converted type of each formal parameter determines how the arguments on the stack are interpreted; if the type of the formal parameter does not match the type of the actual argument, the data on the stack may be misinterpreted.

Note

Type mismatches between actual arguments and formal parameters can produce serious errors, particularly when the sizes are different. The compiler may not be able to detect these errors unless you declare complete prototypes of functions prior to calling them. In the absence of explicit prototypes, the compiler constructs prototypes from whatever information is available in the first reference to the function.

As an example of a serious error, consider a call to a function with an **int** argument. If the function is defined to take a **long**, and the definition occurs in a different module, the compiler-generated prototype will not match the definition, but the error will not be detected because the separate modules will compile without diagnostic messages.

Example

In this example, the *swap* function is declared in *main* to have two arguments, represented respectively by identifiers *num1 and num2*, both of which are pointers to **int** values. The formal parameters *num1* and *num2* in the prototype-style definition are also declared as pointers to **int** type values. In the following function call the address of *x* is stored in *num1* and the address of *y* is stored in *num2*.

```
swap (&x, &y)
```

Now two names, or "aliases," exist for the same location. References to **num1* and **num2* in *swap* are effectively references to *x* and *y* in *main*. The assignments within *swap* actually exchange the contents of *x* and *y*. Therefore, no **return** statement is necessary.

The compiler performs type checking on the arguments to *swap* because the prototype of *swap* includes argument types for each formal parameter. The identifiers within the parentheses of the prototype and definition can be the same or different. What is important is that the types of the actual arguments match those of the formal parameter lists in both the prototype and the eventual definition.

```
main ()
{
      /* function prototype: */

        void swap (int *num1, int *num2);
        int x, y;
        .
        .
        .
        swap(&x, &y);
}

/* function definition: */

void swap (int *num1, int *num2)
{
        int t;

        t = *num1;
        *num1 = *num2;
        *num2 = t;
}
```

Calls with a Variable Number of Arguments

To call a function with a variable number of arguments, simply specify any number of arguments in the function call. If there is a prototype declaration of the function, a variable number of arguments can be specified by placing a comma followed by three periods (,...), the "ellipsis notation," at the end of the formal parameter list or list of argument types (see the section entitled "Function Prototypes (Declarations)"). The function call must include one argument for each type name declared in the formal parameter list or the list of argument type.

Similarly, the formal parameter list (or identifier list, in the obsolete form) in the function definition can end with the ellipsis notation to indicate a variable number of arguments. For more information about the form of the formal parameter list, see the section entitled "Function Definitions" earlier in this chapter.

Note

To maintain compatibility with previous versions, a Microsoft extension to the ANSI C standard allows a comma without trailing periods (,) at the end of the list of formal parameters to indicate a variable number of arguments. For information on enabling and disabling extensions, see your compiler guide.

All the arguments specified in the function call are placed on the stack. The number of formal parameters declared for the function determines how many of the arguments are taken from the stack and assigned to the formal parameters. You are responsible for retrieving any additional arguments from the stack and for determining how many arguments are present. For information about macros that you can use to handle a variable number of arguments in a portable way, see your compiler guide.

Recursive Calls

Any function in a C program can be called recursively; that is, it can call itself. The C compiler allows any number of recursive calls to a function. Each time the function is called, new storage is allocated for the formal parameters and for the **auto** and **register** variables so that their values in previous, unfinished calls are not overwritten. Parameters are only directly accessible to the instance of the function in which they are created. Previous parameters are not directly accessible to ensuing instances of the function.

Note that variables declared with **static** storage do not require new storage with each recursive call. Their storage exists for the lifetime of the program. Each reference to such a variable accesses the same storage area.

Although the C compiler does not limit the number of times a function can be called recursively, the operating environment may impose a practical limit. Since each recursive call requires additional stack memory, too many recursive calls can cause a stack overflow.

Chapter 8

Preprocessor Directives and Pragmas

Introduction 8-1

Manifest Constants and Macros 8-3
- Preprocessor Operators 8-3
- The #define Directive 8-4
- The #undef Directive 8-11

Include Files 8-12

Conditional Compilation 8-14
- The #if, #elif, #else, and #endif Directives 8-14
- The #ifdef and #ifndef Directives 8-18

Line Control 8-19

Pragmas 8-21

Introduction

A ''preprocessor directive'' is an instruction to the C preprocessor. The C preprocessor is a text processor that manipulates the text of a source file as the first phase of compilation. Though the compiler ordinarily invokes the preprocessor in its first pass, the preprocessor can also be invoked separately to process text without compiling.

Preprocessor directives are typically used to make source programs easy to change and easy to compile in different execution environments. Directives in the source file tell the preprocessor to perform specific actions. For example, the preprocessor can replace tokens in the text, insert the contents of other files into the source file, or suppress compilation of part of the file by removing sections of text.

The C preprocessor recognizes the following directives:

#define	**#if**	**#line**
#elif	**#ifdef**	**#undef**
#else	**#ifndef**	
#endif	**#include**	

The number sign (#) must be the first non-white-space character on the line containing the directive; white-space characters can appear between the number sign and the first letter of the directive. Some directives include arguments or values. Any text that follows a directive (except an argument or value that is part of the directive) must be enclosed in comment delimiters (/* */).

Preprocessor directives can appear anywhere in a source file, but they apply only to the remainder of the source file in which they appear.

A ''preprocessor operator'' is an operator that is only recognized as an operator within the context of preprocessor directives. There are only three preprocessor-specific operators: the ''stringizing'' operator (#), the ''token-pasting'' (##) operator, and the **defined** operator. The first two are discussed in the context of the **#define** directive, later in this chapter. The **defined** operator is also discussed later in this chapter. ''The #if, #elif, #else, and #endif Directives.''

Introduction

A "pragma" is a "pragmatic," or practical, instruction to the C compiler. Pragmas in C source files are typically used to control the actions of the compiler in a particular portion of a program without affecting the program as a whole. (The "Pragmas" section later in this chapter describes the syntax for pragmas). However, the compiler implementation defines the particular pragmas that are available and their meanings. For information about the use and effects of specific pragmas, see your compiler guide.

Manifest Constants and Macros

The **#define** directive is typically used to associate meaningful identifiers with constants, keywords, and commonly used statements or expressions. Identifiers that represent constants are called "manifest constants." Identifiers that represent statements or expressions are called "macros."

Once you have defined an identifier, you cannot redefine it to a different value without first removing the original definition. However, you can redefine the identifier with exactly the same definition. Thus, the same definition can appear more than once in a program.

The **#undef** directive removes the definition of an identifier. Once you have removed the definition, you can redefine the identifier to a different value. The section later in this chapter entitled "Manifest Constants and Macros" discusses the **#define** and **#undef** directives.

In practical terms there are two types of macros. "Object-like" macros take no arguments, while "function-like" macros can be defined to accept arguments so that they look and act like function calls. Because macros do not generate actual function calls, you can make programs faster by replacing function calls with macros. However, macros can create problems if you do not define and use them with care. You may have to use parentheses in macro definitions with arguments to preserve the proper precedence in an expression. Also, macros may not handle expressions with side effects correctly. For more information, see the examples in the section entitled "The #define Directive."

Preprocessor Operators

There are three preprocessor-specific operators, one of which is represented by the number sign (#), one by a double number sign (##), and the third by the word **defined**. The "stringizing" operator (#) preceding a macro formal-parameter name in the body of a preprocessor macro causes the corresponding actual argument to be enclosed in string quotation marks. The "token-pasting" operator (##) allows tokens used as actual arguments to be concatenated to form other tokens. These two operators are used in the context of the **#define** directive and are described under "The #define Directive" in the section entitled "Manifest Constants and Macros".

Finally, the **defined** operator simplifies the writing of compound expressions in certain macro directives. It is used in conditional compilation, and is therefore discussed in the section entitled "Conditional Compilation". "The #if, #elif, #else, and #endif Directives."

The #define Directive

Syntax

#define *identifier substitution-text*
#define *identifier*(*parameter-list*) *substitution-text*

The **#define** directive substitutes *substitution-text* for all subsequent occurrences of *identifier* in the source file. The *identifier* is replaced only when it forms a token. (Tokens are described in the "Elements of C" chapter and in the "Syntax Summary.") For instance, *identifier* is not replaced if it appears within a string or as part of a longer identifier.

If *parameter-list* appears after *identifier*, the **#define** directive replaces each occurrence of *identifier*(*parameter-list*) with a version of the *substitution-text* argument that has actual arguments substituted for formal parameters.

The *substitution-text* argument consists of a series of tokens, such as keywords, constants, or complete statements. One or more white-space characters must separate *substitution-text* from *identifier* (or from the closing parenthesis following *parameter-list*). This white space is not considered part of the substituted text, nor is any white space following the last token of the text. Text longer than one line can be continued onto the next line by placing a backslash (\) before the new-line character.

The *substitution-text* argument can also be empty. Choosing this option removes occurrences of *identifier* from the source file. The *identifier* is still considered defined, however, and yields the value 1 when tested with the **#if** directive (discussed in the section entitled "The #if, #elif, #else, and #endif Directives").

The optional *parameter-list* consists of one or more formal parameter names separated by commas. Each name in the list must be unique, and the list must be enclosed in parentheses. No spaces can separate *identifier* and the opening parenthesis. The scope of a formal parameter name extends to the new line that ends *substitution-text*.

Formal parameter names appear in *substitution-text* to mark the places where actual values will be substituted. Each parameter name can appear more than once in *substitution-text*, and the names can appear in any order.

The actual arguments following an instance of *identifier* in the source file are matched to the corresponding formal parameters of *parameter-list*. Each formal parameter in *substitution-text* that is not preceded by a stringizing (#) or token-pasting (##) operator, or followed by a ## operator, is replaced by the corresponding actual argument. Any macros in the actual argument will be expanded before it replaces the formal parameter. (The # and ## operators are described in the section entitled "The #define Directive" later in this chapter.) The actual-argument list must have the same number of arguments as *parameter-list*.

If the name of the macro being defined occurs in *substitution-text* (even as a result of another macro expansion), it is not expanded.

Arguments with side effects sometimes cause macros to produce unexpected results. A given formal parameter may appear more than once in *substitution-text*. If that formal parameter is replaced by an expression with side effects, the expression, with its side effects, may be evaluated more than once.

Stringizing Operator (#)

The number-sign or "stringizing" operator (#) is used only with macros that take arguments. If it precedes a formal parameter in the macro definition, the actual argument passed by the macro invocation is enclosed in quotation marks and treated as a string literal. The string literal then replaces each occurrence of a combination of the stringizing operator and formal parameter within the macro definition. White space preceding the first token of the actual argument and following the last token of the actual argument is ignored. Any white space between the tokens in the actual argument is reduced to a single white space in the resulting string literal. Thus, if a comment occurs between two tokens in the actual argument, it is reduced to a single white space. The resulting string literal is automatically concatenated with any adjacent string literals from which it is separated only by white space. Furthermore, if a character contained in the argument normally requires an escape sequence when used in a string literal—for example, the quotation-mark (") or backslash (\) characters—the necessary escape backslash is automatically inserted before the character. The following example shows a macro definition that includes the stringizing operator and a main function that invokes the macro:

```
#define stringer(x) printf(#x "\n")

main()
{
  stringer (I will be in quotes in the printf function call);
  stringer ("I will be in quotes when printed to the screen");
  stringer (This: \"  prints an escaped double quote mark);
}
```

Such invocations would be expanded during preprocessing, producing the following code:

```
printf("I will be in quotes in the printf function call" "\n");
printf("\"I will be in quotes when printed to the screen\"" "\n");
printf("This \\\" prints an escaped double quote mark");
```

When the program is run, screen output for each line would be as follows:

```
I will be in quotes in the printf function call

"I will be in quotes when printed to the screen"

This: \" prints an escaped double quote mark
```

Note

The Microsoft extension to the ANSI C standard that previously enabled expansion of macro formal arguments appearing in string literals and character constants is no longer supported. Code that relied on this extension should be rewritten using the stringizing (#) operator.

8

Token-Pasting Operator (##)

The double-number-sign or ''token-pasting'' operator (##) is used in both object-like and function-like macros. It permits separate tokens to be joined into a single token, and therefore cannot be the first or last token in the macro definition.

If a formal parameter in a macro definition is preceded or followed by the token-pasting operator, the formal parameter is immediately replaced by the unexpanded actual argument. Macro expansion is not performed on the argument prior to replacement. Then, each occurrence of the token-pasting operator in *substitution-text* is removed, and the tokens preceding and following it are concatenated. The resulting token must be a valid token. If it is, the token is rescanned for possible replacement if it represents a macro name. Example 7 shows how tokens can be pasted together using the token-pasting operator.

Example 1

This example defines the identifier *WIDTH* as the integer constant 80 and defines *LENGTH* in terms of *WIDTH* and the integer constant 10. Each occurrence of *LENGTH* is replaced by (*WIDTH + 10*). In turn, each occurrence of *WIDTH + 10* is replaced by the expression (*80 + 10*).

```
#define WIDTH        80
#define LENGTH       (WIDTH + 10)
```

The parentheses around *WIDTH + 10* are important because they control the interpretation in statements such as the following:

```
var = LENGTH * 20;
```

After the preprocessing stage the statement becomes

```
var = (80 + 10) * 20;
```

which evaluates to 1800. Without parentheses, the result is

```
var = 80 + 10 * 20;
```

which evaluates to 280.

Example 2

This example defines the identifier The definition is extended *FILEMESSAGE.* to a second line by using the convention of a backslash followed by a new-line character.

```
#define FILEMESSAGE "Attempt to create file \
failed because of insufficient space"
```

Example 3

This example defines three identifiers, *REG1*, *REG2*, and *REG3*. *REG1* and *REG2* are defined as the keyword **register**. The definition of *REG3* is empty, so each occurrence of *REG3* is removed from the source file. These directives can be used to ensure that the program's most important variables (declared with *REG1* and *REG2*) are given **register** storage. (For an expanded version of this example, see the discussion of the **#if** directive in the section entitled "The #if, #elif, #else, and #endif Directives")

```
#define REG1        register
#define REG2        register
#define REG3
```

Example 4

This example defines a macro named *MAX*. Each occurrence of the identifier *MAX* after the definition in the source file is replaced by the expression

```
((x) > (y)) ? (x) : (y)
```

where actual values replace the parameters *x* and *y*. For example, the occurrence

```
MAX(1,2)
```

is replaced by

```
((1) > (2)) ? (1) : (2)
```

and the occurrence

```
MAX(i,s[i])
```

is replaced by

```
((i) > (s[i])) ? (i) : (s[i])
```

```
#define MAX(x,y)     ((x) > (y)) ? (x) : (y)
```

Because this macro is easier to read than the corresponding expression, the source program is easier to understand.

Note that arguments with side effects may cause this macro to produce unexpected results. For example, the occurrence *MAX(i, s[i++])* is replaced by *((i) > (s[i++])) ? (i) : (s[i++])*. The expression *(s[i++])* may be evaluated twice, so by the time the ternary expression has been fully evaluated, *i* will have been incremented either once or twice, depending on the result of the comparison.

Example 5

This example defines the macro *MULT*. Once the macro is defined, an occurrence such as *MULT(3, 5)* is replaced by *(3) * (5)*. The parentheses around the parameters are important because they control the interpretation when complex expressions form the arguments to the macro. For instance, the occurrence *MULT(3 + 4, 5 + 6)* is replaced by *(3 + 4) * (5 + 6)*, which evaluates to 77. Without the parentheses, the result would be *3 + 4 * 5 + 6*. This result evaluates to 29 because the multiplication operator (*) has higher precedence than the addition operator (+).

```
#define MULT(a,b)    ((a) * (b))
```

Example 6

This example defines two macros, one an object-like macro that expands to the string literal *Hello,World!*, and the other a function-like macro called *show*, which takes one argument. However, the definition of the second macro includes the stringizing operator (#) immediately preceding the formal parameter *x*. When an argument is passed to the *show* macro, the formal parameter is replaced by the actual argument enclosed in double quotation marks, thus "stringizing" it.

```
#define GREETING Hello, World!
#define show(x) printf(#x)

main()
{
      show(  x + z );
      printf("\n");
      show(n /* some comment */ + p);
      printf("\n");
      show(GREETING);  /* GREETING is not expanded; */
      printf("\n");    /* it is stringized instead */
      show('\x');
      printf("\n");
}
```

As the preprocessor progresses through the source file, the references to *show* are expanded as follows:

show(x + z); produces *printf("x + z");*

show(n / comment */ + p);* produces *printf("n + p");*

show(GREETING); produces *printf("GREETING");*

and finally, *show('\x');* produces *printf("'\\x'");*

When the program is run, the screen output would be:

```
x + z
n + p
GREETING
'\x'
```

Example 7

This example illustrates use of both the "stringizing" and "token-pasting" operators in specifying program output.

```
#define paster(n) printf("token" #n " = %d", token##n)
```

If *token9* is declared, and the macro is called with a numeric argument like:

```
paster(9) ;
```

the macro yields:

```
printf("token" "9" " = %d", token9) ;
```

which becomes

```
printf("token9 = %d", token9) ;
```

The #undef Directive

Syntax

#undef *identifier*

The **#undef** directive removes the current definition of *identifier*. Consequently, subsequent occurrences of *identifier* are ignored by the preprocessor. To remove a macro definition using **#undef**, give only the macro *identifier*; do not give a parameter list.

You can also apply the **#undef** directive to an identifier that has no previous definition. This ensures that the identifier is undefined.

The **#undef** directive is typically paired with a **#define** directive to create a region in a source program in which an identifier has a special meaning. For example, a specific function of the source program can use manifest constants to define environment-specific values that do not affect the rest of the program. The **#undef** directive also works with the **#if** directive (see the section entitled "The #if, #elif, #else, and #endif Directives" later in this chapter.) to control conditional compilation of the source program.

Example

In this example, the **#undef** directive removes definitions of a manifest constant and a macro. Note that only the identifier of the macro is given.

```
#define WIDTH           80
#define ADD(X,Y)        (X) + (Y)
.
.
.
#undef WIDTH
#undef ADD
```

Include Files

Syntax

#include "*path-spec*"
#include <*path-spec*>

The **#include** directive adds the contents of a given "include file" to another file. You can organize constant and macro definitions into include files and then use **#include** directives to add these definitions to any source file. Include files are also useful for incorporating declarations of external variables and complex data types. You only need to define and name the types once in an include file created for that purpose.

The **#include** directive tells the preprocessor to treat the contents of the named file as if they appeared in the source program at the point where the directive appears. The new text can also contain preprocessor directives. The preprocessor carries out directives in the new text, then continues processing the original text of the source file.

The *path-spec* is a file name optionally preceded by a directory specification. It must name an existing file. The syntax of the file specification depends on the operating system the program is compiled on.

The preprocessor uses the concept of a "standard" directory or directories to search for include files. The location of the standard directories for include files depends on the implementation and the operating system. For a definition of the standard directories, see your compiler guide.

The preprocessor stops searching as soon as it finds a file with the given name. If you specify a complete, unambiguous path specification for the include file, between two sets of double quotation marks (" "), the preprocessor searches only that path specification and ignores the standard directories.

If the *path-spec* enclosed in double quotation marks is an incomplete path specification, the preprocessor first searches the "parent" file's directory. A parent file is the file containing the **#include** directive. For example, if you include a file named *file2* within a file named *file1*, *file1* is the parent file.

Include files can be "nested," that is, an **#include** directive can appear in a file named by another **#include** directive. For example, *file2*, above, could include *file3*. In this case, *file1* would still be the parent of *file2*, but would be the "grandparent" of *file3*.

When include files are nested, directory searching begins with the directories of the parent file, then proceeds through the directories of any grandparent files. Thus, searching begins relative to the directory containing the source currently being processed. If the file is not found, the search moves to directories specified on the compiler command line. Finally, the standard directories are searched.

If the file specification is enclosed in angle brackets, the preprocessor does not search the current working directory. It begins by searching for the file in the directories specified on the compiler command line, then in the standard directories.

Nesting of include files can continue up to 10 levels. Once the nested **#include** is processed, the preprocessor continues to insert the enclosing include file into the original source file.

Example 1

This example adds the contents of the file named *stdio.h* to the source program. The angle brackets cause the preprocessor to search the standard directories for *stdio.h*, after searching directories specified on the command line.

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

Example 2

This example adds the contents of the file specified by *defs.h* to the source program. The double quotation marks mean that the preprocessor searches the directory containing the "parent" source file first.

```
#include "defs.h"
```

Conditional Compilation

This section describes the syntax and use of directives that control "conditional compilation." These directives let you suppress compilation of parts of a source file by testing a constant expression or identifier to determine which text blocks will be passed on to the compiler and which text blocks will be removed from the source file during preprocessing.

The #if, #elif, #else, and #endif Directives

Syntax

#if *restricted-constant-expression*
[*text-block*]
[**#elif** *restricted-constant-expression*
text-block]
[**#elif** *restricted-constant-expression*
text-block]
.
.
.
[**#else**
text-block]
#endif

The **#if** directive, together with the **#elif**, **#else**, and **#endif** directives, controls compilation of portions of a source file. Each **#if** directive in a source file must be matched by a closing **#endif** directive. Any number of **#elif** directives can appear between the **#if** and **#endif** directives, but at most one **#else** directive is allowed. The **#else** directive, if present, must be the last directive before **#endif**.

The preprocessor selects one of the given occurrences of *text-block* for further processing. A block specified in *text-block* can be any sequence of text. It can occupy more than one line. Usually *text-block* is program text that has meaning to the compiler or the preprocessor.

The preprocessor processes the selected *text-block* and passes it to the compiler. If *text-block* contains preprocessor directives, the preprocessor carries out those directives.

Any text blocks not selected by the preprocessor are removed from the file during preprocessing. Thus, these text blocks are not compiled.

The preprocessor selects a single *text-block* by evaluating the restricted constant expression following each **#if** or **#elif** directive until it finds a true (nonzero) restricted constant expression. It selects all text (including other preprocessor directives beginning with #) up to its associated **#elif**, **#else**, or **#endif**.

If all occurrences of *restricted-constant-expression* are false, or if no **#elif** directives appear, the preprocessor selects the text block after the **#else** clause. If the **#else** clause is omitted, and all instances of *restricted-constant-expression* in the **#if** block are false, no text block is selected.

Each *restricted-constant-expression* follows the rules for restricted constant expressions discussed in the section entitled "Constant Expressions" in Chapter 5. Such expressions cannot contain **sizeof** expressions, type casts, or enumeration constants. However, they can contain the preprocessor operator **defined** in special constant expressions, as shown by the following syntax:

defined(*identifier*)

This constant expression is considered true (nonzero) if the *identifier* is currently defined; otherwise, the condition is false (0). An identifier defined as empty text is considered defined.

The **#if**, **#elif**, **#else**, and **#endif** directives can nest in the text portions of other **#if** directives. Each nested **#else**, **#elif**, or **#endif** directive belongs to the closest preceding **#if** directive.

Example 1

In this example, the **#if** and **#endif** directives control compilation of one of three function calls. The function call to *credit* is compiled if the identifier *CREDIT* is defined. If the identifier *DEBIT* is defined, the function call to *debit* is compiled. If neither identifier is defined, the call to *printerror* is compiled. Note that *CREDIT* and *credit* are distinct identifiers in C because their cases are different.

```
#if defined(CREDIT)
    credit();
#elif defined(DEBIT)
    debit();
#else
    printerror();
#endif
```

Example 2

Examples 2 and 3 assume a previously defined manifest constant named *DLEVEL*.

Example 2 shows two sets of nested **#if**, **#else**, and **#endif** directives. The first set of directives is processed only if *DLEVEL* > *5* is true. Otherwise, the second set is processed.

```
#if DLEVEL > 5
    #define SIGNAL  1
    #if STACKUSE == 1
            #define STACK   200
    #else
            #define STACK   100
    #endif
#else
    #define SIGNAL  0
    #if STACKUSE == 1
            #define STACK   100
    #else
            #define STACK   50
    #endif
#endif
```

Example 3

In Example 3, **#elif** and **#else** directives are used to make one of four choices, based on the value of *DLEVEL*. The manifest constant *STACK* is set to 0, 100, or 200, depending on the definition of *DLEVEL*. If *DLEVEL* is greater than 5, *display(debugptr);* is compiled and *STACK* is not defined.

```
#if DLEVEL == 0
    #define STACK 0
#elif DLEVEL == 1
    #define STACK 100
#elif DLEVEL > 5
    display( debugptr );
#else
    #define STACK 200
#endif
```

Example 4

Example 4 uses preprocessor directives to control the meaning of **register** declarations in a portable source file. The compiler assigns register storage to variables in the order in which the **register** declarations appear in the source file. If a program contains more **register** declarations than the machine allows, the compiler honors earlier declarations over later ones. The program may be less efficient if the variables declared later are more heavily used.

```
#define REG1    register
#define REG2    register

#if defined(M_86)
    #define REG3
    #define REG4
    #define REG5
#else
    #define REG3    register
    #if defined(M_68000)
        #define REG4    register
        #define REG5    register
    #else
        #define REG4    register
        #define REG5
    #endif
#endif
```

The definitions listed in Example 4 can be used to give priority to the most important register declarations. *REG1* and *REG2* are defined as the **register** keyword to declare **register** storage for the two most important variables in the program. For example, in the following fragment, *b* and *c* have higher priority than *a* or *d*:

```
func(a)

REG3 int a;

{
        REG1 int b;
        REG2 int c;
        REG4 int d;
        .
        .
        .
}
```

When *M_86* is defined, the preprocessor removes the *REG3* identifier from the file by replacing it with empty text. This prevents *a* from receiving **register** storage at the expense of *b* and *c*. When *M_68000* is defined, all four variables are declared to have **register** storage. When neither *M_86* nor *M_68000* is defined, *a*, *b*, and *c* are declared with **register** storage.

The #ifdef and #ifndef Directives

Syntax

#ifdef *identifier*
#ifndef *identifier*

The **#ifdef** and **#ifndef** directives perform the same task as the **#if** directive used with **defined**(*identifier*). You can use the **#ifdef** and **#ifndef** directives anywhere **#if** can be used. These directives are provided only for compatibility with previous versions of the language. The **defined**(*identifier*) constant expression used with the **#if** directive is preferred.

When the preprocessor encounters an **#ifdef** directive, it checks to see whether the *identifier* is currently defined. If so, the condition is true (nonzero); otherwise, the condition is false (0).

The **#ifndef** directive checks for the opposite of the condition checked by **#ifdef**. If the identifier has not been defined (or its definition has been removed with **#undef**), the condition is true (nonzero). Otherwise, the condition is false (0).

Line Control

Syntax

#line *constant* ["*filename*"]

The **#line** directive tells the preprocessor to change the compiler's internally stored line number and file name to a given line number and file name. The compiler uses the line number and file name to refer to errors that it finds during compilation. The line number normally refers to the current input line, and the file name refers to the current input file. The line number is incremented after each line is processed.

If you change the line number and file name, the compiler ignores the previous values and continues processing with the new values. The **#line** directive is typically used by program generators to cause error messages to refer to the original source file instead of to the generated program.

The *constant* value in the **#line** directive can be any integer constant. The *filename* can be any combination of characters and must be enclosed in double quotation marks (" "). If *filename* is omitted, the previous file name remains unchanged.

The current line number and file name are always available through the predefined identifiers **__LINE__** and **__FILE__**. You can use the **__LINE__** and **__FILE__** identifiers to insert self-descriptive error messages into the program text.

The **__FILE__** identifier expands to a string whose contents are the file name, surrounded by double quotation marks (" ").

Example 1

In this example, the internally stored line number is set to 151 and the file name is changed to *copy.c*.

```
#line 151 "copy.c"
```

Example 2

In this example code segment , the macro *ASSERT* uses the predefined identifiers **__LINE__** and **__FILE__** to print an error message about the source file if a given "assertion" is not true.

```
#define ASSERT(cond)         if(!cond)\
{printf("assertion error line %d, file(%s)\n", \
__LINE__, __FILE__ );} else
printf("condition true");
```

Pragmas

Syntax

#pragma *character-sequence*

A **#pragma** is an implementation-de fined instruction to the compiler. The *character-sequence* is a series of characters that gives a specific compiler instruction and arguments, if any. The number sign (#) must be the first non-white-space character on the line containing the pragma; white-space characters can separate the number sign and the word **pragma**.

See your compiler guide for information about the pragmas available in your compiler implementation.

Appendix A

Differences Between K&R C and Microsoft C

Introduction A-1

Introduction

This appendix summarizes differences between Microsoft C and the description of the C language found in Appendix A of *The C Programming Language* by Brian W. Kernighan and Dennis M. Ritchie, published in 1978 by Prentice-Hall, Inc. The following is a list of the differences with cross-references to the corresponding section numbers in *The C Programming Language*:

Section Number in Kernighan and Ritchie	Microsoft C
2.2	Identifiers (including those used in preprocessor directives) are significant to 31 characters. External identifiers are also significant to 31 characters.
2.3	The identifiers **asm** and **entry** are no longer keywords. New keywords are **const**, **volatile**, **enum**, **signed**, and **void**. (The **volatile** keyword is implemented syntactically, but not semantically.) The identifiers **cdecl**, **far**, **fortran**, **huge**, **near**, and **pascal** may be keywords, depending on whether the corresponding options are enabled when a program is compiled (see your system documentation).
2.4.1	As a result of the method used to assign types to hexadecimal and octal constants, these constants always act like unsigned integers in type conversions.
2.4.3	Hexadecimal bit patterns consisting of a backslash (\), the letter **x**, and up to three hexadecimal digits are permitted as character constants (for example, *\x012*). Microsoft C defines three additional escape sequences: \v represents a vertical tab (VT), \" represents the double-quotation-mark character, and **\a** represents the bell (also called alert). Character constants always have type **int**, with the result that they are sign extended in type conversions. Adjacent quoted string literals are concatenated and treated as a single null-terminated string.

2.6 The **short** type is always 16 bits long, and the **long** type is 32 bits long. The size of an **int** is machine dependent. On 8086/8088, 80186, and 80286 processors an **int** is 16 bits long, and on 80386 and 68000 processors it is 32 bits long.

4 The **char** type is signed by default, with the result that a **char** value is sign extended in type conversions. (In some implementations, the default for the **char** type can be changed to unsigned at compile time.)

Two additional unsigned types are supported: **unsigned char** and **unsigned long**.

The keyword **unsigned** or **signed** can be applied as an adjective to an integer type. When **unsigned** appears alone, it means **unsigned int**. Similarly, when **signed** appears alone, it means **int**. The additional floating type **long double** is supported, but the **long float** type is no longer recognized. References to **long float** should be recoded to **double**.

The type specifiers **const** and **volatile** can be used as modifiers for any fundamental, aggregate, or pointer type. The **const** keyword indicates that the object or pointer value will not be modified. The **volatile** keyword means the object may be changed by some process beyond the control of the currently running program. Both the syntax and semantics of **const** are implemented, but only the syntax of **volatile** is implemented.

Microsoft C offers an additional fundamental type: the **enum** (enumeration) type. Variables of **enum** type are treated as integers in all cases.

The keyword **void** has three different uses. As a function-return-type specifier, it indicates that the function will not return a value. In an otherwise empty formal-parameter list, **void** means that no arguments will be passed. In the construction **void ***, it indicates a pointer to an object of unspecified type.

6.4 If the **near**, **far**, and **huge** keywords are enabled, pointers of different sizes can be used in a program. Operations with pointers of different sizes can cause conversion of pointers; the path of the conversion is implementation defined.

6.6 Arithmetic conversions carried out by the compiler are outlined in the "Expressions and Assignments" chapter. Although compatible with the Kernighan and Ritchie conversions, Microsoft C conversions are described in greater detail, including the specific path for each type of conversion.

In addition to the usual arithmetic conversions, conversions between pointers of different sizes can be routinely carried out when the **near**, **far**, and **huge** keywords are enabled. The path of the pointer conversions is implementation defined.

7.2 In connection with the **sizeof** operator, a byte is defined as an 8-bit quantity.

7.14 A structure can be assigned to another structure of the same type.

8.2 The keywords **enum**, **const**, **volatile**, and **void** are additional type specifiers. The **volatile** keyword is implemented syntactically, but not semantically. The keywords **signed** and **unsigned** can serve either as type specifiers or as adjectives modifying an integral type.

Therefore, the following additional combinations are acceptable:

signed char
signed short
signed short int
signed long
signed long int
unsigned char
unsigned short
unsigned short int
unsigned long
unsigned long int

The **long float** type is not recognized. The **long double** type is recognized and treated in all instances the same as **double**.

8.4 The **const** and **volatile** keywords can be used to modify any fundamental, aggregate, or pointer object. The order of the type specifiers is not significant.

Optional formal-parameter lists or argument-type lists can be included in function declarations to notify the compiler of the number and types of arguments expected in a function call.

8.5 Bitfields can be declared to be any **signed** or **unsigned** integral type, except **enum**. However, in expressions, bitfields are always treated as **unsigned**.

The names of structure and union members are not required to be distinct from structure and union tags or from the names of other variables.

No relationship exists between the members of two different structure types.

8.6 Unions can be initialized by giving a value for the first member of the union.

9.7 The *expression* of a **switch** can be any integral expression, but the value of the expression is always converted to an **int** type. An **enum** type is permitted for *expression*. Each of the **case** constant expressions is cast to the type of *expression*.

10.1 New styles for function declarations and definitions, as specified in the Draft Proposed American National Standard — Programming Language C, are completely supported. This includes the function prototype declaration, the prototype-style definition with formal parameters declared in the header, and the default creation of prototypes from the first reference to a function (if no explicit prototype is provided). The old function declaration and definition forms are also supported.

The formal parameter list in a function definition or declaration can end with a comma followed by three periods (,...) or just a comma (,) to indicate that the number of parameters is variable. The latter is supported only for compatibility with older versions of the compiler and should not be used in new code.

12 The number sign (#) introducing the preprocessor directive can be preceded by any combination of white-space characters. White space can also separate the number sign and the preprocessor keyword.

In addition to preprocessor directives, the source file can contain pragmas. Pragmas, like directives, are introduced by a number sign as the first non-white-space character in a line. The action defined by a particular pragma is implementation dependent.

Three preprocessor-only operators are supported: the "stringizing" operator (#), the concatenation or "token-pasting" operator (##), and the **defined** operator.

12.3 The new combination **#if defined** (*identifier*) is intended to supplant the **#ifdef** and **#ifndef** directives. Use of the latter directives is discouraged.

The new directive **#elif** (else if) is designed for use in **#if** and **#if defined** blocks.

14.1 A structure or union can be assigned to another structure or union of the same type. Structures and unions can be passed by value to functions and returned by functions.

In expressions involving the structure-pointer operator (->), the expression preceding the arrow must have the same type (or must be cast to the same type) as the structure to which the member on the right-hand side of the arrow belongs.

17 The listed anachronisms are not recognized.

Appendix B

Syntax Summary

Tokens B-1
- Keywords B-1
- Identifiers B-2
- Constants B-2
- Strings B-5
- Operators B-6
- Separators B-6

Expressions B-7

Declarations B-9

Statements B-14

Definitions B-15

Preprocessor Directives B-16

Pragmas B-17

Tokens

:eyword
dentifier
:onstant
'tring
)perator
'eparator

Keywords

ıuto	**double**	**int**	**struct**
)reak	**else**	**long**	**switch**
:ase	**enum**	**register**	**typedef**
:har	**extern**	**return**	**union**
:onst	**float**	**short**	**unsigned**
:ontinue	**for**	**signed**	**void**
lefault	**goto**	**sizeof**	**volatile†**
lo	**if**	**static**	**while**

† Semantics not yet implemented

The following identifiers may be keywords in some implementations. For nformation, see your compiler guide.

:decl
'ar
'ortran
ıuge
ıear
)ascal

Identifiers

identifier:
    letter
    underscore
    identifier letter
    identifier underscore
    identifier digit

letter—one of the following:
    a b c d e f g h i j k l m
    n o p q r s t u v w x y z
    A B C D E F G H I J K L M
    N O P Q R S T U V W X Y Z

underscore:
    _

digit—one of the following:
    0 1 2 3 4 5 6 7 8 9

Constants

constant:
    integer-constant
    long-constant
    floating-point-constant
    char-constant
    enum-constant

integer-constant:
0
decimal-constant
octal-constant
hexadecimal-constant

decimal-constant:
nonzero-digit
decimal-constant digit

nonzero-digit—one of the following:
1 2 3 4 5 6 7 8 9

octal-constant:
0*octal-digit*
octal-constant octal-digit

octal-digit—one of the following:
0 1 2 3 4 5 6 7

hexadecimal-constant:
0x*hexadecimal-digit*
0X*hexadecimal-digit*
hexadecimal-constant hexadecimal-digit

hexadecimal-digit—one of the following:
0 1 2 3 4 5 6 7 8 9
a b c d e f
A B C D E F

long-constant:
integer-constant **l**
integer-constant **L**

floating-point-constant:
fractional-constant exponent
fractional-constant
digit-seq exponent

fractional-constant:
digit-seq . *digit-seq*
cc+
+cc
digit-seq .

digit-seq:
digit
digit-seq digit

exponent:
e *sign digit-seq*
E *sign digit-seq*
e *digit-seq*
E *digit-seq*

sign:
+
-

char-constant:
'*char*'

char:
rep-char
escape-sequence

rep-char:
Any single representable character except the single quotation-mark ('), backslash (\), or new-line character. Note that the single-quotation-mark character cannot be used alone in a character constant, and the double quotation-mark character cannot be used alone in a string literal.

escape-sequence—one of the following:

\'	\"	\\	*d*	*dd*	*ddd*
\x*d*	\x*dd*	\x*ddd*	\a	\b	\f
\n	\r	\t	\v		

enum-constant:
identifier

Strings

string-literal:
""
"*char-seq*"

char-seq:
char
char-seq char

Operators

operator—one of the following:

```
!     ~     ++    --    +
-     *     /     %     <<
>>    <     <=    >     >=
==    !=    |     &     ^
&&    ||    =     +=    -=
=     /=    %=    >>=   <<=
&=    ^=    |=    ?:    ,
[ ]   ( )   .     ->
```

Separators

separator—one of the following:

```
[   ]   (   )   {   }
*   ,   :   =   ;   #
```

Expressions

expression:
    identifier
    constant
    string
    expression(*expression-list*)
    expression(**void**)
    expression[*expression*]
    expression.*identifier*
    expression->*identifier*
    unary-expression
    binary-expression
    ternary-expression
    assignment-expression
    (*expression*)
    (*type-name*)*expression*
    constant-expression

expression-list:
    expression
    expression-list , *expression*

unary-expression:
    unop expression
    sizeof(*expression*)

unop—one of the following:
    - ~ ! * &

lvalue:
    identifier
    expression[*expression*]
    expression.*expression*
    expression->*expression*
    **expression*
    (*type-name*)*expression*
    (*lvalue*)

type-name:
See Section B.3, "Declarations."

binary-expression:
expression binop expression

binop—one of the following:

```
*     /     %     +     -
<<    >>    <     >     <=
>=    ==    !=    &     |
^     &&    ||    ,
```

ternary-expression:
expression **?** *expression* **:** *expression*

assignment-expression:
lvalue++
lvalue--
++lvalue
--lvalue
lvalue assignment-op expression

assignment-op—one of the following:

```
=     *=          /=     %=    +=    -=
<<=   >>=   &=    /=     ^=
```

constant-expression:
identifier
constant
(*type-name*)*constant-expression*
unary-expression
binary-expression
ternary-expression
(*constant-expression*)

Declarations

declaration:
    sc-specifier type-specifier-list declarator-list;
    type-specifier-list declarator-list;
    sc-specifier declarator-list;
    typedef *type-specifier-list declarator-list*;

sc-specifier:
    auto
    extern
    register
    static

type-specifier:
    char
    double
    long double
    enum-specifier
    float
    int
    long
    short
    struct-specifier
    typedef-name
    union-specifier
    unsigned
    signed
    const
    volatile
    void

type-specifier-list:
    type-specifier
    type-specifier-list type-specifier

enum-specifier:
enum *tag* {*enum-list*}
enum {*enum-list*}
enum *tag*

tag:
identifier

enum-list:
enumerator
enum-list , *enumerator*

enumerator:
identifier
identifier = *constant-expression*

struct-specifier:
struct *tag* {*member-declaration-list*}
struct {*member-declaration-list*}
struct *tag*

member-declaration-list:
member-declaration
member-declaration-list member-declaration

member-declaration:
type-specifier declarator-list;
type-specifier identifier : *constant-expression*;
type-specifier : *constant-expression*;

declarator-list:
declarator
declarator = *initializer*
declarator-list , *declarator*

declarator:
    identifier
    modifier-list identifier
    declarator[ ]
    declarator[*constant-expression*]
    **declarator*
    declarator(**void**)
    declarator([*formal-parameter-list*])
    (*declarator*)

modifier-list
    modifier
    modifier-list modifier

formal-parameter-list
    formal-parameter
    formal-parameter-list, *formal-parameter*
    formal-parameter-list, ...
    formal-parameter-list,
formal-parameter
    sc-spec type-spec declarator
    sc-spec type-spec abstract-declarator

arg-type-list:
    type-name
    arg-type-list, *type-name*
    arg-type-list, ...
    arg-type-list,

type-name:
    type-specifier
    type-specifier abstract-declarator

abstract-declarator:
*
*modifier**
[ ]
(*arg-type-list*)
**abstract-declarator*
*abstract-declarator**
abstract-declarator[ ]
abstract-declarator[*constant-expression*]
[ ]*abstract-declarator*
[*constant-expression*]*abstract-declarator*
abstract-declarator(**void**)
abstract-declarator(*formal-parameter-list*)
abstract-declarator(*arg-type-list*)
(*abstract-declarator*)

initializer:
expression
{*initializer-list*}

initializer-list:
initializer
initializer-list, *initializer*

typedef-name:
identifier

union-specifier:
union *tag* {*member-declaration-list*}
union {*member-declaration-list*}
union *tag*

modifier:
cdecl
far
fortran
huge
near
pascal

modifier-list
    modifier
    modifier-list modifier

Statements

statement:
break;
case *constant-expression* **:** *statement*
compound-statement
continue;
default : *statement*
do *statement* **while**(*expression*);
expression;
for ([*expression*];[*expression*];[*expression*]) *statement*;
goto *identifier*;
identifier **:** *statement*
if (*expression*) *statement* [**else** *statement*];
return [*expression*];
switch (*expression*) *statement*
while (*expression*) *statement*

compound-statement:
{[*declaration-list*][*statement-list*]}

declaration-list:
declaration
declaration-list declaration

statement-list:
statement
statement-list statement

Definitions

definition:
    function-definition
    data-definition

function-definition:
    [*sc-specifier*] [*type-specifier*] *declarator* ([*formal-parameter-list*])
        compound-statement
    [*sc-specifier*] [*type-specifier*] *declarator* ([*parameter-list*])
        [*parameter-decs*] *compound-statement*

    parameter-list:
        fixed-parameter-list
        variable-parameter-list

    fixed-parameter-list:
        identifier
        parameter-list , *identifier*

    variable-parameter-list:
        fixed-parameter-list, ...
        fixed-parameter-list,

    parameter-decs:
        declaration
        declaration-list declaration

    data-definition:
        declaration

Preprocessor Directives

directive:
#define *identifier* [([*parameter-list*])][*token-seq*]
#elif *restricted-constant-expression*
#else
#endif
#if *restricted-constant-expression*
#ifdef *identifier*
#ifndef *identifier*
#include "*string*"
#include <*string*>
#line *digit-seq*
#line *digit-seq string*
#undef *identifier*

token-seq:
token
token-seq token

restricted-constant-expression:
defined (*identifier*)
Any *constant-expression* except **sizeof** expressions, casts, and enumeration constants

Pragmas

pragma:
    #pragma *char-seq*

Index

Special Characters

>> (right-shift operator) 5-24
<> (angle brackets) 8-12
-> (arrow), in member-selection expressions 5-7
> (greater-than operator) 5-25
>= (greater-than-or-equal-to operator) 5-25
-> (member-selection operator) 5-7, A-5
{ } (braces) 4-50, 6-1, 6-4
[ ] (brackets) 1-7
[ ] (brackets)
  array declarators, used in 4-9, 4-26
? : (conditional operator) 5-30
( ) (function modifier) 4-9
? : (ternary operator) 5-14, 5-30
(token-pasting operator)
  described 8-3, 8-6
  differences from Kernighan and Ritchie 8-1
+ (addition operator) 5-22
& (address-of operator) 5-18
- (arithmetic negation operator) 5-16
\ (backslash character) 2-5, 2-6
& (bitwise-AND operator) 5-27
~ (bitwise-complement operator) 5-16
^ (bitwise-exclusive-OR operator) 5-27
| (bitwise-inclusive-OR operator) 5-27
[ ] (brackets)
  subscript expressions, used in 5-4, 5-6
: (colon), with bitfield structure members 4-22
, (comma)
  argument-type lists, used in 4-35
  declarations, used in 4-17, 4-33
  function calls, used in 5-3, 7-16
  initialization, used in 4-50
  sequential-evaluation operator 5-29
-- (decrement operator) 5-34
/ (division operator) 5-21
... (ellipsis notation) 4-35
== (equality operator) 5-25
++ (increment operator) 5-34
* (indirection operator) 5-17
!= (inequality operator) 5-25
<< (left-shift operator) 5-24
< (less-than operator) 5-25
<= (less-than-or-equal-to operator) 5-25
&& (logical-AND operator) 5-28
! (logical-NOT operator) 5-16
|| (logical-OR operator) 5-28
. (member-selection operator) 5-7
* (multiplication operator) 5-21
# (number sign) 8-1
~ (one's complement operator) 5-16
( ) (parentheses)
  complex declarators, used in 4-10
  expressions, used in 5-10
  function calls, used in 5-3
  function declarators, used in 4-9, 4-33
  macros, used in 8-9
* (pointer modifier) 4-9, 4-28
% (remainder operator) 5-21
= (simple-assignment operator) 5-35
(stringizing preprocessor operator) 8-3
- (subtraction operator) 5-23
- (two's complement operator) 5-16
+ (unary plus operator) 5-16
_ (underscore character) 2-17

A

Abstract declarators 4-58
Actual arguments *See* Arguments, actual
Addition operator (+) 5-22
Address-of operator (&) 5-18
Aggregate data-type category 4-7
Aggregate types
  array 4-26
  initialization 4-48, 4-50
  structure 4-21
  union 4-25
Anachronisms A-5
AND operators
  bitwise (&) 5-27
  logical (&&) 5-28
Angle brackets (<>) 8-12
ANSI standard
  enabling ANSI 1-1
  extensions 1-1
Apostrophe (') *See* Escape sequences
argc parameter 3-7
Argument type checking
  conversions 7-20
  default prototypes 7-14
  formal parameters 7-9
  function calls 7-20
  variable-length parameter list 4-36

Arguments
  actual
    conversion 7-20
    evaluation, order of 7-17
    macros 8-5, 8-9
    passing 7-19
    pointers 7-17, 7-20
    side effects 7-17
    type checking 7-20
    variable number 7-22
  command line 3-7
  formal *See* Formal parameters
  main function 3-7
  variable number 4-35, 7-22
Argument-type lists
  abstract declarator, used with 4-58
  default prototype 7-14
  described 4-34
  pointer arguments, used with 4-36
  variable length 4-35
  void *, used with 4-36
  void keyword, used with 4-36
argv parameter 3-7
Arithmetic conversions 5-15, A-3
Arithmetic data-type category 4-7
Arithmetic negation operator (-) 5-16
Array declarators ([ ]) 4-9, 4-26
Arrays
  declarations 4-9, 4-26
  elements 5-4
  identifiers 5-2
  initialization 4-48, 4-50, 4-54
  multidimensional 4-27, 5-6
  references to 5-2, 5-4
  storage 4-27, 5-6
  subscripts 5-4
asm keyword A-1
Assignments
  conversions 5-41
  defined 5-1
  expressions 5-9
  operators 5-32
Associativity
  modifiers 4-10
  operators 5-37
auto storage class 4-40, 4-44, 4-48

B

Backslash character (\) 2-5, 2-6
Backspace escape sequence (\b) 2-5
Bell character (\a) 2-5, A-1
Binary expressions 5-9
Binary operators, table 2-7, 5-14
Bitfields 4-22, 4-23, A-4
Bitwise-AND operator (&) 5-27
Bitwise-complement operator (~) 5-16
Bitwise-exclusive-OR operator (^) 5-2
Bitwise-inclusive-OR operator (|) 5-2
Blocks 3-8
Braces ({ })
  compound statement, used in 6-1, 6
  initialization, used in 4-50
Brackets
  array declarators, used in 4-9, 4-26
  subscript expressions, used in 5-4, 5
Brackets ([ ]) 1-7
Branch statements 6-13, 6-18
break statement 6-3
Bytes, size of A-3

C

C character set 2-2
Call by reference *See* Passing by refer
Call by value *See* Passing by value
Calls *See* Function calls
Carriage-return escape sequence (\r) 2
case keyword 6-18
Case sensitivity 2-3, 2-17
Casts *See* type casts
cdecl keyword 2-19, 4-14, A-1
char type
  conversion 5-42
  described 4-2
  differences from Kernighan and Rit
  range of values 4-4
  storage 4-4
Character constants
  differences from Kernighan and Rit
  form 2-13
  sign extension 2-14
  type 2-14
Character sets 2-2
Characters
  backslash (\) 2-5, 2-6
  backspace escape sequence 2-5
  bell (\a) 2-5, A-1

Characters *(continued)*
carriage-return escape sequence (\r) 2-5
case 2-3, 2-17
continuation (\) 2-6
differences from Kernighan and Ritchie A-1
digits 2-3
double-quotation-mark escape sequence 2-5
escape sequences 2-5
form-feed escape sequence (\f) 2-5
hexadecimal escape sequences 2-5
horizontal tab escape sequence (\t) 2-5
letters 2-3
new-line escape sequence (\n) 2-5
octal escape sequences 2-5
punctuation 2-4
single-quotation-mark escape sequence (\') 2-5
special 2-4
underscore (_) 2-3
vertical-tab escape sequence (\v) 2-5
white space 2-3, 2-5
Colon (:), with bitfield structure members 4-22
Comma (,)
argument-type lists, used in 4-35
declarations, used in 4-17, 4-33
function calls, used in 5-3, 7-16
initialization, used in 4-50
sequential-evaluation operator (,) 5-29
Command-line arguments 3-7
Comments 2-20
Compilation, conditional 8-14, 8-18
Complement operators (~) 5-16
Complex declarators 4-10, 4-14
Compound statements 6-4
Compound-assignment operators 5-36
Concatenation of string literals 2-15
Concatenation operator, differences from Kernighan and Ritchie A-5
Conditional compilation 8-14, 8-18
Conditional operator (? :) 5-30
Conditional statements 6-13, 6-18
const
keyword A-1
pointer modifier, used as 4-28
type specifier 4-3
Constant expressions
case 6-18
conversion 4-7
defined (identifier) 8-15
described 5-1
directives, used in 5-11, 8-15
form 5-11
initializers 5-11
restricted 5-11, 8-15
Constant expressions *(continued)*
switch statement, used in 6-18
Constants
character *See* Character constants
conversion 4-7
decimal integer 2-10, 2-11
described 2-10
enumeration 4-20
floating point 2-12, 4-6
hexadecimal integer
conversion 2-11, 4-7
form 2-10
type 2-11
integer
differences from Kernighan and Ritchie A-1
form 2-10
long 2-12
negative 2-11
octal *See* Octal constants
type 2-11
manifest 8-3, 8-4, 8-11
string *See* String literals
summarized B-2
type 5-2
Continuation character (\) 2-6
continue statement 6-5
Control, returning 6-16
Conventions, notational 1-5
Conversions
actual arguments 7-20
assignment 5-41
constant expressions 4-7
constants 4-7
enumeration types 5-49
floating types 5-46
formal parameters 7-9, 7-20
function call 5-50, 7-20
function prototypes 5-50
hexadecimal constants 4-7
implicit 5-49
octal constants 4-7
operator 5-50
pointer types 5-48
range of values, effects on 4-7
signed integral types 5-41, 5-49
structure types 5-49
type cast 5-50
union types 5-49
unsigned integral types 5-44, 5-49
usual arithmetic 5-15, A-3
void type 5-49

D

Data type categories 4-7
Data types *See* Types
Decimal integer constants 2-10, 2-11
Declaration modifiers 4-14
Declarations
  defining 3-3
  form 4-1
  formal parameter names 4-33
  formal parameters 7-7, 7-8
  forward *See* Function declarations (prototypes)
  function *See* Function declarations (prototypes)
  pointer 4-9, 4-28, 7-14
  referencing 3-3
  storage allocation 3-3
  summarized B-9
  type 4-55
  typedef 4-55, 4-56
  variable
    array 4-26
    default storage class 4-42
    described 3-2
    enumeration 4-19
    external 4-40
    form 4-17
    global 4-41
    internal 4-40
    local 4-44
    multidimensional arrays 4-27
    pointer 4-28
    simple 4-18
    structure 4-21
    union 4-25
Declarators
  abstract 4-58
  array 4-9
  complex 4-10, 4-14
  described 4-9
  function 4-9
  parentheses, enclosed in 4-10
  pointer 4-9
  special keywords, used with 4-14
Decrement operator (--) 5-34
default keyword 6-18
Default return type 4-33
Default storage class
  function declarations 4-47
  global variable declarations 4-42
  local variable declarations 4-44
#define directive 8-4
defined (identifier) constant expression 8-15
defined preprocessor operator 8-1, 8-3, A-5
Defining declaration 4-41
Definitions
  function
    described 3-3, 7-1, 7-3
    full prototype form 7-3
    obsolete form 7-4
    storage class 7-4
    summarized B-15
    visibility 7-4
  removing 8-11
  storage allocation 3-3
  variable
    described 3-3, 4-41
    storage class 4-41
    summarized B-15
    visibility 4-41, 4-44
Digits 2-3
Dimensions *See* Multidimensional arrays
Directives
  constant expressions, used in 5-11, 8-15
  #define 8-4
  described 3-2, 8-1
  differences from Kernighan and Ritchie A-4
    A-5
  #elif
    described 8-14
    differences from Kernighan and Ritchie A-5
    nesting 8-15
  #else 8-14, 8-15
  #endif 8-14, 8-15
  #if 8-14, 8-15, A-5
  #ifdef 8-18, A-5
  #ifndef 8-18, A-5
  #include 8-12
  lifetime 3-5
  #line 8-19
  restricted constant expressions 5-11
  summarized B-16
  #undef 8-11
Division operator (/) 5-21
do statement
  described 6-6
  execution
    continuation of 6-5
    termination of 6-3
Double quotation mark ( ) *See* Quotation mark
double type
  conversion 5-47
  described 4-2
  internal representation 4-6
  range of values 4-4

double type *(continued)*
range of values 4-4
storage 4-4
Double-quotation-mark escape sequence *See* Escape sequences

E

Elements 5-4, 5-6
#elif directive
described 8-14
differences from Kernighan and Ritchie A-5
nesting 8-15
Ellipsis notation (...) 1-6
#else directive 8-14, 8-15
else keyword 6-13
#endif directive 8-14, 8-15
entry keyword A-1
enum type specifier 4-19, A-1
Enumeration constants 3-14, 4-20
Enumeration expressions 5-2
Enumeration set 4-19
Enumeration types
conversion 5-49
declaration 4-19, 4-55
described 4-2
differences from Kernighan and Ritchie A-2
identifiers 5-2
range of values 4-4
storage 4-4, 4-19
tags
defined 3-14
naming class 3-14
type declarations 4-55
variable declarations 4-19
Enumeration variables 4-17
envp 3-7
Equality operator (==) 5-25
Escape sequences
described 2-5
differences from Kernighan and Ritchie A-1
double quotation mark 2-5
\' (single quotation mark) 2-5
\a (bell) 2-5
\b (backspace) 2-5
\\ (backslash) 2-5
\f (form feed) 2-5
\n (new line) 2-5
\r (carriage return) 2-5
\t (horizontal tab) 2-5
\v (vertical tab) 2-5
Evaluation
Evaluation *(continued)*
order of 5-28, 5-38
unary plus (+), forcing order with 5-16
Execution *See* Program execution
Exit from functions 6-16
Exponents 2-12
Expressions
assignment 5-9
binary 5-9
case constant 6-18
constant *See* constant expressions
described 5-1
enumeration 5-2
floating type 5-2
function call 5-4
grouping 5-37
integral 5-2
list 5-3
lvalue 5-33
member selection 5-7, A-5
operators, used in 5-9
order of evaluation 5-38
parentheses, enclosed in 5-10
pointer 5-2
side effects 5-12
statements 6-7
string literal 5-3
structure 5-2
subscript 5-4, 5-6
summarized B-7
switch 6-18, A-4
ternary 5-9
type cast 5-10
unary 5-9
union 5-2
Extensions to ANSI C standard 1-1
extern storage class
described 4-40
function
declarations 4-46
definitions 7-4
function declarations 7-13
global variables 4-41
local variables 4-44
External declarations
described 4-40
function 4-46
External level 3-3

F

far keyword
  conversions 7-20
  described 4-14
  differences from Kernighan and Ritchie A-1
  listed 2-19
Fields *See* Bitfields
__FILE__ identifier 8-19
Files
  inclusion 8-12
  name, changing 8-19
  nesting 8-13
float type
  conversion 5-46
  described 4-2
  internal representation 4-6
  range of values 4-4
  storage 4-4
Floating point
  constants
    form 2-12
    internal representation 4-6
    negative 2-12
  data-type category 4-7
  expressions 5-2
  identifiers 5-2
  types
    described 4-2
    internal representation 4-6
  types, conversion of 5-46
for statement
  described 6-9
  execution continuation 6-5
  execution termination 6-3
Forcing evaluation order 5-16
Formal parameters
  conversion 7-9, 7-20
  declaration 7-8
  described 4-34, 7-7
  following function header 7-4
  identifiers 7-9
  list 7-3
  macro 8-4
  names 4-33
  naming class 3-13
  obsolete form 7-8
  storage class 7-9
  type checking 7-9, 7-20
Form-feed escape sequence (\f) 2-5
fortran keyword 2-19, 4-14, A-1
Forward declarations *See* Function declarations (prototypes)
Function
  body 7-4, 7-11
  calls
    argument type checking 7-20
    arguments,variable number of 7-
    conversions 5-50, 7-20
    described 7-1
    expressions 5-4
    form 5-3, 7-16
    indirect 7-17
    operator, used as sequence point
    pointers, use of 7-17
    recursive 7-23
  declarations (prototypes)
    arguments, variable number of 4-
    arguments, without 4-36
    default return type 4-33
    default storage class 4-47
    described 3-2, 7-1, 7-13
    differences from Kernighan and Ritchie A-4
    implicit 7-13
    parameter list 4-36
    pointer 4-33
    pointer arguments 4-36
    return type 4-34, 7-13
    return value 7-12
    storage class 4-46, 4-47, 7-13
    visibility 4-46, 7-13
  definition
    full prototype form 7-3
    obsolete form 7-4
  definitions *See* Definitions function
  modifier ( ) 4-9
  names *See* Identifiers
  pointers 7-14, 7-17
  prototypes
    conversions 5-50
    defined 4-36, 7-1
  return type *See* Return type
  type *See* Return type
Function-like macros 8-3
Functions
  described 7-1
  exit from 6-16
  identifiers 5-3
  main 3-7
  naming class 3-13
  return value 6-16

G

Global
  level 3-3
  lifetime 3-8, 4-40
  variables
    described 3-10
    initialization 4-48
    references to 4-45
  visibility 3-9
Global declarations
  variable 4-41
goto statement 6-11
Greater-than operator (>) 5-25
Greater-than-or-equal-to operator (>=) 5-25

H

Hexadecimal
  constants
    conversion 2-11, 4-7
    differences from Kernighan and Ritchie A-1
    form 2-10
    sign extension 2-11
    type 2-11
  escape sequences 2-5, A-1
Horizontal-tab escape sequence (\t) 2-5
huge keyword
  conversion 7-20
  described 4-14
  differences from Kernighan and Ritchie A-1
  listed 2-19

I

Identifier lists 7-8
Identifiers
  array 5-2
  characters allowed 2-17
  differences from Kernighan and Ritchie A-1
  enumeration 5-2
  __FILE__ 8-19
  floating type 5-2
  formal parameters 7-9
  function 5-3
  integral 5-2
  length 2-17
Identifiers *(continued)*
  __LINE__ 8-19
  modified 4-9
  naming classes 3-13
  pointer 5-2
  structure 5-2
  summarized B-2
  union 5-2
#if directive 8-14, 8-15, A-5
if statement 6-13
#ifdef directive 8-18, A-5
#ifndef directive 8-18, A-5
#include directive 8-12
Include files 8-12, 8-13
Increment operator (++) 5-34
Indirection operator (*) 5-17
Inequality operator (!=) 5-25
Initialization
  arrays 4-48, 4-50, 4-54
  auto storage class 4-48
  constant expressions 5-11
  differences from Kernighan and Ritchie A-4
  fundamental types 4-49
  global variables 4-48
  link time 4-42
  pointers 4-49
  register storage class 4-48
  restrictions 4-48
  static variables 4-48
  string literals 4-54
  structure variables 4-48, 4-50
  union variables 4-48, 4-50
Insertion of files 8-12
int type
  conversion 5-43
  described 4-2
  differences from Kernighan and Ritchie A-2
  portability 4-6
  range of values 4-4, 4-5
  storage 4-4
Integer constants
  decimal 2-10, 2-11
  differences from Kernighan and Ritchie A-1
  hexadecimal 2-10, 2-11
  long 2-12
  negative 2-11
  octal 2-10, 2-11
Integral
  data-type category 4-7
  expressions 5-2
  identifiers 5-2
  types
    conversion 5-41, 5-44, 5-49
    described 4-2

Internal
  declarations 4-40
  representation 4-6, 4-7
Internal level 3-3
Italics 1-5
Iterative statements
  do 6-6
  for 6-9
  while 6-21

K

Keywords
  differences from Kernighan and Ritchie A-1, A-3
  listed 2-19, B-1
  notational conventions 1-5
  special 4-14, 4-29
  statements, used in 6-1
  system dependent 2-19

L

Labeled statements 6-11
Labels
  case 6-18
  default 6-18
  described 6-1
  form 6-11
  naming class 3-14
Left-shift operator (<<) 5-24
Less-than operator (<) *See* Relational operators
Less-than-or-equal-to operator (<=) *See* Relational operators
Letters 2-3
Lifetime
  described 3-8
  directives 3-5
  global 3-8, 4-40
  local 3-8, 4-40
Line control 8-19
#line directive 8-19
__LINE__ identifier 8-19
Lines, continuation 2-6
Linked lists 4-22
_loadds keyword 4-14
Local
  declarations 4-44
  level 3-3
Local *(continued)*
  lifetime 3-8, 4-40
  variables 3-10, 7-12
Logical-AND operator (&&) 5-28
Logical-NOT operator (!) 5-16
Logical-OR operator (||) 5-28
long type
  conversion 5-43
  described 4-2
  differences from Kernighan and Ritch
  range of values 4-4
  storage 4-4
long-double type, conversion 5-47
long-float type 4-2
Loops
  do statement 6-6
  for statement 6-9
  while statement 6-21
Lvalue expressions 5-33

M

Macros
  actual arguments 8-5
  #define directive 8-4
  described 8-3
  empty definition 8-4
  example, with arguments 8-9
  example, with side effects 8-9
  function like 8-3
  object like 8-3
  side effects of arguments 8-5
  #undef, effect of 8-11
Main function 3-7
Manifest constants 8-3, 8-4, 8-11
Members
  bitfields 4-22
  naming class 3-14
  referring to 5-7
  structure 4-21
  union 4-25
Member-selection expressions 5-7, A-5
Member-selection operators (-> and .) 5
Modifiers
  array 4-9, 4-26
  associativity 4-10
  declaration 4-14
  function 4-9
  pointer 4-9, 4-28
  precedence 4-10
Multidimensional arrays 4-27, 5-6
Multiplication operator (*) 5-21

N

Names *See* Identifiers
Naming classes 3-13, A-4
near keyword
  conversions 7-20
  described 4-14
  differences from Kernighan and Ritchie A-1
  listed 2-19
Negation 5-16
Nested visibility 3-10
New-line escape sequence (\n) 2-5
Nongraphic escape sequences 2-5
NOT operator (!) *See* Logical-NOT operator
Notational conventions 1-5
Null statement 6-15
Number sign (#) 8-1

O

Object-like macros 8-3
Octal
  constants
    conversion 2-11, 4-7
    differences from Kernighan and Ritchie A-1
    form 2-10
    sign extension 2-11
    type 2-11
  escape sequences 2-5
One's complement operator (~) 5-16
Operands 5-1
Operators
  addition (+) 5-22
  address of (&) 5-18
  arithmetic negation (-) 5-16
  assignment
    compound 5-36
    listed 5-32
    simple (=) 5-35
  associativity 5-37
  binary
    described 5-14
    table 2-7
  bitwise AND (&) 5-27
  bitwise complement (~) 5-16
  bitwise-exclusive OR (^) 5-27
  bitwise-inclusive OR (|) 5-27
  complement 5-16
  compound assignment 5-36
  conditional (? :) 5-30
Operators *(continued)*
  conversions 5-50
  decrement (--) 5-34
  differences from Kernighan and Ritchie A-5
  division (/) 5-21
  equality (==) 5-25
  expressions, used in 5-9
  increment (++) 5-34
  indirection (*) 5-17
  inequality (!=) 5-25
  left-shift (<<) 5-24
  listed 2-7, B-6
  logical
    described 5-28
    evaluation, order of 5-28
  logical AND (&&) 5-28
  logical NOT (!) 5-16
  logical OR (||) 5-28
  multiplication (*) 5-21
  one's complement (~) 5-16
  precedence 5-37
  preprocessor
    differences from Kernighan and Ritchie A-5
    stringizing A-5
    token pasting A-5
  preprocessor specific, listed 8-3
  relational (>,<,<=,>=) 5-25
  remainder (%) 5-21
  right shift (>>) 5-24
  sequence points, used as 5-12
  sequential evaluation (,) 5-29
  shift (<< and >>) 5-24
  simple assignment (=) 5-35
  sizeof 5-19
  subtraction (-) 5-23
  ternary (?:) 5-14
  ternary (? :) 5-30
  two's complement (-) 5-16
  unary 2-7, 5-14
OR operators
  bitwise exclusive (^) 5-27
  bitwise inclusive (|) 5-27
  logical (||) 5-28
Overview 1-1

P

Parameter list 4-36
Parameters
  argc 3-7
  argv 3-7
  envp 3-7
  formal *See* Formal parameters
  macro 8-4
  main function 3-7
Parentheses
  complex declarators, used in 4-10
  expressions, used in 5-10
  function calls, used in 5-3
  function declarators, used in 4-9, 4-33
  macros, used in 8-9
pascal keyword 2-19, 4-14, A-1
Passing by
  reference 7-19
  value 7-16, 7-19
Pointer
  modifier (*) 4-9, 4-28
  void (void *) 4-29
Pointer data-type category 4-7
Pointers
  adding 5-23
  arithmetic 5-23
  comparisons 5-26
  const, modified by 4-28
  conversion 5-48
  declarations 4-9, 4-28, 7-14
  differences from Kernighan and Ritchie A-2
  expressions 5-2
  function calls through 7-17
  functions 7-14, 7-17
  identifiers 5-2
  implicit conversion 5-49
  initialization 4-49
  storage 4-29
  structure 4-28
  subtraction 5-23
  union 4-29
  volatile, modified by 4-28
Portability 4-6
Pound sign (#) *See* Number sign
Pragmas
  described 3-2, 8-2
  differences from Kernighan and Ritchie A-5
  form 8-21
Precedence
  modifiers 4-10
  operators 5-37
Predefined identifiers 8-19
Preprocessor directives *See* Directives
Preprocessor operators
  described 8-1
  listed 8-3
Program execution 3-7
Program structure 3-1, 3-2
Prototypes, function 4-36, 7-1
Punctuation characters 2-4

Q

Quotation marks
  #include directives, used in 8-12
  notational conventions 1-7
  representation 2-5, A-1

R

Recursion 7-23
Reference, passing by 7-19
References to global variables 4-41, 4-42, 4-45
Referencing declarations 4-41
register storage class
  described 4-44
  initialization 4-48
  lifetime 4-40
  local variables 4-44
Relational operators (>,<,<=,>=) 5-25
Representable character set 2-2
Representation, internal 4-6, 4-7
Reserved words *See* Keywords
Restricted constant expressions 5-11, 8-15
return statement 6-16
Return type
  declaration 7-13
  default 4-33
  described 4-34, 7-5
  implicit 7-13
Return value 6-16, 7-12
Right-shift operator (>>) 5-24

S

_saveregs keyword 4-14
Scalar data-type category 4-7
Selection statements 6-13, 6-18
Sensitivity, case 2-3
Separators B-6
Sequence points
  described 5-1, 5-12
  listed 5-12
  operators, other than 5-12
Sequential-evaluation operator (,) 5-29
Shift operators (<< and >>) 5-24
short type
  conversion 5-42
  described 4-2
  differences from Kernighan and Ritchie A-2
  range of values 4-4
  storage 4-4
Side effects
  expressions 5-1, 5-12
  macros, used with 8-5, 8-9
  sequence points, used with 5-12
Sign extension 2-11, 2-14
signed
  char type 4-2, A-3
  int type 4-2
  keyword 4-3, A-2
  long int type A-3
  long type 4-2, A-3
  short int type 4-2, A-3
  short type 4-2, A-3
  type 4-2, A-2
Simple variable declarations 4-18
Simple-assignment operator (=) 5-35
Single-quotation-mark escape sequence (') *See* Escape sequences
sizeof operator 5-19
Source files 3-5
Special characters 2-4
Special keywords
  conversions 7-20
  declarators, used with 4-29
  differences from Kernighan and Ritchie A-1
Standard directories 8-12
Statement labels
  described 6-1
  form 6-11
  naming class 3-14
Statements
  body 6-1
  break 6-3
  compound 6-4
Statements *(continued)*
  continue 6-5
  do 6-6
  expression 6-7
  for 6-9
  form 6-1
  goto 6-11
  if 6-13
  keywords 6-1
  labeled 6-1, 6-11
  listed 6-1
  null 6-15
  return 6-16
  summarized B-14
  switch 6-18
  while 6-21
static storage class
  described 4-40
  function
    declarations 4-46, 7-13
    definitions 7-4
  global variables 4-41
  initialization 4-48
  local variables 4-44
Storage
  bitfields 4-23
  global 4-40
  local 4-40
  type
    char 4-4
    double 4-4
    float 4-4
    int 4-4, 4-5
    long 4-4
    unsigned char 4-4
    unsigned int 4-4, 4-5
    unsigned long 4-4
    void 4-4
  types
    array 4-27, 5-6
    enumeration 4-4, 4-19
    pointer 4-29
    structure 4-23
    union 4-25
Storage allocation for variables 3-3
Storage classes
  described 4-40
  formal parameters 7-9
  function
    declarations 7-13
  function declarations 4-47
  function definitions 7-4
  global variable declarations 4-42
  local variable declarations 4-44

Storage-class specifiers
  auto 4-40, 4-44
  extern *See* extern storage class
  listed 4-40
  register 4-40, 4-44
  static *See* static storage class
String concatenation 2-15
String literals
  concatenation 2-15
  form 2-14, 5-3
  initializers 4-54
  length 2-16, 5-3
  storage 2-16
  type 2-16
Stringizing preprocessor operator (#)
  described 8-3, 8-5
  differences from Kernighan and Ritchie A-5
Strings *See* String literals
struct type-specifier 4-21
Structures
  conversion 5-49
  declaration 4-21, 4-55
  differences from Kernighan and Ritchie A-3, A-4, A-5
  expressions 5-2
  identifiers 5-2
  initialization 4-48, 4-50
  members *See* Members
  pointers to 4-29
  storage 4-23
  tags
    naming class 3-14
    type declarations 4-55
    variable declarations 4-22
Subscript expressions 5-4, 5-6
Subtraction operator (-) 5-23
switch statement
  constant expressions, used in 6-18
  described 6-18
  differences from Kernighan and Ritchie A-4
  termination of execution 6-3
Symbolic constants *See* Manifest constants
Syntax
  conventions *See* Notational conventions
  summary B-1
System-dependent keywords 2-19

T

Tab escape sequences 2-5
Tags
  enumeration 4-19, 4-55
  naming class 3-14
  structure 4-22, 4-55
  union 4-55
Ternary expressions 5-9
Ternary operator (?:) 5-14
Ternary operator (? :) 5-30
Token-pasting preprocessor operator (##
  described 8-3, 8-6
  differences from Kernighan and Ritchi
Tokens 2-7, 2-22, B-1
Transfer statements
  break 6-3
  continue 6-5
  goto 6-11
  labeled statements 6-11
Two's complement operator (-) 5-16
Type
  checking *See* Arguments
  declarations 4-55
  modifiers
    differences from Kernighan and Ritchie A-3
  names
    argument-type lists, used in 4-36
    described 4-58
    sizeof, used with 5-19
    void 7-20
  specifiers
    abbreviations 4-3
    const 4-3
    differences from Kernighan and Ritchie A-2
    enum 4-2, 4-19
    fundamental types 4-2
    struct 4-21
    union 4-25
    volatile 4-3
Type-cast conversions 5-50
Type-cast expressions
  constraints 5-10
  defined 5-10
  void, to and from 5-10
typedef
  declarations 4-55, 4-56
  types 3-14, 4-56
Types
  array
    declaration 4-9, 4-26

Types *(continued)*
array *(continued)*
initialization 4-48, 4-50, 4-54
multidimensional 4-27
storage 4-27, 5-6
char *See* char type
const
described 4-3
pointers, used with 4-29
conversions *See* Conversions
differences from Kernighan and Ritchie A-2
double 4-2, 4-4, 4-6
enumeration *See* Enumeration types
float *See* float type
floating point
described 4-2
internal representation 4-6
function *See* Return type
fundamental
declaration 4-18
described 4-2
differences from Kernighan and Ritchie A-2
initialization 4-49
listed 4-2
range of values 4-4
storage 4-4
int *See* int type
integral
conversion 5-41, 5-44, 5-49
described 4-2
long double, differences from Kernighan and Ritchie A-2
long float A-2
long *See* long type
pointer
conversion 5-48
declaration 4-9, 4-28
implicit conversion 5-49
initialization 4-49
storage 4-29
short *See* short type
signed
char 4-2, A-3
int 4-2
long 4-2
short 4-2
structure
conversion 5-49
declaration 4-21, 4-55
initialization 4-48, 4-50
pointers to 4-29
storage 4-23
typedef 3-14, 4-56
Types *(continued)*
union
conversion 5-49
declaration 4-25, 4-55
initialization 4-48, 4-50
pointers to 4-29
storage 4-25
unsigned char *See* unsigned char type
unsigned int *See* unsigned int type
unsigned long *See* unsigned long type
unsigned short *See* unsigned short type
user defined 4-55, 4-56
void 4-3, 4-4
volatile
described 4-3
pointers, used with 4-29

U

Unary expressions 5-9
Unary operators, table 2-7, 5-14
Unary plus operator (+) 5-16
#undef directive 8-11
Underscore character (_) 2-3, 2-17
Union declarations
types 4-55
variables 4-25
union type specifier 4-25
Unions
conversion 5-49
declaration 4-25, 4-55
differences from Kernighan and Ritchie A-4, A-5
expressions 5-2
identifiers 5-2
initialization 4-48, 4-50
members
described 4-25
naming class 3-14
referring to 5-7
pointers to 4-29
storage 4-25
tags 3-14, 4-55
unsigned
char type
conversion 5-44
described 4-2
differences from Kernighan and Ritchie A-2, A-3
range of values 4-4
storage 4-4
int type

unsigned *(continued)*
  int type *(continued)*
    conversion 5-46
    described 4-2
    portability 4-6
    range of values 4-4, 4-5
    storage 4-4
  keyword 4-3, A-2
  long int type *See* unsigned long type
  long type
    conversion 5-45
    described 4-2
    differences from Kernighan and Ritchie A-2, A-3
    range of values 4-4
    storage 4-4
  short int type *See* unsigned short type
  short type
    conversion 5-44
    described 4-2
    differences from Kernighan and Ritchie A-3
    range of values 4-4
    storage 4-4
  type 4-2, A-2
Unspecified type, pointer to (void *) 4-29
User-defined types *See* Types
Usual arithmetic conversions 5-15, A-3

V

Values
  range of 4-4, 4-5, 4-7
Values, passing by 7-16, 7-19
Variable names *See* Identifiers
Variables
  array
    declaration 4-26
    initialization 4-50, 4-54
    storage 4-27
  auto 4-40, 4-44, 4-48
  communal 4-42
  declarations
    array 4-9, 4-26, 4-27
    described 3-2
    enumeration 4-19
    external 4-40
    form 4-17
    fundamental types 4-18
    global 4-41, 4-42, 4-44
    internal 4-40
    local 4-44
Variables *(continued)*
  declarations *(continued)*
    multidimensional arrays 4-27
    pointer 4-28
    simple 4-18
    structure 4-21
    summarized B-9
    union 4-25
    visibility 4-41
  definitions
    described 3-3, 4-41
    summarized B-15
    visibility 4-41, 4-44
  enumeration 4-19
  extern 4-41, 4-45
  fundamental types 4-18, 4-49
  global 3-10, 4-41, 4-45
  lifetime
    global 3-8, 4-40, 4-48
    local 3-10, 7-12
  local 3-10, 7-12
  multidimensional arrays 4-27, 5-6
  naming class 3-13, A-4
  pointer 4-28, 4-29, 4-49
  register 4-44, 4-48
  simple 4-18
  static 4-41, 4-45, 4-48
  storage allocation 3-3
  structure 4-21, 4-23, 4-50
  union 4-25, 4-50
  visibility 4-41
Vertical-tab escape sequence (\v) 2-5, 4
Visibility
  described 3-8
  function declarations 4-46, 7-13
  function definitions 7-4
  global 3-9
  nested 3-10
  variable declarations 4-41
  variable definitions 4-41, 4-44
void
  argument-type list 4-34, 4-36
  formal parameter list, used in A-2
  function-return type 4-34
  keyword A-1
  pointer modifier, used as A-2
  pointer to 4-29
  type name 7-20
void type
  conversion 5-49
  described 4-2, 4-3
  range of values 4-4
  storage 4-4
  type specifier A-2

volatile
keyword A-1
pointer modifier, used as 4-28
type specifier 4-3

W

while statement
described 6-21
execution, continuation of 6-5
execution, termination of 6-3
White-space characters 2-3, 2-5