MPLAB® XC32 C/C++ Compiler User's Guide for PIC32M MCUs

XC32 Compiler for PIC32M

Notice to Development Tools Customers

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Documents are identified with a DS number located on the bottom of each page. The DS format is DS<DocumentNumber><Version>, where <DocumentNumber> is an 8-digit number and <Version> is an uppercase letter.

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1. Preface

MPLAB® XC32 C/C++ Compiler for PICM MCUs documentation and support information is discussed in this section.

1.1. Conventions Used in This Guide

The following conventions may appear in this documentation. In most cases, formatting conforms to the *OASIS Darwin Information Typing Architecture (DITA) Version 1.3 Part 3: All-Inclusive Edition*, 19 June 2018.

Table 1-1. Documentation Conventions

Description	Implementation	Examples
References	DITA: cite	*MPLAB® XC32 C/C++ Compiler User's Guide for PIC32M MCUs.*
Emphasized text	Italics	...is the *only* compiler...
A window, window pane or dialog name.	DITA: wintitle	the **Output** window. the **New Watch** dialog.
A field name in a window or dialog.	DITA: uicontrol	Select the **Optimizations** option category.
A menu name or item.	DITA: uicontrol	Select the **File** menu and then **Save**.
A menu path.	DITA: menucascade, uicontrol	**File** > **Save**
A tab	DITA: uicontrol	Click the **Power** tab.
A software button.	DITA: uicontrol	Click the **OK** button.
A key on the keyboard.	DITA: uicontrol	Press the **F1** key.
File names and paths.	DITA: filepath	`C:/Users/User1/Projects`
Source code: inline.	DITA: codeph	Remember to `#define START` at the beginning of your code.

Source code: block.	DITA: codeblock	An example is:
		`#include <xc.h>`
		`main(void) {`
		`  while(1);`
		`}`

User-entered data.	DITA: userinput	Type in a device name, for example `PIC18F47Q10`.
Keywords	DITA: codeph	`static`, `auto`, `extern`
Command-line options.	DITA: codeph	`-Opa+, -Opa-`
Bit values	DITA: codeph	`0, 1`
Constants	DITA: codeph	`0xFF, 'A'`
A variable argument.	DITA: codeph + option	*`file`*`.o`, where *`file`* can be any valid file name.
Optional arguments	Square brackets [ ]	`xc8 [`*`options`*`] `*`files`*
Choice of mutually exclusive arguments; an OR selection.	Curly brackets and pipe character: { | }	`errorlevel {0|1}`
Replaces repeated text.	Ellipses...	*`var_name`* `[, `*`var_name`*`...]`

Represents code supplied by user.	Ellipses...	`void main (void)`
		`{ ...`
		`}`

A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.	N'Rnnnn	4'b0010, 2'hF1

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Table 1-1. Documentation Conventions (continued)

Description	Implementation	Examples
Device Dependent insignia. Specifies that a feature is not supported on all devices. Please see your device data sheet for details.	[DD]	Assembler Special Operators

1.2. Recommended Reading

The MPLAB® XC32 language toolsuite for PIC32 MCUs consists of a C compilation driver (`xc32-gcc`), a C++ compilation driver (`xc32-g++`), an assembler (`xc32-as`), a linker (`xc32-ld`), and an archiver/librarian (`xc32-ar`). This document describes how to use the MPLAB XC32 C/C++ Compiler. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

Release Notes (Readme Files)

For the latest information on Microchip tools, read the associated Release Notes (HTML files) included with the software.

MPLAB® XC32 Assembler, Linker and Utilities User's Guide (DS50002186)

A guide to using the 32-bit assembler, object linker, object archiver/librarian and various utilities.

Microchip Unified Standard Library Reference Guide (DS50003209)

This guide details the functions, types, and preprocessor macros provided by the standard libraries that ship with the compiler.

PIC32 Configuration Settings

Lists the Configuration Bit settings for the Microchip PIC32 devices supported by the `#pragma config` of the MPLAB XC32 C/C++ Compiler.

Device-Specific Documentation

The Microchip website contains many documents that describe 32-bit device functions and features. Among these are:

- Individual and family data sheets
- Family reference manuals
- Programmer's reference manuals

C Standards Information

International Standardization Organization (ISO) and International Electrotechnical Commission (IEC) – *ISO/IEC 9899:1999 Programming languages — C*. ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

This standard specifies the form and establishes the interpretation of programs expressed in the programming language C. Its purpose is to promote portability, reliability, maintainability and efficient execution of C language programs on a variety of computing systems.

C++ Standards Information

Stroustrup, Bjarne, *C++ Programming Language: Special Edition,* 3rd Edition. Addison-Wesley Professional; Indianapolis, Indiana, 46240.

ISO/IEC 14882:2014 C++ Standard. The ISO C++ Standard is standardized by ISO (The International Standards Organization) in collaboration with ANSI (The American National Standards Institute), BSI (The British Standards Institute) and DIN (The German national standards organization).

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This standard specifies the form and establishes the interpretation of programs expressed in the programming language C++. Its purpose is to promote portability, reliability, maintainability and efficient execution of C++ language programs on a variety of computing systems.

C Reference Manuals

Harbison, Samuel P. and Steele, Guy L., *C A Reference Manual*, Fourth Edition, Prentice-Hall, Englewood Cliffs, N.J. 07632.

Kernighan, Brian W. and Ritchie, Dennis M., *The C Programming Language*, Second Edition. Prentice Hall, Englewood Cliffs, N.J. 07632.

Kochan, Steven G., *Programming In ANSI C*, Revised Edition. Hayden Books, Indianapolis, Indiana 46268.

Plauger, P.J., *The Standard C Library*, Prentice-Hall, Englewood Cliffs, N.J. 07632.

Van Sickle, Ted., *Programming Microcontrollers in C*, First Edition. LLH Technology Publishing, Eagle Rock, Virginia 24085.

GCC Documents

Important:

1. Features and options described in the following GCC and Binutils documentation might not be officially supported by MPLAB XC32. It is recommended that only features described in the Microchip XC32 documentation be used.

gcc.gnu.org/onlinedocs/

sourceware.org/binutils/

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2. Compiler Overview

The MPLAB XC32 C/C++ Compiler for PIC32M MCUs is defined and described in this section.

2.1. Device Description

The MPLAB XC32 C/C++ Compiler fully supports most Microchip PIC32M and MEC 14 devices.

2.2. Compiler Description and Documentation

The MPLAB XC32 C/C++ Compiler is a full-featured, optimizing compiler that translates standard C and C++ programs into 32-bit device assembly language code. The toolchain supports the PIC32M microcontroller families. The compiler also supports many command-line options and language extensions that allow full access to the 32-bit device hardware capabilities, and affords fine control of the compiler's code generator.

The compiler is based on GCC, the GNU Compiler Collection, from the Free Software Foundation.

The compiler is available for several popular operating systems, including Windows®, Linux® and macOS®.

The compiler can run in Free or PRO operating mode. The PRO operating mode is a licensed mode and requires an activation key and Internet connectivity to enable it. Free mode is available for unlicensed customers. The basic compiler operation, supported devices and available memory are identical across all modes. The modes only differ in the level of optimization employed by the compiler.

2.2.1. Conventions

Throughout this manual, the term “the compiler” is often used. It can refer to either all, or some subset of, the collection of applications that form the MPLAB XC32 C/C++ Compiler. Often it is not important to know, for example, whether an action is performed by the parser or code generator application, and it is sufficient to say it was performed by “the compiler.”

It is also reasonable for “the compiler” to refer to the command-line driver (or just driver) as this is the application that is always executed to invoke the compilation process. The C/ASM language driver for the MPLAB XC32 C/C++ Compiler package is called `xc32-gcc`. The C/C++/ASM language driver is called `xc32-g++`. The drivers and their options are discussed in Driver Option Descriptions. Following this view, “compiler options” should be considered command-line driver options, unless otherwise specified in this manual.

Similarly “compilation” refers to all, or some part of, the steps involved in generating source code into an executable binary image.

2.2.2. Language Standards

The MPLAB XC32 compiler is a fully validated tool that conforms to the ISO/IEC 9899:1990 C Programming Language Standard (referred to in this document as C90) as well the ISO/IEC 9899:1999 C Programming Language Standard (C99) for programming languages. In addition, it conforms to the ISO/IEC 14882:2014 C++ Programming Language Standard (C++14). The compiler also supports many PIC32 MCU-oriented language extensions that allow full access to the 32-bit device hardware capabilities, and affords fine control of the compiler's code generator.

2.2.3. Optimization

The compiler uses a set of sophisticated optimization passes that employ many advanced techniques for generating efficient, compact code from C/C++ source. The optimization passes include high-level optimizations that are applicable to any C/C++ code, as well as PIC32M MCU-specific optimizations that take advantage of the particular features of the device architecture.

For more on optimizations, see Optimizations.

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2.2.4. ISO/IEC C Library Support

The MPLAB XC32 C/C++ Compiler provides libraries of functions, macros, types, and objects that can assist with your code development.

The Microchip Unified Standard Library or Picolibc is used for C projects. This library is C99 compliant. The same library implementations are used as the C library (`libc`) within the standard C++ library (`libstdc++`) when building C++ projects.

Several math libraries are available, handling devices with and without a hardware floating-point unit.

The Standard C libraries are described in the separate *Microchip Unified Standard Library Reference Guide* document, whose content is relevant for all MPLAB XC C compilers.

2.2.5. ISO/IEC C++ Library Support

The MPLAB XC32 C/C++ Compiler is distributed with a ISO/IEC 14882:2011 compliant Standard C++ Library (`libstdc++`) based on the GNU C++ Library. The Microchip Unified Standard Library or Picolibc is used as the C library (`libc`) within the standard C++ library when building C++ projects.

The Standard C libraries are described in the separate *Microchip Unified Standard Library Reference Guide* document, whose content is relevant for all MPLAB XC C compilers.

2.2.6. Compiler Driver

The compiler includes a powerful command-line driver program. Using the driver program, application programs can be compiled, assembled and linked in a single step.

2.3. Compiler and Other Development Tools

The compiler works with many other Microchip tools including:

- MPLAB XC32 assembler and linker - see the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186).
- The MPLAB® X IDE and MPLAB® Extensions for VS Code®.
- The MPLAB® Simulator.
- All Microchip debug tools and programmers.
- Demo boards and starter kits that support 32-bit devices.

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3. How To's

This section contains help and references for situations that are frequently encountered when building projects for Microchip 32-bit devices. Click the links at the beginning of each section to assist finding the topic relevant to your question. Some topics are indexed in multiple sections.

Start here:

- Installing and Activating the Compiler
- Invoking the Compiler
- Writing Source Code
- Getting My Application To Do What I Want
- Understanding the Compilation Process
- Fixing Code That Does Not Work

3.1. Installing and Activating the Compiler

This section details questions that might arise when installing or activating the compiler.

- How Do I Install and Activate My Compiler?
- How Can I Tell if the Compiler has Activated Successfully?
- Can I Install More Than One Version of the Same Compiler?

3.1.1. How Do I Install and Activate My Compiler?

Installation and activation of the license are performed simultaneously by the XC compiler installer. The guide *Installing and Licensing MPLAB XC C Compilers* (DS50002059) is available on https://www.microchip.com/compilers, under the **Documentation** tab. It provides details on single-user and network licenses, as well as how to activate a compiler for evaluation purposes.

The default install path is different on these operating systems:

Windows:`"C:\Program Files\Microchip\xc32\vx.xx\bin\xclm" -status`

macOS: `macOS: "/Applications/microchip/xc32/vx.xx/bin/xclm" -status`

Linux: `Linux: "/opt/microchip/xc32/vx.xx/bin/xclm" -status`

Where `vx.xx` is is the version of the compiler.

3.1.2. How Can I Tell if the Compiler has Activated Successfully?

If you think the compiler may not have installed correctly or is not working, it is best to verify its operation outside of MPLAB X IDE to isolate possible problems. Try running the compiler from the command line to check for correct operation. You do not actually have to compile code.

From your terminal or command-line prompt, run the license manager xclm with the option `-status`. This option instructs the license manager to print all MPLAB XC licenses installed on your system and exit. So, for example, depending on your operating system, type the following line, replacing the path information with a path that is relevant to your installation.

Windows:`"C:\Program Files\Microchip\xc32\vx.xx\bin\xclm" -status`

macOS: `macOS: "/Applications/microchip/xc32/vx.xx/bin/xclm" -status`

Linux: `Linux: "/opt/microchip/xc32/vx.xx/bin/xclm" -status`

The license manager should run, print all of the MPLAB XC compiler license available on your machine, and quit. Confirm that the your license is listed as activated (for example, Product:swxc32-pro) Note: if it is not activated properly, the compiler will continue to operate, but only in the

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Free mode. If an error is displayed, or the compiler indicates Free mode, then activation was not successful.

3.1.3. Can I Install More Than One Version of the Same Compiler?

Yes, the compilers and installation process has been designed to allow you to have more than one version of the same compiler installed. For MPLAB X IDE, you can easily swap between version by changing options in the IDE (see How Can I Select Which Compiler I Want to Build With?.)

Compilers should be installed into a directory whose name is related to the compiler version. This is reflected in the default directory specified by the installer. For example, the MPLAB XC32 compilers v1.00 and v1.10 would typically be placed in separate directories.

```
C:\Program Files\Microchip\xc32\v1.00\
```

```
C:\Program Files\Microchip\xc32\v1.10\
```

3.2. Invoking the Compiler

This section discusses how the compiler is run, both on the command-line and from the IDE. It includes information about how to get the compiler to do what you want in terms of options and the build process itself.

How Do I Compile from Within a Microchip IDE?

How Do I Compile on the Command-Line?

How Do I Compile Using a Make Utility?

How Can I Select Which Compiler I Want to Build With?

How Can I Change the Compiler's Operating Mode?

How Do I Build Libraries?

How Do I Know What Compiler Options Are Available and What They Do?

How Do I Know What the Build Options in Microchip IDEs Do?

What is Different About an MPLAB X IDE Debug Build?

See also How Do I Stop the Compiler From Using Certain Memory Locations?

See also What Do I Need to Do When Compiling to Use a Debugger?

See also How Do I Use Library Files in My Project?

See also What Optimizations Are Employed by the Compiler?

3.2.1. How Do I Compile from Within a Microchip IDE?

See the *MPLAB® X IDE User's Guide* for detailed information on how to create and configure an MPLAB X IDE project. For assistance with the MPLAB extensions for VS Code, see developerhelp.microchip.com/xwiki/bin/view/software-tools/ides/extensions/.

For information on compiler options within the IDE, see IDE Integration.

3.2.2. How Do I Compile on the Command-Line?

The compiler driver is called `xc32-gcc` for all 32-bit devices; for example, in Windows, it is named `xc32-gcc.exe`. This application should be invoked for all aspects of compilation. It is located in the `bin` directory of the compiler distribution. Avoid running the individual compiler applications (such as the assembler or linker) explicitly. You can compile and link in the one command, even if your project is spread among multiple source files.

The driver is introduced in Invoking The Compiler. See How Can I Select Which Compiler I Want to Build With? to ensure you are running the correct driver if you have more than one installed. The

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command-line options to the driver are detailed in Driver Option Descriptions. The files that can be passed to the driver are listed and described in Input File Types.

3.2.3. How Do I Compile Using a Make Utility?

When compiling using a make utility (such as `make`), the compilation is usually performed as a two-step process: first generating the intermediate files, and then the final compilation and link step to produce one binary output. This is described in Multi-Step C Compilation.

3.2.4. How Can I Select Which Compiler I Want to Build With?

The compilation and installation process has been designed to allow you to have more than one compiler installed at the same time For MPLAB X IDE, you can create a project and then build this project with different compilers by simply changing a setting in the project properties.

In MPLAB X IDE, you select which compiler to use when building a project by opening the Project Properties window (`File>Project Properties`) and selecting the Configuration category (`Conf: [default]`). A list of MPLAB XC32 compiler versions is shown in the Compiler Toolchain, on the far right. Select the MPLAB XC32 compiler you require.

Once selected, the controls for that compiler are then shown by selecting the XC32 global options, XC32 Compiler and XC32 Linker categories. These reveal a pane of options on the right; each category has several panes which can be selected from a pull-down menu that is near the top of the pane.

3.2.5. How Can I Change the Compiler's Operating Mode?

The compiler's operating mode (Free, Evaluation, or PRO) is based on its level of optimizations (see Optimizations) which can be specified as a command line option (see Options for Controlling Optimization.) If you are building under MPLAB X IDE, go to the Project Properties window, click on the compiler name (xc32-gcc for C language projects or xc32-g++ for C++ language projects), and select the Optimization option category to set optimization levels - see XC32 C Compiler Options.

When building your project, the compiler will emit a warning message if you have selected an option that is not available for your licensed operating mode. The compiler will continue compilation with the option disabled.

3.2.6. How Do I Build Libraries?

When you have functions and data that are commonly used in applications, you can make all the C source and header files available so other developers can copy these into their projects. Alternatively, you can build these modules into object files and package them into library archives, which, along with the accompanying header files, can then be built into an application.

Libraries can be more convenient because there are fewer files to manage. However, libraries do need to be maintained. MPLAB XC32 uses *.a library archives. Be sure to rebuild your library objects when you move your project to a new release of the compiler toolchain.

Using the compiler driver, libraries can begin to be built by listing all the files that are to be included into the library on the command line. None of these files should contain a `main()` function, nor settings for configuration bits or any other such data.

For information on how to create your own libraries, see User-Defined Libraries.

3.2.7. How Do I Know What Compiler Options Are Available and What They Do?

A list of all compiler options can be obtained by using the `--help` option on the command line. Alternatively, all options are listed in Driver Option Descriptions in this user's guide.

If you are compiling within a Microchip IDE, see IDE Integration.

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3.2.8. How Do I Know What the Build Options in Microchip IDEs Do?

Most of the widgets and controls in the Project Properties for MPLAB X IDE and MPLAB extensions for VS Code map directly to XC32 command-line driver options. See IDE Integration for the mapping between the IDE controls and the corresponding command-line options.

3.2.9. What is Different About an MPLAB X IDE Debug Build?

The main difference between a command-line debug build and an MPLAB X IDE debug build is the setting of a preprocessor macro called `__DEBUG` to be 1 when a debug is selected. This macro is not defined if it is not a debug build.

You may make code in your source conditional on this macro using `#ifdef` directives, etc (see Options for Controlling the Preprocessor) so that you can have your program behave differently when you are still in a development cycle. Some compiler errors are easier to track down after performing a debug build.

In MPLAB X IDE, memory will be reserved for your debugger only when you perform a debug build. See What Do I Need to Do When Compiling to Use a Debugger?.

3.3. Writing Source Code

This section addresses issues pertaining to the source code you write. It has been subdivided into sections listed below.

- C Language Specifics
- Device-Specific Features
- Memory Allocation
- Variables
- Functions
- Interrupts
- Assembly Code

3.3.1. C Language Specifics

This section discusses commonly asked source code issues that directly relate to the C language itself.

- When Should I Cast Expressions?
- Can Implicit Type Conversions Change The Expected Results Of My Expressions?
- How Do I Enter Non-English Characters Into My Program?
- How Can I Use A Variable Defined In Another Source File?
- How Do I Port My Code To Different Device Architectures?

3.3.1.1. When Should I Cast Expressions?

Expressions can be explicitly cast using the cast operator -- a type in round brackets, for example, (`int`). In all cases, conversion of one type to another must be done with caution and only when absolutely necessary.

Consider the example:

```
unsigned long l;
unsigned short s;

s = l;
```

Here, a `long` type is being assigned to an `int` type and the assignment will truncate the value in `l`. The compiler will automatically perform a type conversion from the type of the expression on the right of the assignment operator (`long`) to the type of the value on the left of the operator

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(short).This is called an implicit type conversion. The compiler typically produces a warning concerning the potential loss of data by the truncation.

A cast to type short is not required and should not be used in the above example if a long to short conversion was intended. The compiler knows the types of both operands and performs the conversion accordingly. If you did use a cast, there is the potential for mistakes if the code is later changed. For example, if you had:

```
s = (short)l;
```

the code works the same way; but if in the future, the type of s is changed to a long, for example, then you must remember to adjust the cast, or remove it, otherwise the contents of l will continue to be truncated by the assignment, which may not be correct. Most importantly, the warning issued by the compiler will not be produced if the cast is in place.

Only use a cast in situations where the types used by the compiler are not the types that you require. For example, consider the result of a division assigned to a floating-point variable:

```
int i, j;
float fl;

fl = i/j;
```

In this case, integer division is performed, then the rounded integer result is converted to a float format. So if i contained 7 and j contained 2, the division yields 3 and this is implicitly converted to a float type (3.0) and then assigned to fl. If you wanted the division to be performed in a float format, then a cast is necessary:

```
fl = (float)i/j;
```

(Casting either i or j forces the compiler to encode a floating-point division.) The result assigned to fl now is 3.5.

An explicit cast can suppress warnings that might otherwise have been produced. This can also be the source of many problems. The more warnings the compiler produces, the better chance you have of finding potential bugs in your code.

3.3.1.2. Can Implicit Type Conversions Change The Expected Results Of My Expressions?

Yes! The compiler will always use integral promotion and there is no way to disable this (see Integral Promotion). In addition, the types of operands to binary operators are usually changed so that they have a common type, as specified by the C Standard. Changing the type of an operand can change the value of the final expression, so it is very important that you understand the type C Standard conversion rules that apply when dealing with binary operators. You can manually change the type of an operand by casting; see When Should I Cast Expressions?

3.3.1.3. How Do I Enter Non-English Characters Into My Program?

The ANSI standard and MPLAB XC C do not support extended characters set in character and string literals in the source character set. See Constant Types and Formats to see how these characters can be entered using escape sequences.

3.3.1.4. How Can I Use A Variable Defined In Another Source File?

Provided the variable defined in the other source file is not static (see Static Variables) or auto (see Auto Variable Allocation and Access), adding a declaration for that variable into the current file will allow you to access it. A declaration consists of the keyword extern in addition to the type and the name of the variable, as specified in its definition, for example,

```
extern int systemStatus;
```

This is part of the C language. Your favorite C textbook will give you more information.

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The position of the declaration in the current file determines the scope of the variable. That is, if you place the declaration inside a function, it will limit the scope of the variable to that function. If you place it outside of a function, it allows access to the variable in all functions for the remainder of the current file.

Often, declarations are placed in header files and then they are `#include`d into the C source code (see Preprocessor Directives).

3.3.1.5. How Do I Port My Code To Different Device Architectures?

Porting code to different devices within an architectural family requires a minimum update to application code. However, porting between architectural families can require significant rewrite.

In an attempt to reduce the work to port between architectures, a Common C Interface, or CCI, has been developed. If you use these coding styles, your code will more easily migrate upward. For more on CCI, see Common C Interface.

3.3.2. Device-Specific Features

This section discusses the code that needs to be written to set up or control a feature that is specific to Microchip PIC devices.

- How Do I Set the Configuration Bits?
- How Do I Determine the Cause of Reset?
- How Do I Access SFRS?
- How Do I Stop the Compiler From Using Certain Memory Locations?

See also the following linked information in other sections.

- What Do I Need to Do When Compiling to Use a Debugger?

3.3.2.1. How Do I Set the Configuration Bits?

These should be set in your code using either a macro or pragma. Earlier versions of MPLAB IDE allowed you to set these bits in a dialog, but MPLAB X IDE requires that they be specified in your source code. Config bits are set in source code using the config pragma. See Configuration Bit Access, for more information on the config pragma.

3.3.2.2. How Do I Determine the Cause of Reset?

The bits in the Reset Control (RCON) Register allow you to determine the cause of a Reset. See the data sheet for your target device for a description of the RCON register.

3.3.2.3. How Do I Access SFRS?

The compiler ships with header files, see ID Locations, that define variables which are mapped over the top of memory-mapped SFRs. Since these are C variables, they can be used like any other C variable and no new syntax is required to access these registers.

Bits within SFRs can also be accessed. Bit-fields are available in structures which map over the SFR as a whole. See Bit Fields in Structures.

The name assigned to the variable is usually the same as the name specified in the device data sheet. See How Do I Find The Names Used To Represent SFRs And Bits? if these names are not recognized.

3.3.2.4. How Do I Find The Names Used To Represent SFRs And Bits?

Special function registers, and the bits within them, are accessed via special variables that map over the register (see How Do I Access SFRS?). However, the names of these variables sometimes differ from those indicated in the data sheet for the device you are using.

View the device-specific header file which allows access to these special variables. Begin by searching for the data sheet SFR name. If that is not found, search on what the SFR represents, as comments in the header often spell out what the macros under the comment do.

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3.3.3. Memory Allocation

Here are questions relating to how your source code affects memory allocation.

- How Do I Position Variables at an Address I Nominate?
- How Do I Position Functions at an Address I Nominate?
- How Do I Place Variables in Program Memory?
- How Do I Stop the Compiler From Using Certain Memory Locations?
- Why Are Some Objects Positioned Into Memory That I Reserved?

3.3.3.1. How Do I Position Variables at an Address I Nominate?

The easiest way to do this is to make the variable absolute by using the `address` attribute (see Variable Attributes) or the `__at()` CCI construct (see Absolute Addressing). This means that the address you specify is used in preference to the variable's symbol in generated code. Since you nominate the address, you have full control over where objects are positioned, but you must also ensure that absolute variables do not overlap.

See also Auto Variable Allocation and Access for information on moving auto variables, Non-Auto Variable Allocation for moving non-auto variables and Variables in Program Memory for moving program-space variables.

3.3.3.2. How Do I Position Functions at an Address I Nominate?

The easiest way to do this is to make the functions absolute, by using the `address` attribute (see Function Attributes and Specifiers). This means that the address you specify is used in preference to the function's symbol in generated code. Since you nominate the address, you have full control over where functions are positioned, but must also ensure that absolute functions do not overlap.

3.3.3.3. How Do I Place Variables in Program Memory?

The `const` qualifier implies that the qualified variable is read only. See the `-membedded-data` option in Options Specific to PIC32M Devices for information about allocating 'const' qualified variables to program memory (Flash). As a consequence of this any variables, except for auto variables or function parameters, qualified `const` are placed in program memory, thus freeing valuable data RAM (see Variables in Program Memory). Variables qualified `const` can also be made absolute, so that they can be positioned at an address you nominate.

3.3.3.4. How Do I Stop the Compiler From Using Certain Memory Locations?

Concatenating an address attribute with the `noload` attribute can be used to block out sections of memory. Also, you can use the option `-mreserve`. For more on variable attributes and options, see the following sections in this user's guide:

Variable Attributes

Options Specific to PIC32M Devices

See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186) for details on linker scripts.

3.3.4. Variables

This examines questions that relate to the definition and usage of variables and types within a program.

- Why Are My Floating-point Results Not Quite What I Am Expecting?
- How Can I Access Individual Bits of a Variable?
- How Long Can I Make My Variable and Macro Names?
- How Do I Share Data Between Interrupt and Main-line Code?
- How Do I Position Variables at an Address I Nominate?

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- How Do I Place Variables in Program Memory?
- How Can I Rotate a Variable?
- How Do I Find Out Where Variables and Functions Have Been Positioned?

3.3.4.1. Why Are My Floating-point Results Not Quite What I Am Expecting?

First, make sure that if you are watching floating-point variables in MPLAB IDE that the type and size of these match how they are defined. In MPLAB XC32, the `float` type is 32 bits wide, the `double` and `long double` types are 64-bits wide, as discussed in Floating-Point Data Types.

Since floating-point variables only have a finite number of bits to represent the values they are assigned, they will hold an approximation of their assigned value. A floating-point variable can only hold one of a set of discrete real number values. If you attempt to assign a value that is not in this set, it is rounded to the nearest value. The more bits used by the mantissa in the floating-point variable, the more values can be exactly represented in the set and the average error due to the rounding is reduced.

Whenever floating-point arithmetic is performed, rounding also occurs. This can also lead to results that do not appear to be correct.

3.3.4.2. How Can I Access Individual Bits of a Variable?

There are several ways of doing this. The simplest and most portable way is to define an integer variable and use macros to read, set, or clear the bits within the variable using a mask value and logical operations, such as the following.

```
#define  testbit(var, bit)    (!!(var) & (1 <<(bit)))
#define  setbit(var, bit)     ((var) |= (1 << (bit)))
#define  clrbit(var, bit)     ((var) &= ~(1 << (bit)))
```

These, respectively, test to see if bit number, `bit`, in the integer, `var`, is set; set the corresponding `bit` in `var`; and clear the corresponding `bit` in `var`. Alternatively, a union of an integer variable and a structure with bit-fields (see Bit Fields in Structures) can be defined, for example,

```
union both {
   unsigned char byte;
   struct {
      unsigned b0:1, b1:1, b2:1, b3:1, b4:1, b5:1, b6:1, b7:1;
   } bitv;
} var;
```

This allows you to access `byte` as a whole (using var.byte), or any bit within that variable independently (using `var.bitv.b0` through `var.bitv.b7`).

3.3.4.3. How Long Can I Make My Variable and Macro Names?

The C Standard indicates that only a number of initial characters in an identifier are significant, but it does not actually state what this number is and it varies from compiler to compiler. For MPLAB XC32, no limit is imposed, but for CCI there is a limit (see The Number of Significant Initial Characters in an Identifier). CCI Compliant names are more portable across Microchip architectures.

If two identifiers only differ in the non-significant part of the name, they are considered to represent the same object, which will almost certainly lead to code failure.

3.3.5. Functions

This section examines questions that relate to functions.

- What Is the Optimum Size for Functions?
- How Can I Tell How Big a Function Is?
- How Do I Know What Resources Are Being Used by Each Function?
- How Do I Find Out Where Variables and Functions Have Been Positioned?

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- How Do I Use Interrupts in C?
- How Do I Stop An Unused Function Being Removed?
- How Do I Make a Function Inline?

3.3.5.1. What Is the Optimum Size for Functions?

Generally speaking, the source code for functions should be kept small as this aids in readability and debugging. It is much easier to describe and debug the operation of a function which performs a small number of tasks. Also smaller-sized functions typically have less side effects, which can be the source of coding errors. On the other hand, in the embedded programming world, a large number of small functions, and the calls necessary to execute them, may result in excessive memory and stack usage. Therefore a compromise is often necessary.

Function size can cause issues with memory paging, as addressed in Function Size Limits. The smaller the functions, the easier it is for the linker to allocate them to memory without errors.

3.3.5.2. How Do I Stop An Unused Function Being Removed?

The `__attribute__((keep))` may be applied to a function. The keep attribute will prevent the linker from removing the function with `--gc-sections`, even if it is unused. See the *"MPLAB® XC32 Assembler, Linker and Utilities User's Guide"* (DS50002186) for more information on section garbage collection using the `--gc-sections` option.

3.3.5.3. How Do I Make a Function Inline?

The XC32 compiler does not inline any functions when not optimizing.

By declaring a function inline, you can direct the XC32 compiler to make calls to that function faster. One way XC32 can achieve this is to integrate that function's code into the code for its callers. This makes execution faster by eliminating the function-call overhead; in addition, if any of the actual argument values are constant, their known values may permit simplifications at compile time so that not all of the inline function's code needs to be included. The effect on code size is less predictable; object code may be larger or smaller with function inlining, depending on the particular case.

To declare a function inline, use the inline keyword in its declaration, like this:

```
static inline int
inc (int *a)
{
   return (*a)++;
}
```

When a function is both inline and static, if all calls to the function are integrated into the caller, and the function's address is never used, then the function's own assembler code is never referenced. In this case, XC32 does not actually output assembler code for the function. Some calls cannot be integrated for various reasons (in particular, calls that precede the function's definition cannot be integrated, and neither can recursive calls within the definition). If there is a non-integrated call, then the function is compiled to assembler code as usual. The function must also be compiled as usual if the program refers to its address, because that can't be inlined. Enable optimization level -O1 or greater to enable function inlining.

3.3.6. Interrupts

Interrupt and interrupt service routine questions are discussed in this section.

- How Do I Use Interrupts in C?
- How Can I Make My Interrupt Routine Faster?
- How Do I Share Data Between Interrupt and Main-line Code?

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3.3.6.1. How Do I Use Interrupts in C?

First, be aware of what interrupt hardware is available on your target device. 32-bit devices implement several separate interrupt vector locations and use a priority scheme. For more information, see Interrupt Operation.

In C source code, a function can be written to act as the interrupt service routine by using the `interrupt` attribute. Such functions save/restore program context before/after executing the function body code and a different return instruction is used. For more on writing interrupt functions, see Writing an Interrupt Service Routine. To populate the interrupt vector table, use the `vector` or `at_vector` attribute. An `__ISR()` macro is provided in the sys/attribs.h header file that simplifies the usage of the `interrupt` and `vector` attributes.

Prior to any interrupt occurring, your program must ensure that peripherals are correctly configured and that interrupts are enabled. For details, see Enabling/Disabling Interrupts.

For all other interrupt related tasks, including specifying the interrupt vector, context saving, nesting and other considerations, consult Interrupts.

3.3.7. Assembly Code

This section examines questions that arise when writing assembly code as part of a C project.

- How Should I Combine Assembly and C Code?
- What Do I Need Other Than Instructions in an Assembly Source File?
- How Do I Access C Objects from Assembly Code?
- How Can I Access SFRs From Within Assembly Code?
- What Things Must I Manage When Writing Assembly Code?

3.3.7.1. How Should I Combine Assembly and C Code?

Ideally, any hand-written assembly should be written as separate routines that can be called. This offers some degree of protection from interaction between compiler-generated and hand-written assembly code. Such code can be placed into a separate assembly module that can be added to your project, as specified in Mixing Assembly Language and C Variables and Functions.

If necessary, assembly code can be added in-line with C code by using either of two forms of the `asm` instruction; simple or extended. An explanation of these forms, and some examples, are shown in Using Inline Assembly Language.

Macros are provided which in-line several simple instructions, as discussed in Predefined Macros. More complex in-line assembly that changes register contents and the device state should be used with caution.

See Register Usage for those registers used by the compiler.

3.3.7.2. What Do I Need Other Than Instructions in an Assembly Source File?

Assembly code typically needs assembler directives as well as the instructions themselves. The operation of all the directives is described in the *"MPLAB® XC32 Assembler, Linker and Utilities User's Guide"* (DS50002186). Two common directives are discussed below.

All assembly code must be placed in a section, using the .section directive, so it can be manipulated as a whole by the linker and placed in memory. See the "Linker Processing" chapter of the *"MPLAB® XC32 Assembler, Linker and Utilities User's Guide"* (DS50002186) for more information.

Another commonly used directive is `.global` which is used to make symbols accessible across multiple source files. Find more on this directive in the aforementioned user's guide.

3.3.7.3. How Do I Access C Objects from Assembly Code?

Most C objects are accessible from assembly code. There is a mapping between the symbols used in the C source and those used in the assembly code generated from this source. Your assembly

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should access the assembly-equivalent symbols which are detailed in Mixing Assembly Language and C Variables and Functions.

Instruct the assembler that the symbol is defined elsewhere by using the `.global` assembler directive. This is the assembly equivalent of a C declaration, although no type information is present. This directive is not needed and should not be used if the symbol is defined in the same module as your assembly code.

Any C variable accessed from assembly code will be treated as if it were qualified `volatile` (see Volatile Type Qualifier). Specifying the `volatile` qualifier in C code is preferred as it makes it clear that external code may access the object.

3.3.7.4. How Can I Access SFRs From Within Assembly Code?

The safest way to gain access to SFRs in assembly code is to have symbols defined in your assembly code that equate to the corresponding SFR address. For the XC32 compiler, the xc.h include file can be used from either preprocessed assembly code or C/C++ code.

There is no guarantee that you will be able to access symbols generated by the compilation of C code, even code that accesses the SFR you require.

3.3.7.5. What Things Must I Manage When Writing Assembly Code?

There are several things that you must manage if you are hand-writing assembly code.

- You must place any assembly code you write into a section. See the "Linker Processing" chapter of the *"MPLAB® XC32 Assembler, Linker and Utilities User's Guide"* (DS50002186) for more information.

  Assembly code that is placed in-line with C code will be placed in the same section as the compiler-generated assembly and you should not place this into a separate section.
- You must ensure that any registers you write to in assembly code are not already in use by compiler-generated code. If you write assembly in a separate module, then this is less of an issue as the compiler will, by default, assume that all registers are used by these routines (see Register Usage, registers). No assumptions are made for in-line assembly (see Mixing Assembly Language and C Variables and Functions) and you must be careful to save and restore any resources that you use (write) and which are already in use by the surrounding compiler-generated code.

3.4. Getting My Application To Do What I Want

This section provides programming techniques, applications and examples. It also examines questions that relate to making an application perform a specific task.

- What Can Cause Glitches on Output Ports?
- How Do I Link Bootloaders and Downloadable Applications?
- What Do I Need to Do When Compiling to Use a Debugger?
- How Do I Share Data Between Interrupt and Main-line Code?
- How Can I Prevent Misuse of My Code?
- How Do I Use Printf to Send Text to a Peripheral?
- How Can I Implement a Delay in My Code?
- How Can I Rotate a Variable?

3.4.1. What Can Cause Glitches on Output Ports?

In most cases, this is caused by using ordinary variables to access port bits or the entire port itself. These variables should be qualified `volatile`. See Volatile Type Qualifier.

The value stored in a variable mapped over a port (hence the actual value written to the port) directly translates to an electrical signal. It is vital that the values held by these variables only change

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when the code intends them to, and that they change from their current state to their new value in a single transition. The compiler attempts to write to `volatile` variables in one operation.

3.4.2. How Do I Link Bootloaders and Downloadable Applications?

Exactly how this is done depends on the device you are using and your project requirements, but the general approach when compiling applications that use a bootloader is to allocate discrete program memory space to the bootloader and application so they have their own dedicated memory. In this way the operation of one cannot affect the other. This will require that either the bootloader or the application is offset in memory. That is, the Reset and interrupt location are offset from address 0 and all program code is offset by the same amount.

Typically the application code is offset, and the bootloader is linked with no offset so that it populates the Reset and interrupt code locations. The bootloader Reset and interrupt code merely contains code which redirects control to the real Reset and interrupt code defined by the application and which is offset.

The contents of the Hex file for the bootloader can be merged with the code of the application by using loadable projects in MPLAB X IDE. (See MPLAB X IDE documentation for details.) This results in a single Hex file that contains the bootloader and application code in the one image. Check for warnings from this application about overlap, which may indicate that memory is in use by both bootloader and the downloadable application.

See the PIC32 Bootloader Application Note (DS01388) on the Microchip website.

3.4.3. What Do I Need to Do When Compiling to Use a Debugger?

You can use debuggers, such as the MPLAB PICkit™ 4 or ICD 4 in-circuit debuggers or the MPLAB REAL ICE™ in-circuit emulator, to debug code built with the MPLAB XC32 compiler. These debuggers use some of the data and program memory of the device for its own use, so it is important that your code does not also use these resources.

The command-line option `-g` (see Options for Debugging) is used to tell the compiler to generate debugging information. The compiler can then reserve the memory used by the debugger so that your code will not be placed in these locations.

In the MPLAB X IDE, the appropriate debugger option is specified if you perform a Debug Run. It will not be specified if you perform a regular Run, Build Project, or Clean and Build.

Since some device memory is being reserved for use by the debugger, there is less available for your program and it is possible that your code or data may no longer fit in the device when a debugger is selected. For 32-bit devices, some boot flash memory is required for debugging. In addition, some data memory (RAM) is used by the debug tool and may impact the variable allocation in your application.

The specific memory locations used by the debuggers are attributes of MPLAB X IDE, the debug tool in use and the target device. If you move a project to a new version of the IDE, the resources required may change. For this reason, you should not manually reserve memory for the debugger, or make any assumptions in your code as to what memory is used. A summary of the debugger requirements is available in the MPLAB X IDE help files.

To verify that the resources reserved by the compiler match those required by the debugger, you may view the boot-flash, application-flash and data-memory usage in the map file or memory-usage report.

To create a map file in MPLAB X IDE, open the Project Properties window (*File>Project Properties*) and click on the linker category (xc32-ld). Under “Option Categories,” select “Diagnostics.” Next to “Generate map file,” enter a path and name for the map file. The logical place to put the map file is in the project folder.

Debug Run your code to generate the map file. View in your favorite text viewer.

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See also Why Are Some Objects Positioned Into Memory That I Reserved?.

3.4.4. How Do I Share Data Between Interrupt and Main-line Code?

Variables accessed from both interrupt and main-line code can easily become corrupted or mis-read by the program. The `volatile` qualifier (see Volatile Type Qualifier) tells the compiler to avoid performing optimizations on such variables. This will fix some of the issues associated with this problem.

The other issues relates to whether the compiler/device can access the data atomically. With 32-bit PIC devices, this is rarely the case. An atomic access is one where the entire variable is accessed in only one instruction. Such access is uninterruptible. You can determine if a variable is being accessed atomically by looking at the assembler list file (see the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*, DS50002186, for more information). If the variable is accessed in one instruction, it is atomic. Since the way variables are accessed can vary from statement to statement it is usually best to avoid these issues entirely by disabling interrupts prior to the variable being accessed in main-line code, then re-enable the interrupts afterwards. See Enabling/Disabling Interrupts for more information. When writing to Special Function Registers (SFRs), use the SET/CLR/INV registers as described in ID Locations.

3.4.5. How Can I Prevent Misuse of My Code?

First, many devices with flash program memory allow all or part of this memory to be write protected. The device configuration bits need to be set correctly for this to take place, see Configuration Bit Access, Specifying Configuration Bits for CCI, and your device data sheet.

Second, you can prevent third-party code being programmed at unused locations in the program memory by filling these locations with a value rather than leaving them in their default unprogrammed state. You can choose a fill value that corresponds to an instruction, or set all the bits so the values cannot be further modified. Consider what will happen if your program somehow reaches and starts executing from these filled values. What instruction will be executed?

Use the `--fill` command to fill unused memory. Find usage information for this command in Options for Linking.

3.4.6. How Do I Use Printf to Send Text to a Peripheral?

The `printf` function does two things: it formats text based on the format string and placeholders you specify, and sends (prints) this formatted text to a destination (or stream). You may choose the `printf` output go to an LCD, SPI module or USART, for example.

For more on the ANSI C function `printf`, see the *32-bit Language Tool Libraries* manual (DS51685).

To check what is passed to the `printf` function, you may attempt to statically analyze format strings passed to the function by using the `-msmart-io` option (Options Specific to PIC32M Devices). Also you may use the `-Wformat` option to specify a warning when the arguments supplied to the function do not have types appropriate to the format string specified (see Options for Controlling Warning and Errors).

If you wish to create your own `printf`-type function, you will need to use the attributes `format` and `format_arg` as discussed in Function Attributes and Specifiers.

3.4.7. How Can I Implement a Delay in My Code?

If an accurate delay is required, or if there are other tasks that can be performed during the delay, then using a timer to generate an interrupt is the best way to proceed.

Microchip does not recommend using a software delay on PIC32 devices as there are many variables that can affect timing such as the configuration of the L1 cache, prefetch cache, & Flash wait states. On PIC32 devices, you may choose to poll the core timer, which increments every two instruction cycles.

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3.4.8. How Can I Rotate a Variable?

The C language does not have a rotate operator, but rotations can be performed using the shift and bitwise OR operators. Since the 32-bit devices have a rotate instruction, the compiler will look for code expressions that implement rotates (using shifts and ORs) and use the rotate instruction in the generated output wherever possible.

If you are using CCI, you should consult Bitwise Operations on Signed Values and Right-Shifting Signed Values if you will be using signed variables.

For the following example C code:

```
int rotate_left (unsigned a, unsigned s)
{
  return (a << s) | (a >> (32 - s));
}
```

the compiler may generate assembly instructions similar to the following:

```
rotate_left:
   subu      $2,$0,$5
   jr        $31
   ror       $2,$4,$2
```

3.5. Understanding the Compilation Process

This section tells you how to find out what the compiler did during the build process, how it encoded output code, where it placed objects, etc. It also discusses the features that are supported by the compiler.

- What's the Difference Between a Free and PRO Compiler?
- How Can I Make My Code Smaller?
- How Can I Reduce RAM Usage?
- How Can I Make My Code Faster?
- How Does the Compiler Place Everything in Memory?
- How Can I Make My Interrupt Routine Faster?
- How Big Can C Variables Be?
- What Optimizations Will Be Applied to My Code?
- What Devices are Supported by the Compiler?
- How Do I Know What Code the Compiler Is Producing?
- How Can I Tell How Big a Function Is?
- How Do I Know What Resources Are Being Used by Each Function?
- How Do I Find Out Where Variables and Functions Have Been Positioned?
- Why Are Some Objects Positioned Into Memory That I Reserved?
- How Do I Know How Much Memory Is Still Available?
- How Do I Use Library Files in My Project?
- How Do I Customize the C Runtime Startup Code?
- What Optimizations Are Employed by the Compiler?
- Why Do I Get Out-of-Memory Errors When I Select a Debugger?
- How Do I Set Up Warning/Error Messages?
- How Do I Find the Code that Caused Compiler Errors or Warnings in My Program?

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- How Can I Stop Spurious Warnings From Being Produced?
- Why Can't I Even Blink an LED?
- What Can Cause Corrupted Variables and Code Failure When Using Interrupts?
- How Do I Build Libraries?
- What is Different About an MPLAB X IDE Debug Build?
- How Do I Stop An Unused Function Being Removed?
- How Do I Use Library Files in My Project?
- How Do I Customize the C Runtime Startup Code?
- What Optimizations Are Employed by the Compiler?
- Why Do I Get Out-of-Memory Errors When I Select a Debugger?
- How Do I Stop My Project's Checksum From Changing?

3.5.1. What's the Difference Between a Free and PRO Compiler?

The purchase of a compiler license allows the compiler to operate in PRO mode, with more advanced optimizations. These include level `-O3` and `-Os` optimizations, as well as other compiler-specific optimization features.

Without a license, the compiler will operate in Free mode. In this mode, the compiler can build for all devices and use all the available memory for the selected device, but it will be limited to at most level `-O2` optimizations. This makes the generated output of an unlicensed compiler less efficient than that of a licensed compiler, meaning that project code will require more memory and be slower to execute.

3.5.2. How Can I Make My Code Smaller?

There are a number of ways that this can be done, but results vary from one project to the next. Use the assembly list file to observe the assembly code produced by the compiler to verify that the following tips are relevant to your code. For information on the list file, see the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186).

Use the smallest data types possible as less code is needed to access these (this also reduces RAM usage). For examples, a short integer type exists for this compiler. See Supported Data Types and Variables for all data types and sizes.

There are two sizes of floating-point type, which are discussed in the same section. Replace floating-point variables with integer variables wherever possible. For many applications, scaling a variable's value makes eliminating floating-point operations possible.

Use unsigned types, if possible, instead of signed types, particularly if they are used in expressions with a mix of types and sizes. Try to avoid an operator acting on operands with mixed sizes whenever possible.

Whenever you have a loop or condition code, use a "strong" stop condition, that is, the following:

```
for(i=0; i!=10; i++)
```

is preferable to:

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

A check for equality (== or `!=`) is usually more efficient to implement than the weaker < comparison.

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In some situations, using a loop counter that decrements to zero is more efficient than one that starts at zero and counts up by the same number of iterations. So you might be able to rewrite the above as:

```
for(i=10; i!=0; i--)
```

Ensure that you enable all the optimizations allowed for the edition of your compiler (see Optimizations). If you have a PRO edition, you can use the `-Os` option (see Options for Controlling Optimization) to optimize for size. Otherwise, pick the highest optimization available.

Consider also the PRO-edition standard link-time optimizer, controlled by the `-flto` option. This optimization adds internal bytecode representations of the code to special sections in the object file that are then processed as if they had been part of the same translation unit. This can allow the compiler to make certain assumptions about the program code and improved the effectively of some optimizations.

Consider using the a compressed ISA mode such as MIPS16 or microMIPS if it is supported on your device. Use the `-mips16` or `-mmicromips` option for your project to make the compiler default to these modes. Use the mips16 or micromips function attributes to change the mode at the function level. You may also choose the optimized and compressed variants of the libraries in the linker options. Be aware of what optimizations the compiler performs so you can take advantage of them and don't waste your time manually performing optimizations in C code that the compiler already handles, for example, don't turn a multiply-by-4 operation into a shift-by-2 operation as this sort of optimization is already detected.

3.5.3. How Can I Reduce RAM Usage?

Consider using `auto` variables rather than `global` or `static` variables as there is the potential that these may share memory allocated to other `auto` variables that are not active at the same time. Memory allocation of auto variables is made on a stack, described in Auto Variable Allocation and Access.

Rather than pass large objects to, or from, functions, pass pointers which reference these objects. This is particularly true when larger structures are being passed.

Objects that do not need to change throughout the program can be located in program memory using the `const` qualifier (see Variables in Program Memory). This frees up precious RAM, but slows execution.

3.5.4. How Can I Make My Code Faster?

To a large degree, smaller code is faster code, so efforts to reduce code size often decrease execution time. To accomplish this, see How Can I Make My Code Smaller? and How Can I Make My Interrupt Routine Faster?. However, there are ways some sequences can be sped up at the expense of increased code size.

Depending on your compiler edition (see Optimizations), you may be able to use the `-O3` option (see Options for Controlling Optimization) to optimize for speed. This will use alternate output in some instances that is faster, but larger.

Generally, the biggest gains to be made in terms of speed of execution come from the algorithm used in a project. Identify which sections of your program need to be fast. Look for loops that might be linearly searching arrays and choose an alternate search method such as a hash table and function. Where results are being recalculated, consider if they can be cached.

3.5.5. How Does the Compiler Place Everything in Memory?

Assembly instructions and directives associated with both code and data are grouped into sections, and these are then positioned into containers, typically, by a linker script. To see those sections defined and where they have been located, create and check the assembly listing file and the linker's map file.

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3.5.6. How Can I Make My Interrupt Routine Faster?

Consider suggestions made in How Can I Make My Code Smaller? (code size) for any interrupt code. Smaller code is often faster code.

In addition to the code you write in the ISR, there is the code the compiler produces to switch context. This is executed immediately after an interrupt occurs and immediately before the interrupt returns, so must be included in the time taken to process an interrupt. This code is optimal in that only registers used in the ISR will be saved by this code. Thus, the fewer registers used in your ISR will mean potentially less context switch code to be executed.

Generally simpler code will require fewer resources than more complicated expressions. Use the assembly list file to see which registers are being used by the compiler in the interrupt code. For information on the list file, see the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186).

Avoid calling other functions from the ISR. In addition to the extra overhead of the function call, the compiler also saves all general purpose registers that may or may not be used by the called function. Consider having the ISR simply set a flag and return. The flag can then be checked in main-line code to handle the interrupt. This has the advantage of moving the complicated interrupt-processing code out of the ISR so that it no longer contributes to its register usage. Always use the `volatile` qualifier (see Volatile Type Qualifier for variables shared by the interrupt and main-line code, see How Do I Share Data Between Interrupt and Main-line Code?.

3.5.7. How Big Can C Variables Be?

This question specifically relates to the size of individual C objects, such as arrays or structures. The total size of all variables is another matter.

To answer this question you need to know in which memory space the variable will be located.

With the default `-membedded-data` option, objects qualified `const` will be located in program memory; other objects will be placed in data memory. Program memory object sizes are discussed in Size Limitations of const Variables. Objects in data memory are broadly grouped into autos and non-autos and the size limitations of these objects, respectively, are discussed in Non-Auto Variable Allocation and Non-Auto Variable Size Limits.

3.5.8. What Optimizations Will Be Applied to My Code?

Code optimizations available depend on the edition of your compiler (see Optimizations). A description of optimization options can be found under Options for Controlling Optimization.

3.5.9. What Devices are Supported by the Compiler?

New devices are usually added with each compiler release. Check the readme document for a full list of devices supported by a compiler release.

3.5.10. How Do I Know What Code the Compiler Is Producing?

The assembly list file may be set up, using assembler listing file options, to contain a great deal of information about the code, such as the assembly output for almost the entire program, including library routines linked in to your program, section information, symbol listings, and more.

The list file may be produced as follows:

- On the command line, create a basic list file using the option: `-Wa, -a=projectname.lst`.
- For MPLAB X IDE, right click on your project and select **Properties**. In the **Project Properties** window, click on **xc32-as** under **Categories**. From **Option categories**, select **Listing file options** and ensure **List to file** is checked.

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- For projects containing multiple source files, add the following command to the MPLAB X Post-Build Step or run it on the command line.

```
xc32-objdump -SD code.elf > code.lst
```

By default, the assembly list file will have a `.lst` extension.

For information on the list file and utility applications, see the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186).

3.5.11. How Can I Tell How Big a Function Is?

This size of a function (the amount of assembly code generated for that function) can be determined from the assembly list file. See How Do I Know What Code the Compiler Is Producing? for more on creating an assembly listing file.

3.5.12. How Can I Find Stack Usage Information For Each Function of My Program?

The compiler's stack guidance feature analyzes your program and reports on the estimated maximum depth of any stack that has been used. If you need stack depth information displayed individually for each function in your program, you will need to perform an additional step after you build.

Use the MPLAB XC32 `-mchp-stack-usage` option when you build your program. Then use the `xc32-objdump` utility and its `-D` option with the object file containing the functions whose stack depth is required. You might need to use the compiler's `-save-temps` option when you build the project so that the object files needed for this utility are not deleted after compilation.

For example, to see the stack information for all the functions in the `main.o` module, the following commands could be issued.

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -save-temps -mchp-stack-usage main.c init.c
xc32-objdump -D main.o
```

The output of `xc32-objdump` utility might show you something similar to the following.

```
XC32 stack usage information:
  <func1>:
    used_stack: 0x70
    flags: 0x0
    kind: STATIC
  <main>:
    used_stack: 0x8
    flags: 0x0
    kind: STATIC
XC32 Stack Usage Version: 0x1
```

3.5.13. How Do I Know What Resources Are Being Used by Each Function?

In the assembly list file there is information printed for every C function, including library functions. See How Do I Know What Code the Compiler Is Producing? for more on creating an assembly listing file.

To see information on functions calls, you can view the Call Graph in MPLAB X IDE (**Window** > **Output** > **Call Graph**). You must be in debug mode to see this graph. Right click on a function and select **Show Call Graph** to see what calls this function and what it calls.

Auto, parameter and temporary variables used by a function may overlap with those from other functions as these are placed in a compiled stack by the compiler, see Auto Variable Allocation and Access.

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3.5.14. How Do I Find Out Where Variables and Functions Have Been Positioned?

You can determine where variables and functions have been positioned from either the assembly list file (generated by the assembler) or the map file (generated by the linker). Only global symbols are shown in the map file; all symbols (including locals) are listed in the assembly list file.

There is a mapping between C identifiers and the symbols used in assembly code, which are the symbols shown in both of these files. The symbol associated with a variable is assigned the address of the lowest byte of the variable; for functions it is the address of the first instruction generated for that function.

For more on assembly list files and linker map files, see the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186).

3.5.15. Why Are Some Objects Positioned Into Memory That I Reserved?

Most variables and function are placed into sections that are defined in the linker script. See the *"MPLAB® XC32 Assembler, Linker and Utilities User's Guide"* (DS50002186) for details on linker scripts. However, some variables and function are explicitly placed at an address rather than being linked anywhere in an address range, as described in How Do I Position Variables at an Address I Nominate? and How Do I Position Functions at an Address I Nominate?.

Check the assembly list file to determine the names of sections that hold objects and code. Check the linker options in the map file to see if sections have been linked explicitly or if they are linked anywhere in a class. See the *"MPLAB® XC32 Assembler, Linker and Utilities User's Guide"* (DS50002186) for information on each of these files.

3.5.16. How Do I Know How Much Memory Is Still Available?

A memory usage summary is available from the compiler after compilation (`--report-mem` option), from MPLAB X IDE in the Dashboard window. All of these summaries indicate the amount of memory used and the amount still available, but none indicate whether this memory is one contiguous block or broken into many small chunks. Small blocks of free memory cannot be used for larger objects and so out-of-memory errors may be produced even though the total amount of memory free is apparently sufficient for the objects to be positioned.

Additionally, a Memory Report by Module, showing the memory usage (text, data, and bss sections) per object file, is provided. This report indicates the size in the final ELF file attributable to each input object. A miscellaneous entry showing those sections whose input object file cannot be determined or the type of memory cannot be established is also shown.

Consult the linker map file to determine exactly what memory is still available in each linker class. This file also indicates the largest contiguous block in that class if there are memory page divisions. See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186) for information on the map file.

3.5.17. How Do I Use Library Files in My Project?

See How Do I Build Libraries? for information on how you build your own library files. The compiler will automatically include any applicable standard library into the build process when you compile, so you never need to control these files.

To use one or more library files that were built by yourself or a colleague, include them in the list of files being compiled on the command line. The library files can be specified in any position in the file list relative to the source files, but if there is more than one library file, they will be searched in the order specified in the command line.

For example:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-
EC_DFP.1.4.150" main.c int.c mylib.a
```


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If you are using MPLAB IDE to build a project, add the library file(s) to the Libraries folder that will shown in your project, in the order in which they should be searched. The IDE will ensure that they are passed to the compiler at the appropriate point in the build sequence.

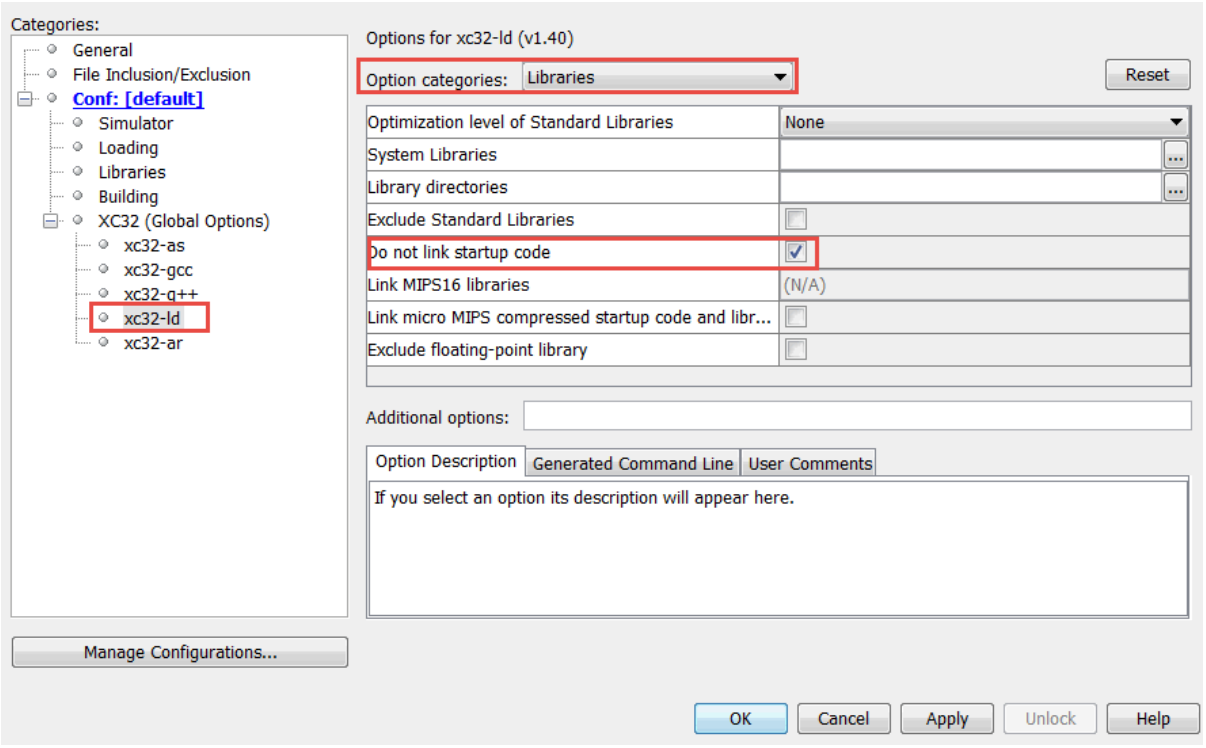
3.5.18. How Do I Customize the C Runtime Startup Code?

Some applications may require an application-specific version of the C runtime startup code. For instance, you may want to modify the startup code for an application loaded by a bootloader.

To customize the startup code for your application, you will first need to obtain the source code for the default startup code.

1. Unzip the `pic32m-libs.zip` file located in the`<install-directory>/pic32-libs/` directory. If the tar files within this archive are not automatically expanded by your archive utility, you might need to run `tar -xvf` or an alternative application on these tar files. The runtime startup source code can then be found at `pic32m-libs/pic32m-libs/pic32m-libs/libpic32/startup/crt0.S` in the unzipped directory, although note that some archive utilities might expand the files in directories with slightly different names.
2. Make a copy of the unarchived `crt0.S` file, rename it, and add it to your project.
3. Change your MPLAB X project to exclude the default startup code by enabling the **Do not link startup code** checkbox in the **Libraries** Option category under **xc32-ld** , as shown below. When you build your project, the MPLAB X IDE will build your new application-specific copy of the startup code rather than linking in the default code.

Figure 3-1. Startup Code Properties Setting



4. You can now edit the assembly code in your new copy of the runtime startup file. The default source code uses macros defined in the device-specific header files, which are included by `<xc.h>`. These macros define various device specific behavior. Be sure to take this device-specific code into account when customizing your copy of the code.

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Table 3-1. Device-Specific Macros

Device-Specific Macro	Description
__PIC32_SRS_SET_COUNT	Defined to the number of Register Sets implemented on the device. The default startup code uses this value to determine how many register sets to use for $GP-register initialization.
__PIC32_HAS_L1CACHE	Defined if the device features an L1 cache.
__PIC32_HAS_MIPS32R2	Defined if the device supports the MIPS32r2 Instruction Set.
__PIC32_HAS_MICROMIPS	Defined if the device supports the microMIPS compressed Instruction Set.
__PIC32_HAS_DSPR2	Defined if the device supports the DSPr2 Application-Specific Extension.
__PIC32_HAS_FPU64	Defined if the device supports the single- and double-precision hardware Floating Point Unit.
__PIC32_HAS_SSX	Defined if the device does *not* require initialization of the bus matrix registers in order to support execution from data memory.
__PIC32_HAS_MMU_MZ_FIXED	Defined if the device features a Memory Management Unit that should be pre-initialized to a standard SQI and EBI mapping.
__PIC32_HAS_INIT_DATA	Defined if the device requires data initialization by copying from a template located in Flash to RAM.

3.5.19. What Optimizations Are Employed by the Compiler?

Code optimizations available depend on the edition of your compiler (see Optimizations). A description of optimization options can be found under Options for Controlling Optimization.

3.5.20. Why Do I Get Out-of-Memory Errors When I Select a Debugger?

If you use a hardware tool debugger such as MPLAB PICkit 4 in-circuit debugger or MPLAB ICD 4 in-circuit debugger memory is required for the on-board debug executive.

3.5.21. How Do I Stop My Project's Checksum From Changing?

The checksum that represents your built project (whether this is generated by the MPLAB X IDE or by tools such as Hexmate) is calculated from the generated output of the compiler. Indeed, the algorithms used to obtain the checksum are specifically designed so that even small changes in this output are almost guaranteed to produce a different checksum result. Checksums are not calculated from your project's source code. To ensure that your checksum does not change from build to build, you must ensure that the output of the compiler does not change.

The following actions and situations could cause changes in the compiled output and hence changes in your project's checksum.

- Changing the source code, header files, or library code used by the project between builds.
- Changing the order in which source files or libraries are compiled or linked between builds.
- Having source code that makes using of macros such as __DATE__ and __TIME__, which produce output that is dependent on when the project was built.
- Moving the location of source files between builds, where those files use macros such as __FILE__, which produces output that is dependent on where the source file is located.
- Changing the compiler options between builds.
- Changing the compiler version between builds.

Note that the checksum algorithms used by tools such as Hexmate and the MPLAB X IDE can change, which can result in a different checksum for the same compiler output. Such changes are rare, but check the compiler and IDE release notes to see if the tools have been modified.

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3.6. Fixing Code That Does Not Work

This section examines issues relating to projects that do not build due to compiler errors, or those that build, but do not work as expected.

- How Do I Set Up Warning/Error Messages?
- How Do I Find the Code that Caused Compiler Errors or Warnings in My Program?
- How Can I Stop Spurious Warnings From Being Produced?
- Why Can't I Even Blink an LED?
- What Can Cause Corrupted Variables and Code Failure When Using Interrupts?
- Invoking the Compiler
- What Can Cause Corrupted Variables and Code Failure When Using Interrupts?
- Why Are Some Objects Positioned Into Memory That I Reserved?

3.6.1. How Do I Set Up Warning/Error Messages?

To control message output, see Options for Controlling Warning and Errors.

3.6.2. How Do I Find the Code that Caused Compiler Errors or Warnings in My Program?

In most instances, where the error is a syntax error relating to the source code, the message produced by the compiler indicates the offending line of code (see Compiler Messages). If you are compiling in MPLAB X IDE, then you can double-click the message and have the editor take you to the offending line; in VS Code, **Ctlr+*click*** (macOS use **Cmd+*click***) the file name-line number link in the **Terminal** view. Identifying the offending code, however, is not always so easy.

In some instances, the error is reported on the line of code following the line that needs attention. This is because a C statement is allowed to extend over multiple lines of the source file. It is possible that the compiler cannot be able to determine that there is an error until it has started to scan to statement following. So in the following code

```
input = PORTB   // oops - forgot the semicolon
if(input>6)
// ...
```

The missing semicolon on the assignment statement will be flagged on the following line that contains the `if()` statement.

In other cases, the error might come from the assembler, not the code generator. If the assembly code was derived from a C source file, then the compiler will try to indicate the line in the C source file that corresponds to the assembly that is at fault. If the source being compiled is an assembly module, the error directly indicates the line of assembly that triggered the error. In either case, remember that the information in the error relates to some problem is the assembly code, not the C code.

Finally, there are errors that do not relate to any particular line of code at all. An error in a compiler option or a linker error are examples of these. If the program defines too many variables, there is no one particular line of code that is at fault; the program as a whole uses too much data. Note that the name and line number of the last processed file and source can be printed in some situations even though that code is not the direct source of the error.

If you need to see the assembly code generated by the compiler, look in the assembly list file. For information on where the linker attempted to position objects, see the map file. See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186) for information about the list and map files.

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3.6.3. How Can I Stop Spurious Warnings From Being Produced?

Warnings indicate situations that could possibly lead to code failure. Always check your code to confirm that it is not a possible source of error. In many situations the code is valid and the warning is superfluous. In this case, you may:

- Inhibit specific warnings by using the `-Wno-` version of the option.
- Inhibit all warnings with the `-w` option.
- In MPLAB X IDE, inhibit warnings in the Project Properties window under each tool category. Also look in the Tool Options window, Embedded button, Suppressible Messages tab.

See Options for Controlling Warning and Errors for details.

3.6.4. Why Can't I Even Blink an LED?

Even if you have set up the TRIS register and written a value to the port, there are several things that can prevent such a seemingly simple program from working.

- Make sure that the device's configuration registers are set up correctly, as discussed in Configuration Bit Access. Make sure that you explicitly specify every bit in these registers and don't just leave them in their default state. All the configuration features are described in your device data sheet. If the configuration bits that specify the oscillator source are wrong, for example, the device clock may not even be running.
- If the internal oscillator is being used, in addition to Configuration bits there may be SFRs you need to initialize to set the oscillator frequency and modes, see ID Locations and your device data sheet.
- To ensure that the device is not resetting because of the watchdog time, either turn off the timer in the configuration bits or clear the timer in your code. There are library functions you can use to handle the watchdog timer, described in the 32-bit Language Tool Libraries manual (DS51685). If the device is resetting, it may never reach the lines of code in your program that blink the LED. Turn off any other features that may cause device Reset until your test program is working.
- The device pins used by the port bits are often multiplexed with other peripherals. A pin might be connected to a bit in a port, or it might be an analog input, or it might be the output of a comparator, for example. If the pin connected to your LED is not internally connected to the port you are using, then your LED will never operate as expected. The port function tables in your device data sheets will show other uses for each pin which will help you identify peripherals to investigate.

3.6.5. What Can Cause Corrupted Variables and Code Failure When Using Interrupts?

This is usually caused by having variables used by both interrupt and main-line code. If the compiler optimizes access to a variable or access is interrupted by an interrupt routine, then corruption can occur. See How Do I Share Data Between Interrupt and Main-line Code? for more information.

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4. IDE Integration

The MPLAB XC32 C/C++ Compiler may be integrated into and controlled from many Integrated Development Environments (IDEs), such as the MPLAB® X IDE and Microsoft® Visual Studio Code®. Use of an IDE provides a graphical user interface to control the compiler's many command-line options, as well as access to simulators and hardware debuggers that can execute the built code.

For installation of the MPLAB X IDE, and the creation and setup of projects to use the MPLAB XC32 C/C++ Compiler, see the *MPLAB® X IDE User's Guide* for more information. For assistance with the MPLAB extensions for VS Code, see developerhelp.microchip.com/xwiki/bin/view/software-tools/ides/extensions/.

4.1. MPLAB X IDE and VS Code Option Equivalents

The descriptions in the following sections map the controls in the **Project Properties** for both MPLAB X IDE and the MPLAB Extensions for VS Code to their corresponding command-line options. A link to the relevant section in the user's guide is provided to learn more about the feature that the option controls.

In the MPLAB X IDE, click any option to see online help and examples shown in the **Option Description** field in the lower part of the dialog. See also Options Page Features for features common to all option dialogs.

In VS Code, verbose descriptions of the options are provided next to the control itself.

4.1.1. XC32 Global Options

The following global feature controls are displayed in the MPLAB X IDE and VS Code project property dialogs, along with their corresponding driver options. When used, these options are applied at each stage of the compilation process.

Table 4-1. XC32 Global General Options Category

Option	Description	Command Line
Override default device support	Select "Do not override" to build the project with a default DFP. Select "Compiler location" to use the relevant DFP shipped with the compiler. DFPs provide device-specific information, such as register names and addresses, which can be used by code in the project.	`-mdfp`
Don't delete intermediate files	Don't delete intermediate Files. Place them in the object directory and name them based on the source file.	`-save-temps[=dir]`
Link-Time Optimizations	When these optimzations are enabled, the build will be constrained in the following ways: - The per-file build settings will be ignored - The build will no longer be an incremental one (full build only)	`-f[no-]lto`
Use GP relative addressing threshold	Put definitions of externally-visible data in a small data section if that data is no bigger than `num` bytes.	`-G num`

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Table 4-1. XC32 Global General Options Category (continued)

Option	Description	Command Line
Relaxed floating-point math	Link in a relaxed-compliance math library, providing alternative floating-point support routines that are faster and smaller than the default math routines, but make some sacrifices in compliance.	`-relaxed-math`
Common include dirs	Directory paths entered here will be appended to the already existing include paths of the compiler. Relative paths are from the MPLAB X IDE project directory.	`-I dir`

4.1.2. XC32 Assembler Options

The following assembler feature controls are displayed in the MPLAB X IDE and VS Code project property dialogs, along with their corresponding driver options. When used, these options are passed to the assembler application `xc32-as` and are not relevant for the `xc32-gcc` driver. For additional assembler options, see the *MPLAB® XC32 Assembler, Linker And Utilities User's Guide*.

Table 4-2. XC32 Assembler General Options Category

Option	Description	Command Line
Have symbols in production build	Generate debugging information for source-level debugging in MPLAB X.	`--gdwarf-2` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Keep local symbols	Check to keep local symbols, that is, labels beginning with `.L` (upper case only). Uncheck to discard local symbols.	`--keep-locals` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Exclude floating-point library	Exclude support for floating-point operations reducing code size for applications that do not require floating-point support.	`-mno-float`
Generate MIPS16 16-bit code (X IDE only)	Changes the assembler's default assembly mode so it will attempt to build for the MIPS16 ISA. You can still override this setting with the `.set isa-mode` directives.	`-mips16` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Generate microMIPS compressed code (X IDE only)	Changes the assembler's default assembly mode so it will attempt to build for the microMIPS ISA. You can still override this setting with the `.set isa-mode` directives.	`-mmicromips` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Preprocessor macro definitions	Project-specific preprocessor macro defines passed via the compiler's `-D` option.	`-Dmacro[=defn]` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Assembler symbols	Define symbol *sym* to a given *value*.	`--defsym sym=value` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Preprocessor Include directories	Add a directory to the list of those searched for headers included by the preprocessor. Relative paths are from MPLAB X project directory.	`-I dir` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Assembler Include directories	Add a directory to the list of those searched for files specified in `.include` directives. Relative paths are from MPLAB X project directory. You may add as many directories as necessary to include a variety of paths. The current working directory is always searched first and then `-I` directories in the order in which they were specified (left to right) here.	`-Idir` See the *MPLAB ®XC32 Assembler, Linker and Utilities User's Guide*.

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Table 4-2. XC32 Assembler General Options Category (continued)

Option	Description	Command Line
Additional Options (VS Code only)	Add options which do not have a dedicated control widget present in the properties dialog.	

Table 4-3. XC32 Assembler Other Options Category

Option	Description	Command Line

Diagnostics level	Select warnings to display in the Output window. Select “Generate warnings” to have the usual warnings issued by the compiler; “Suppress warnings”to have only errors displayed, and "Fatal Warnings" to have the assembler treat warnings as if they were errors.	`--[no-]warn`
		`--fatal-warnings`
		See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*

Include source code	Check for a high-level language listing. High-level listings require that the assembly source code is generated by a compiler, a debugging option like `-g` is given to the compiler, and assembly listings (`-al`) are requested. Uncheck for a regular listing.	`-ah` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Expand macros	Check to expand macros in a listing. Uncheck to collapse macros.	`-am` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Include false conditionals	Check to include false conditionals (`.if, .ifdef`) in a listing. Uncheck to omit false conditionals.	`-ac` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Omit forms processing	Check to turn off all forms processing that would be performed by the listing directives `.psize`, `.eject`, `.title` and `.sbttl`. Uncheck to process by listing directives.	`-an` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Include assembly	Check for an assembly listing. This `-a` suboption may be used with other suboptions. Uncheck to exclude an assembly listing.	`-al` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
List symbols	Check for a symbol table listing. Uncheck to exclude the symbol table from the listing.	`-as` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
Omit debugging directives	Check to omit debugging directives from a listing. This can make the listing cleaner. Uncheck to included debugging directives.	`-ad` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*
List to file	Use this option if you want the assembly listing for any assembly source files in the project. They will have the same basename as the source, with a `.lst` extension.	`-a=file.lst` See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*

4.1.3. XC32 C Compiler Options

The following are C compiler feature controls displayed in the MPLAB X IDE and VS Code project property dialogs, along with their corresponding driver options. When used, these options are applied at the first (code generation) stage of the compilation process.

Table 4-4. XC32 C Compiler General Options Category

Option	Description	Command Line
Have symbols in production build	Build for debugging in a production build image.	`-g`
Enable App IO	Support the APPIN/APPOUT debugging feature with REAL ICE.	`-mappio-debug`

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Table 4-4. XC32 C Compiler General Options Category (continued)

Option	Description	Command Line
Isolate each function in a section	This option is often used with the linker's `--gc-sections` option to remove unreferenced functions. Check to place each function into its own section in the output file. The name of the function determines the section's name in the output file. Note: When you specify this option, the assembler and linker may create larger object and executable files and will also be slower. Uncheck to place multiple functions in a section.	`-ffunction-sections`
Place data into its own section	This option is often used with the linker's `--gc-sections` option to remove unreferenced statically-allocated variables. Place each data item into its own section in the output file. The name of the data item determines the name of the section. When you specify this option, the assembler and linker may create larger object and executable files and will also be slower.	`-fdata-sections`
Enable toplevel reordering	Allows the compiler to reorder top-level functions, variables, and `asm` statements, in which case, they might not be output in the same order that they appear in the input file.	`-ftoplevel-reorder`
Use indirect calls	Enable full-range calls.	`-mlong-calls`
Generate MIPS16 16-bit code (X IDE only)	Generate code for the MIPS16 instruction set, reducing code size.	`-[mno-]mips16`
Generate microMIPS compressed code (X IDE only)	Generate code using the microMIPS™ instructions. This feature is available only in the PRO edition.	`-m[no-]micromips`
Exclude floating-point library	Exclude support for floating-point operations reducing code size for applications that do not require floating-point support.	`-mno-float`
Additional Options (VS Code only)	Add options which do not have a dedicated control widget present in the properties dialog.	

Note that some of the compiler options specified by fields in Project Property Categories other than Optimization can affect the size and execution speed of your project. Consider using the Compiler Advisor, accessible via the MPLAB X IDE **Tools** > **Analysis** > **Compiler Advisor** menu item, to compare the size of your project when built with different combination of compiler options.

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Table 4-5. XC32 C Compiler Optimization Options Category

Option	Description	Command Line
Optimization Level	Select an optimization level. Your compiler edition may support only some optimizations. Equivalent to `-On` option, where `n` is an option below: 0 - Do not optimize. The compiler's goal is to reduce the cost of compilation and to make debugging produce the expected results. 1 - Optimize. Optimizing compilation takes somewhat longer and a lot more host memory for a large function. The compiler tries to reduce code size and execution time. 2 - Optimize even more. The compiler performs nearly all supported optimizations that do not involve a space-speed trade-off. 3 - Optimize yet more favoring speed (superset of O2). s - Optimize yet more favoring size (superset of O2).	`-O0 -O1 -O2 -O3 -Os`
Unroll loops	This option often increases execution speed at the expense of larger code size. Check to perform the optimization of loop unrolling. This is only done for loops whose number of iterations can be determined at compile time or run time. Uncheck to not unroll loops.	`-funroll-loops`
Omit frame pointer	Check to not keep the Frame Pointer in a register for functions that don't need one. Uncheck to keep the Frame Pointer.	`-fomit-frame-pointer`
Pre-optimization instruction scheduling	Default for optimization level: - Disable - Enable	`-f[no-]schedule-insns`
Post-optimization instruction scheduling	Default for optimization level: - Disable - Enable	`-f[no-]schedule-insns2`
Use common tentative definitions	Controls the placement of global variables defined without an initializer.	`-f[no-]common`

Table 4-6. XC32 C Compiler Preprocessing and Messages Category

Option	Description	Command Line
Preprocessor macros	Project-specific preprocessor macro defines passed via the compiler's `-D` option.	*`-Dmacro=defn`*
Include directories	Search these directories for project-specific include files.	*`-I dir`*
Make warnings into errors	Check to halt compilation based on warnings as well as errors. Uncheck to halt compilation based on errors only.	`-Werror`

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Table 4-6. XC32 C Compiler Preprocessing and Messages Category (continued)

Option	Description	Command Line
Additional warnings	Check to enable all warnings. Uncheck to disable warnings.	`-Wall`
Enable address-attribute warning		`-Waddress-attribute-use`
support-ansi	Check to issue all warnings demanded by strict ANSI C. Uncheck to issue all warnings.	`-ansi`
strict-ansi	Issue all the warnings demanded by strict ISO C and ISO C++; reject all programs that use forbidden extensions, and some other programs that do not follow ISO C and ISO C++.	`-pedantic`
Use CCI syntax	Enable support for the CCI syntax (see Common C Interface).	`-mcci`
Use IAR syntax	Enable support for syntax used by other toolchain vendors.	`-mext=IAR`

4.1.4. XC32 C++ Compiler Options

The following are C++ compiler feature controls displayed in the MPLAB X IDE and VS Code project property dialogs, along with their corresponding driver options. When used, these options are applied at the first (code generation) stage of the compilation process.

Table 4-7. XC32 C++ Compiler C++ Specific Options Category

Option	Description	Command Line
Generate run time type descriptor information	Enable generation of information about every class with virtual functions for use by the C++ runtime type identification features (`dynamic_cast` and `typeid`). If you don't use those parts of the language, you can save some space by disabling this option. Note that exception handling uses the same information, but it will generate it as needed. The `dynamic_cast` operator can still be used for casts that do not require runtime type information, that is, casts to `void *` or to unambiguous base classes.	`-frtti`
Enable C++ exception handling	Enable exception handling. Generates extra code needed to propagate exceptions.	`-fexceptions`
Check that the pointer returned by operator 'new' is non-null	Check that the pointer returned by operator new is non-null before attempting to modify the storage allocated.	`-fcheck-new`
Generate code to check for violation of exception specification	Generate code to check for violation of exception specifications at runtime. Using this option may increase code size in production builds.	`-fenforce-eh-specs`

Table 4-8. XC32 C++ Compiler General Options Category

Option	Description	Command Line
Have symbols in production build	Build for debugging in a production build image.	`-g`
Enable App IO	Support the APPIN/APPOUT debugging feature with REAL ICE.	`-mappio-debug`
Isolate each function in a section	Place each function into its own section in the output file if the target supports arbitrary sections. The name of the function or the name of the data item determines the section's name in the output file. This option is useful when combined with the linker's `--gc-sections` option to remove unreferenced functions.	`-ffunction-sections`

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Table 4-8. XC32 C++ Compiler General Options Category (continued)

Option	Description	Command Line
Place data into its own section	Place each data item into its own section in the output file if the target supports arbitrary sections. The name of the function or the name of the data item determines the section's name in the output file. This option is useful when combined with the linker's `--gc-sections` option to remove unreferenced variables.	`-fdata-sections`
Enable toplevel reordering	Allows the compiler to reorder top-level functions, variables, and `asm` statements, in which case, they might not be output in the same order that they appear in the input file.	`-ftoplevel-reorder`
Use indirect calls	Enable full-range calls.	`-mlong-calls`
Generate MIPS16 16-bit code	By default, generate code for the MIPS16 instruction set, reducing code size.	`-mips16`
Generate microMIPS compressed code	Generate code using the microMIPS™ instructions. This feature is available only in the PRO edition.	`-m[no-]micromips`
Exclude floating-point library	Exclude support for floating-point operations reducing code size for applications that do not require floating-point support.	`-mno-float`
Additional Options	Add options which do not have a dedicated control widget present in the properties dialog.	

Table 4-9. XC32 C++ Compiler Optimization Category

Option	Description	Command Line
Optimization Level	Select an optimization level. Your compiler edition may support only some optimizations. Equivalent to `-On` option, where *n* is an option below: 0 - Do not optimize. The compiler's goal is to reduce the cost of compilation and to make debugging produce the expected results. 1 - Optimize. Optimizing compilation takes somewhat longer and a lot more host memory for a large function. The compiler tries to reduce code size and execution time. 2 - Optimize even more. The compiler performs nearly all supported optimizations that do not involve a space-speed trade-off. 3 - Optimize yet more favoring speed (superset of O2). s - Optimize yet more favoring size (superset of O2).	`-O0 -O1 -O2 -O3 -Os`
Unroll loops	Check to perform the optimization of loop unrolling. This is only done for loops whose number of iterations can be determined at compile time or run time. Uncheck to not unroll loops.	`-funroll-loops`
Omit frame pointer	Check to not keep the Frame Pointer in a register for functions that don't need one. Uncheck to keep the Frame Pointer.	`-fomit-frame-pointer`
Pre-optimization instruction scheduling	Default for optimization level: - Disable - Enable	`-f[no-]schedule-insns`
Post-optimization instruction scheduling	Default for optimization level: - Disable - Enable	`-f[no-]schedule-insns2`

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Table 4-10. XC32 C++ Compiler Preprocessing and Messages Category

Option	Description	Command Line
Preprocessor macros	Project-specific preprocessor macro defines passed via the compiler's `-D` option.	`-Dmacro[=defn]`
Include directories	Search these directories for project-specific include files.	`-I path`
Make warnings into errors	Check to halt compilation based on warnings as well as errors. Uncheck to halt compilation based on errors only.	`-Werror`
Additional warnings	Check to enable all warnings. Uncheck to disable warnings.	`-Wall`
Enable address-attribute warning		`-Waddress-attribute-use`
Support ansi	Check to issue all warnings demanded by strict ANSI C. Uncheck to issue all warnings.	`-ansi`
Strict ansi	Issue all the warnings demanded by strict ISO C and ISO C++; reject all programs that use forbidden extensions, and some other programs that do not follow ISO C and ISO C++.	`-pedantic`
Use CCI syntax	Enable support for the CCI syntax (Common C Interface).	`-mcci`
Use IAR syntax	Enable support for syntax used by other toolchain vendors.	`-mext=IAR`

4.1.5. XC32 Linker Options

The following are linker feature controls displayed in the MPLAB X IDE and VS Code project property dialogs, along with their corresponding driver options. When used, these options are passed to the linker application `xc32-ld` and are not relevant for the `xc32-gcc` driver. For additional linker options, see *MPLAB® XC32 Assembler, Linker And Utilities User's Guide* documentation.

Table 4-11. XC32 Linker General Category

Option	Description	Command Line
Heap Size (bytes)	Specify the size of the heap in bytes. Allocate a run-time heap of size bytes for use by C programs. The heap is allocated from unused data memory. If not enough memory is available, an error is reported.	`-Wl,--defsym=_min_heap_size=size` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Minimum stack size (bytes)	Specify the minimum size of the stack in bytes. By default, the linker allocates all unused data memory for the run-time stack. Alternatively, the programmer may allocate the stack by declaring two global symbols: `__SP_init` and `__SPLIM_init`. Use this option to ensure that at least a minimum sized stack is available. The actual stack size is reported in the link map output file. If the minimum size is not available, an error is reported.	`-Wl,--defsym=_min_stack_size=size` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Allow overlapped sections	Check to not check section addresses for overlaps. Uncheck to check for overlaps.	`-Wl,--[no-]check-sections` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Remove unused sections	Check to enable garbage collection of unused input sections (on some targets). Uncheck to disable garbage collection.	`-Wl,--[no-]gc-sections` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Use response file to link	Pass linker options in a file rather than on the command line. On Windows systems, this option allows you to properly link projects with a large number of object files that would normally overrun the command-line length limitation of the Windows OS.	

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Table 4-11. XC32 Linker General Category (continued)

Option	Description	Command Line
Write Start Linear Address record	Set the start linear address for a type 5 records in HEX files.	`--write-sla` (`xc32-bin2hex` option) See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Additional driver options	Type here any additional driver options that do not have dedicated GUI widgets in the Project Properties dialog. The string entered here will be emitted verbatim with the other driver options.	
Place code in data init template	Place code sections into the data-initialization template stored in the `.dinit` section.	`-Wl,--code-in-dinit` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Allocate data-init section to serial memory	Allocate the `.dinit` template section to a memory region named `serial_mem` rather than `kseg0_program_mem`.	`-Wl,--dinit-in-serial-mem` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

Table 4-12. XC32 Linker Libraries Option Category

Option	Description	Command Line
Optimization level of Standard Libraries	Select an optimization level. Your compiler edition may support only some optimizations. Equivalent to `-On` option, where `n` is an option below: 0 - Do not optimize. The compiler's goal is to reduce the cost of compilation and to make debugging produce the expected results. 1 - Optimize. Optimizing compilation takes somewhat longer and a lot more host memory for a large function. The compiler tries to reduce code size and execution time. 2 - Optimize even more. The compiler performs nearly all supported optimizations that do not involve a space-speed trade-off. 3 - Optimize yet more favoring speed (superset of O2). s - Optimize yet more favoring size (superset of O2).	`-On` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
System Libraries	Add libraries to be linked with the project files. You may add more than one.	`--library=`*name* See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Library directories	Add a library directory to the library search path. You may add more than one.	`--library-path="name"` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Exclude Standard Libraries	Check to not use the standard system startup files or libraries when linking. Only use library directories specified on the command line. Uncheck to use the standard system startup files and libraries.	`-nostdlib` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Do no link crt0 startup code	Exclude the default startup code because the project provides application-specific startup code.	`-nostartfiles` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Do not link device startup code (X IDE only)		
Link MIPS16 libraries (X IDE only)	Link the libraries precompiled for the MIPS16 instruction set, reducing code size.	`-mips16` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

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Table 4-12. XC32 Linker Libraries Option Category (continued)

Option	Description	Command Line
Link microMIPS™ compressed startup code and libraries (X IDE only)	Generate code using the microMIPS™ instructions. This feature is available only in the PRO edition.	`-mmicromips` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

Table 4-13. XC32 Linker Fill Flash Memory Options Category

Option	Description	Command Line
Which areas to fill	Specify which area of Flash memory to fill. **No Fill** - None (default). **Fill All Unused** - Fill all unused memory. **Provide Range to fill** - Fill a range of memory. Enter a range under "Memory Address Range."	`--fill=sequence` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
How to fill it	Specify how to fill Flash memory. **Provide sequence of values** - provide a sequence under the Sequence option. **Constant or incrementing value** - provide a constant, increment/decrement or increment/decrement constant under the same-named option.	`--fill=sequence` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Sequence	When **Provide sequence of values** is selected, enter a sequence. The form is n1, n2, ... where n1 uses C syntax. Example: 0x10, 25, 0x3F, 16.	`--fill=sequence` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Constant	When **Constant or incrementing value** is selected, enter a constant. Specify the constant using C syntax (for example, 0x for hex, 0 for octal). Example: 0x10 is the same as 020 or 16.	`--fill=sequence` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Increment/Decrement	When **Constant or incrementing value** is selected, you can select to increment or decrement the initial value of "Constant" on each consecutive address. **No Incrementing** - do not change constant value. **Increment Const** - increment the constant value by the amount specified under the option "Increment/Decrement Constant." **Decrement Const** - decrement the constant value by the amount specified under the option "Increment/Decrement Constant."	`--fill=sequence` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Increment/Decrement Constant	When **Increment Const** or **Decrement Const** is selected, enter a constant increment or decrement value. Specify the constant using C syntax (for example, 0x for hex, 0 for octal). Example: 0x10 is the same as 020 or 16.	`--fill=sequence` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Memory Address Range	When **Provide Range to fill** is selected, enter the range here. Specify range as Start:End where Start and End use C syntax. Example 0x100:0x1FF is the same as 256:511.	`--fill=sequence` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

Table 4-14. XC32 Linker Diagnostics Options Category

Option	Description	Command Line
Generate map file	Create a map file.	`-Map="file"` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Display memory usage	Check to print memory usage report. Uncheck to not print a report.	`--report-mem` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Generate cross-reference file	Check to create a cross-reference table. Uncheck to not create this table.	`--cref` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

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Table 4-14. XC32 Linker Diagnostics Options Category (continued)

Option	Description	Command Line
Warn on section realignment	Check to warn if start of section changes due to alignment. Uncheck to not warn.	`--warn-section-align` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Trace Symbols	Add/remove trace symbols.	`-Y symbol` or `--trace-symbol=symbol` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

Table 4-15. XC32 Linker Symbols and Macros Options Category

Option	Description	Command Line
Linker symbols	Create a global symbol in the output file containing the absolute address (`expr`). You may use this option as many times as necessary to define multiple symbols in the command line. A limited form of arithmetic is supported for the `expr` in this context: you may give a hexadecimal constant or the name of an existing symbol, or use + and - to add or subtract hexadecimal constants or symbols.	`--defsym=sym` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Preprocessor macro definitions	Add linker macros.	`-Dmacro` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.
Symbols	Specify symbol information in the output.	`-S` or `--strip-debug`; `-s` or `--strip-all` See *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

4.1.6. XC32 Library Archiver Options

The following archiver feature controls are displayed in the MPLAB X IDE and VS Code project property dialogs. These features analyze your code to highlight safety or performance issues.

Table 4-16. XC32 Library Archiver General Options Category

Option	Description	Command Line
Break line into multiple lines(X IDE only)	When using the Windows compiler to archive many file into libraries, the link command line might go over the 8191 character line limit. This option has XC32 break up the command line into smaller lines to avoid this limitation.	n/a

4.1.7. XC32 Analysis Options

The following analysis feature controls are displayed in the MPLAB X IDE and VS Code project property dialogs, along with their corresponding driver options. These features analyze your code to highlight safety or performance issues.

Table 4-17. XC32 Analysis General Options Category

Option	Description	Command Line
Code coverage instrumentation	Enable the code coverage feature.	`-mcodecov`
Stack guidance	Check to enable the stack guidance feature, which gives an estimate of stack usage.	`-mchp-stack-usage`

4.1.8. Options Page Features

The Options section of the **Project Properties** dialog in the MPLAB X IDE has the following features for all tools:

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Table 4-18. Page Features Options

Reset	Reset the page to default values.
Additional options	Enter options in a command-line (non-GUI) format.
Option Description	Click on an option name to see information on the option in this window. Not all options have information in this window.
Generated Command Line	Click on an option name to see the command-line equivalent of the option in this window.

If you are using the MPLAB Extension in VS Code, use the **Filter** field at the top of the page to help locate the option you need to change.

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5. Command-line Driver

The MPLAB XC32 C/C++ Compiler command-line driver, `xc32-gcc`, can be invoked to perform all aspects of compilation, including C code generation, assembly and link steps. Its use is the recommended way to invoke the compiler, as it hides the complexity of all the internal applications and provides a consistent interface for all compilation steps. Even if an IDE is used to assist with compilation, the IDE will ultimately call `xc32-gcc`.

If you are developing a project that contains C++ source code, an alternate driver called `xc32-g++` is supplied and that will link in an alternate set of libraries. Its operation is similar to the `xc32-gcc` driver.

This chapter describes the steps that the driver takes during compilation, the files that the driver can accept and produce, as well as the command-line options that control the compiler's operation.

5.1. Invoking The Compiler

This section explains how to invoke `xc32-gcc` on the command line and discusses the input files that can be passed to the compiler.

Environment variables that can be set to specify certain aspects of the compiler's behavior are also explained.

5.1.1. Driver Command-line Format

The `xc32-gcc` driver can be used to compile and assemble C and assembly source files, as well as link object files and library archives to form a final program image.

The `xc32-g++` driver must instead be used when the module source is written in C++.

The driver has the following basic command format:

```
xc32-gcc [options] files
```

So, for example, to compile and link the C source file `hello.c`, you could use the command:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -O2 -o
hello.elf hello.c
```

The format for the C++ driver is similar.

```
xc32-g++ [options] files
```

And this driver is used in a similar way, for example:

```
xc32-g++ -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -O2 -o
hello.elf hello.cpp
```

Throughout this manual, it is assumed that the compiler applications are in your console's search path. See Environment Variables for information on the environment variable that specifies the search locations. Alternatively, use the full directory path along with the driver name when executing the compiler.

It is customary to declare *`options`* (identified by a leading dash "–" or double dash "––") before the files' names; however, this is not mandatory.

Command-line options are case sensitive, with their format and description being supplied in Driver Option Descriptions. Many of the command-line options accepted by `xc32-gcc` are common to all the MPLAB XC compilers, to allow greater portability between devices and compilers.

The *`files`* can be any mixture of C/C++ and assembler source files, as well as relocatable object files and archive files. While the order in which these files are listed does not directly affect the operation

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of the program, it can affect the allocation of code or data. Note, that the order of the archive files will dictate the order in which they are searched, and in some situations, this might affect which modules are linked in to the program.

It is recommended that C-only projects use the `xc32-gcc` driver. If you have C++ source code or a mix of C and C++ source, always use `xc32-g++` driver to ensure the correct libraries are linked in.

5.1.2. Environment Variables

The environment variables in this section are optional, but if defined, they will be used by the compiler. The compiler driver (or other subprogram) may choose to determine an appropriate value for some of the following environment variables if they are not set. The driver (or other subprogram) takes advantage of internal knowledge about the installation of the compiler. As long as the installation structure remains intact, with all subdirectories and executables remaining in the same relative position, the driver or subprogram will be able to determine a usable value.

The XC32-style variables should be used for new projects; however, the PIC32-style variables may be used for legacy projects.

Table 5-1. Compiler-Related Environment Variables

Variable	Description
XC32_C_INCLUDE_PATH or PIC32_C_INCLUDE_PATH	This variable's value is a semicolon-separated list of directories, much like your host terminal's `PATH` environment variable. When the compiler searches for header files, it tries the directories listed in the variable, after the directories specified with `-I` but before the standard header file directories. If the environment variable is undefined, the preprocessor chooses an appropriate value based on the standard installation. By default, the following directories are searched for the following include files: `<install-path>/pic32m/include.`
XC32_COMPILER_PATH or PIC32_COMPILER_PATH	The value of this variable is a semicolon-separated list of directories, much like your host terminal's `PATH` environment variable. The compiler tries the directories thus specified when searching for subprograms, if it can't find the subprograms using `PIC32M_EXEC_PREFIX`.
XC32_EXEC_PREFIX or PIC32_EXEC_PREFIX	If this environment variable is set, it specifies a prefix to use in the names of subprograms executed by the compiler. No directory delimiter is added when this prefix is combined with the name of a subprogram, but you can specify a prefix that ends with a slash if you wish. If the compiler cannot find the subprogram using the specified prefix, it tries looking in your `PATH` environment variable. If the environment variable is not set or set to an empty value, the compiler driver chooses an appropriate value based on the standard installation. If the installation has not been modified, this will result in the driver being able to locate the required subprograms. Other prefixes specified with the `-B` command line option take precedence over the user- or driver-defined value of the variable. Under normal circumstances it is best to leave this value undefined and let the driver locate subprograms itself.
XC32_LIBRARY_PATH or PIC32_LIBRARY_PATH	This variable's value is a semicolon-separated list of directories, much like `PATH`. This variable specifies a list of directories to be passed to the linker. The driver's default evaluation of this variable is: *`<install-path>`*`/lib;` *`<install-path>`*`/pic32m/lib`
TMPDIR	If this variable is set, it specifies the directory to use for temporary files. The compiler uses temporary files to hold the output of one stage of compilation that is to be used as input to the next stage: for example, the output of the preprocessor, which is the input to the compiler proper.

5.1.3. Input File Types

The `xc32-gcc` driver distinguishes source files, intermediate files and library files solely by the file type, or extension. The following case-sensitive extensions, listed below are recognized.

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Table 5-2. Input File Types

Extension	File format
`.c`	C source file
`.i`	Preprocessed C source file
`.cpp`	C++ source file
`.ii`	Preprocessed C++ source file
`.s`	Assembler source file
`.S`	Assembly source file requiring preprocessing
`.o`	Relocatable object code file
`.a`	Archive (library) file
other	A file to be passed to the linker

There are no compiler restrictions imposed on the names of source files, but be aware of case, name-length, and other restrictions that are imposed by your host operating system.

Avoid using the same base name for assembly and C/C++ source files, even if they are located in different directories. So, for example, if a project contains a C source file called `init.c`, do not also add to the project an assembly source file with the name `init.s`. Avoid, also, having source files with the same base name as the MPLAB X IDE project name.

The terms *source file* and *module* are often used interchangeably, but they refer to the source code at different points in the compilation sequence. A module is also referred to as a *translation unit* and is the preferred terminology, particularly when working with C++ languages since C++20.

A source file is a file that contains all or part of a program. It may contain C/C++ code, as well as preprocessor directives and commands. Source files are initially passed to the preprocessor by the compiler driver.

A module, or translation unit, is the output of the preprocessor for a given source file, after the inclusion of any header files specified by`#include` preprocessor directives, and after the processing and subsequent removal of other preprocessor directives (with the possible exception of some commands for debugging). Thus, a module is usually the amalgamation of a source file and several header files, and it is this output that is passed to the remainder of the compiler applications.

This terminology also applies to assembly files, which can also be preprocessed and include other header files.

5.2. The C Compilation Sequence

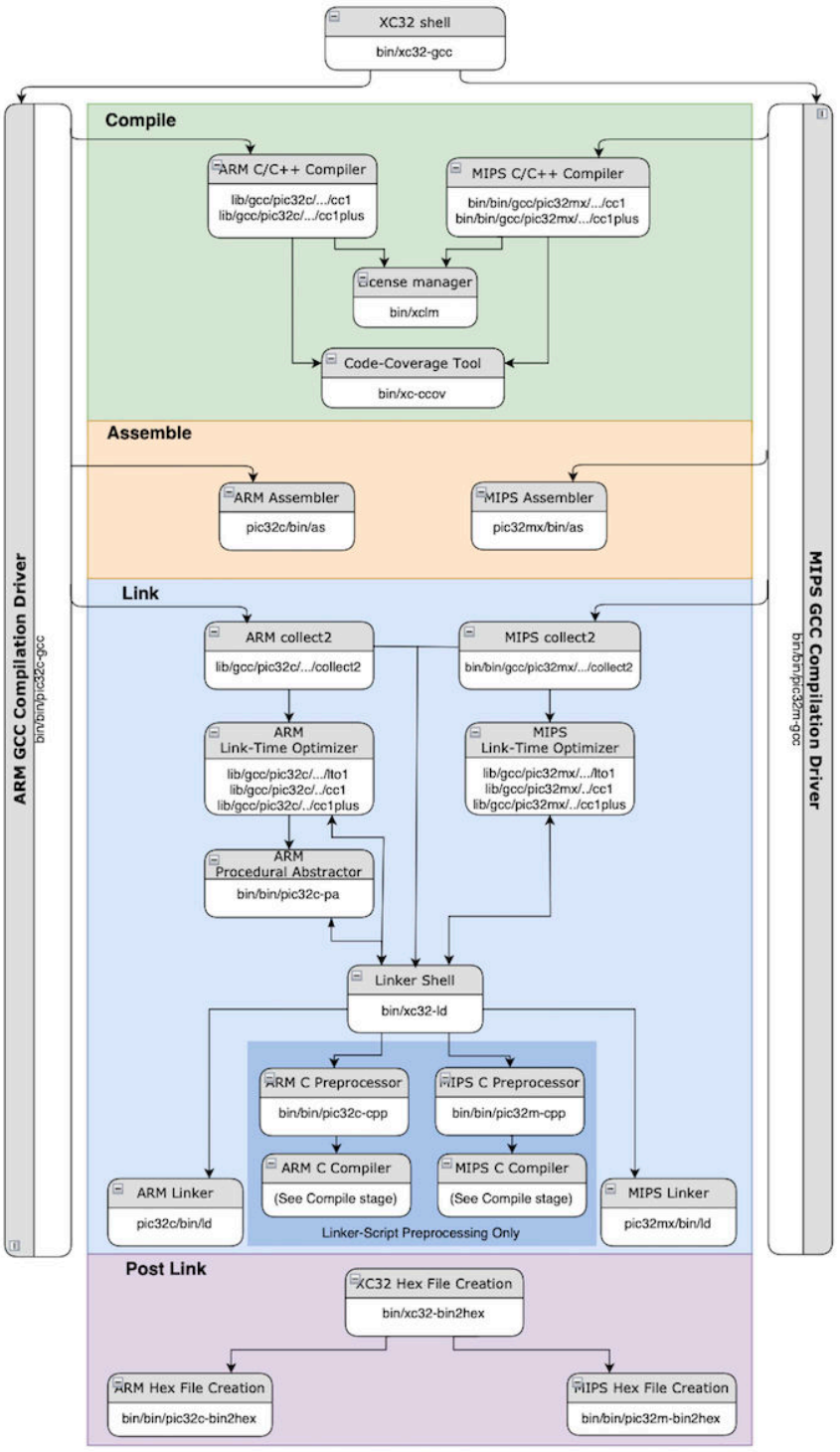
When you compile a project, many internal applications are called by the driver to do the work. This section introduces these internal applications and describes how they relate to the build process, especially when a project consists of multiple source files. This information should be of particular interest if you are using a make system to build projects.

5.2.1. The Compiler Applications

The main internal compiler applications are shown in the illustration below. This shows the tool chain employed for both PIC32M as well as PIC32C/SAM devices.

All the internal applications are controlled by the command line driver, `xc32-gcc`, which calls the internal applications (located in the compiler's bin directories) when required. An understanding of the internal operation of the compiler, while not necessary, does assist with using the tool.

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5.2.2. Single-Step C Compilation

Full compilation of one or more C source files, including the link step, can be performed in just one command using the `xc32-gcc` driver.

5.2.2.1. Compiling a Single C File

The following is a simple C program that adds two numbers. To illustrate how to compile and link a program consisting of a single C source file, copy the code into any text editor and save it as a plain text file with the name `ex1.c`.

```
#include <xc.h>

unsigned int add(unsigned int a, unsigned int b) {
  return a + b;
}

int main(void) {
  unsigned int x, y, z;
  x = 2;
  y = 5;
  z = add(x, y);

  return 0;
}
```

In the interests of clarity, this code does not specify device configuration bits, nor has any useful purpose.

Compile the program by typing the following command at the prompt in your favorite terminal. For the purpose of this discussion, it is assumed that in your terminal you have changed into the directory containing the source file you just created, and that the compiler is installed in the standard directory location and is in your host's search path.

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150"  -o
ex1.elf ex1.c
```

This command compiles the `ex1.c` source file for a 32MZ2048ECH100 device and has the output written to `ex1.elf`, which may be loaded into the MPLAB X IDE.

If a hex file is required, for example, to load into a device programmer, then use the following command:

```
xc32-bin2hex ex1.elf
```

This creates an Intel hex file named `ex1.hex`.

The driver will compile the source file, regardless of whether it has changed since the last build command. Development environments (such as MPLAB X IDE) and make utilities must be employed to achieve incremental builds (see Multi-Step C Compilation).

Unless otherwise specified, an ELF file (this is by default called `a.out`) is produced as the final output.

5.2.2.2. Compiling Multiple C Files

This section demonstrates how to compile and link a project, in a single step, that consists of multiple C source files.

Copy the example code shown into a text file called `add.c`.

```
/* add.c */
#include <xc.h>

unsigned int add(unsigned int a, unsigned int b) {
  return a + b;
}
```


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And place the following code in another file, `ext.c`.

```
/* ex1.c */
#include <xc.h>

unsigned int add(unsigned int a, unsigned int b);

int main(void) {
  unsigned int x, y, z;
  x = 2;
  y = 5;
  z = add(x, y);

  return 0;
}
```

In the interests of clarity, this code does not specify device configuration bits, nor has any useful purpose.

Compile both files by typing the following at the prompt:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150"  -o
ex1.elf ex1.c add.c
```

This command compiles the modules `ex1.c` and `add.c` in the one step. The compiled modules are linked with the relevant compiler libraries and the executable file `ex1.elf` is created.

5.2.3. Multi-Step C Compilation

A multi-step compilation method can be employed to build projects consisting of one or more C source files. Make utilities can use this feature, taking note of which source files have changed since the last build to speed up compilation. Incremental builds are also be performed by integrated development environments, such as the MPLAB X IDE when selecting the Build Project icon or menu item.

Make utilities typically call the compiler multiple times: once for each source file to generate an intermediate file and once to perform the second stage compilation, which links the intermediate files to form the final output. If only one source file has changed since the last build, the intermediate file corresponding to the unchanged source file need not be regenerated.

For example, the files `ex1.c` and `add.c` are to be compiled using a make utility. The command lines that the make utility could use to compile these files might be something like:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -c
ex1.c
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -c
add.c
```

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150"  -o
ex1.elf ex1.o add.o
```

The `-c` option used with the first two commands will compile the specified file into the intermediate file format, but not link. The resultant intermediate files are linked in the final step to create the final output `ex1.elf`. All the files that constitute the project must be present when performing the second stage of compilation.

The above example uses the command-line driver, `xc32-gcc`, to perform the final link step. You can explicitly call the linker application, `pic32m-ld`, but this is not recommended as the commands are complex and when driving the linker application directly, you must specify linker options, not driver options, as shown above.

For more information on using the linker, see the MPLAB® XC32 Assembler, Linker and Utilities User's Guide relevant to your project.

You may also wish to generate intermediate files to construct your own library archive files.

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See MPLAB® XC32 Assembler, Linker and Utilities User's Guide relevant to your project for more information on library creation.

5.3. The C++ Compilation Sequences

When you compile a project, many internal applications are called by the driver to do the work. This section introduces these internal applications and describes how they relate to the build process, especially when a project consists of multiple source files. This information should be of particular interest if you are using a make system to build projects.

5.3.1. Single-step C++ Compilation

A single command-line instruction can be used to compile one file or multiple files.

5.3.1.1. Compiling a Single C++ File

The following is a simple C++ program. To illustrate how to compile and link a program consisting of a single C++ source file, copy the code into any text editor and save it as a plain text file with the name `ex2.cpp`.

```
/* ex2.cpp */
#include <xc.h>
#include <iostream>
#include <vector>
#include <deque>
#include <list>
#include <set>
#include <map>
#include <string>
#include <algorithm>
#include <iterator>
#include <functional>
#include <numeric>
using namespace std;
//Device - Specific Configuration - bit settings
#pragma config FPLLMUL=MUL_20, FPLLIDIV=DIV_2, FPLLODIV=DIV_1
#pragma config FWDTEN=OFF
#pragma config POSCMOD=HS, FNOSC=PRIPLL, FPBDIV=DIV_8
template < class T >
inline void
print_elements(const T & coll, const char *optcstr = "") {
    typename T::const_iterator pos;
    std::cout << optcstr;
    for (pos = coll.begin(); pos != coll.end(); ++pos) {
        std::cout << *pos << ' ';
    }
    std::cout << std::endl;
}
template < class T >
inline void
insert_elements(T & coll, int first, int last) {
    for (int i = first; i <= last; ++i) {
        coll.insert(coll.end(), i);
    }
}
int
main(void) {
    //Direct stdout to UART 1 for use with the simulator
    __XC_UART = 1;
    deque<int>coll;
    insert_elements(coll, 1, 9);
    insert_elements(coll, 1, 9);
    print_elements(coll, "on entry: ");
    // sortelements
    sort(coll.begin(), coll.end());
    print_elements(coll, "sorted: ");
    //sorted reverse
    sort(coll.begin(), coll.end(), greater < int >());
    print_elements(coll, "sorted >: ");
    while (1);
}
```


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The first line of the program includes the header file `xc.h`, which provides definitions for all Special Function Registers (SFRs) on the target device. The second file of the program includes the header file, which provides the necessary prototypes for the peripheral library.

Compile the program by typing the following command at the prompt in your favorite terminal. For the purpose of this discussion, it is assumed that in your terminal you have changed into the directory containing the source file you just created, and that the compiler is installed in the standard directory location and is in your host's search path.

```
xc32-g++ -mprocessor=32MX795F512L -mdfp="Microchip/Microchip.PIC32MX_DFP.1.6.369" -Wl,--
defsym=_min_heap_size=0xF000 -o ex2.elf ex2.cpp
```

The option `-o ex2.elf` names the output executable file. This elf file may be loaded into MPLAB X IDE.

If a hex file is required, for example, to load into a device programmer, then use the following command

```
xc32-bin2hex ex2.elf
```

This creates an Intel hex file named `ex2.hex`.

5.3.2. Compiling Multiple C and C++ Files

This section demonstrates how to compile and link multiple C and C++ files in a single step.

File 1

```
/* main.cpp */
#include <xc.h>
#include <iostream>
using namespace std;
//Device - Specific Configuration - bit settings
#pragma config FPLLMUL=MUL_20, FPLLIDIV=DIV_2, FPLLODIV=DIV_1
#pragma config FWDTEN=OFF
#pragma config POSCMOD=HS, FNOSC=PRIPLL, FPBDIV=DIV_8
// add() must have C linkage
extern "C" {
    extern unsigned int add(unsigned int a, unsigned int b);
}
int main(void) {
    int myvalue = 6;
    //Direct stdout to UART 1 for use with the simulator
    __XC_UART = 1;
    std::cout << "original value: " << myvalue << endl;
    myvalue = add(myvalue, 3);
    std::cout << "new value:
    while (1);
}
```

File 2

```
/* ex3.c */
unsigned int
add(unsigned int a, unsigned int b)
{
return(a+b);
}
```

Compile both files by typing the following at the prompt:

```
xc32-g++ -mprocessor=32MX795F512L -mdff="Microchip/Microchip.PIC32MX_DFP.1.6.369" -o ex3.elf
main.cpp ex3.c
```

The command compiles the modules `main.cpp` and `ex3.c`. The compiled modules are linked with the compiler libraries for C++ and the executable file `ex3.elf` is created.

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Note: Use the xc32-g++ driver (as opposed to the xc32-gcc driver) in order to link the project with the C++ support libraries necessary for the C++ source file in the project.

5.4. Runtime Files

In addition to the C/C++ and assembly source files and user-defined libraries specified on the command line, the compiler can also link into your project compiler-generated source files and pre-compiled library files, whose content falls into the following categories:

- C/C++ standard library routines
- Implicitly called arithmetic library routines
- User-defined library routines
- The runtime start-up code

Note: Some PIC32 target devices allow you to select to boot in either the MIPS32® or microMIPS™ ISA mode via a device configuration bit (BOOTISA). On these devices, if your BOOTISA bit is set to microMIPS mode, pass the `-mmicromips` mode to the xc32-gcc/g++ compilation driver to tell it to link with the microMIPS variant of the runtime start-up code. If your BOOTISA bit is set to MIPS32 mode, pass the `-mno-micromips` option to the compilation driver so that the MIPS32 variant of the runtime start-up code is linked.

5.4.1. Location and Naming Convention

By default, the compiler uses the directory `<install-directory>/lib/gcc/` to store the specific libraries and the directory `<install-directory>/pic32m/lib` to store the target-specific libraries, based on the target device family.

The target libraries that are distributed with the compiler are built for the corresponding command-line options:

- Size vs. speed (`-Os` vs. `-O3`)
- MIPS16 vs. MIPS32 vs. microMIPS ISA mode (`-mips16` vs. `-mno-mips16` vs. `-mmicromips`)
- Software floating-point vs no floating-point support (`-msoft-float` vs. `-mno-float`)

The following examples provide details on which of the library subdirectories are searched.

If no optimization option has been specified or an optimization of level 2 or lower has been specified, for example, `xc32-gcc -O1 foo.c`, then the libraries in the top-level of the library subdirectories are used.

If `-Os` level optimizations have been chosen, for example, `xc32-g++ -Os foo.cpp`, then the libraries in the `size` directories of the library subdirectories are used.

If `-Os` level optimizations and the MIPS16 instruction set option have both been chosen, for example, `xc32-gcc -Os -mips16 foo.c`, then the libraries in the `size/mips16` directories of the library subdirectories are searched.

5.4.2. Library Files

The names of the C/C++ standard library files appropriate for the selected target device, and other driver options, are determined by the driver.

The target libraries, called multilibs, are built multiple times with a permuted set of options. When the compiler driver is called to compile and link an application, the driver chooses the version of the target library that has been built with the same options.

By default, the 32-bit language tools use the directory `<install-directory>/lib/gcc/` to store the specific libraries and the directory `<install-directory>/pic32m/lib` to store the target-specific libraries. Both of these directory structures contain subdirectories for each of the multilib combinations specified above.

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The target libraries that are distributed with the compiler are built for the corresponding command-line options:

- Size vs speed (`-Os` vs. `-O3`)
- MIPS16 vs MIPS32 vs microMIPS ISA mode (`-mips16` vs. `-mno-mips16` vs `-mmicromips`)
- Software floating-point vs no floating-point support (`-msoft-float` vs `-mno-float`)

The following examples provide details on which of the multilibs subdirectories are chosen.

`xc32-gcc foo.c` `xc32-g++ foo.cpp`	For this example, no command line options have been specified (that is, the default command line options are being used). In this case, the `.` subdirectories are used.
`xc32-gcc -Os foo.c` `xc32-g++ -Os foo.cpp`	For this example, the command line option for optimizing for size has been specified (that is, `-Os` is being used). In this case, the `./size` subdirectories are used.
`xc32-gcc -O2 foo.c` `xc32-g++ -O2 foo.cpp`	For this example, the command line option for optimizing has been specified; however, this command line option optimizes for neither size nor space (that is, `-O2` is being used). In this case, the `.` subdirectories are used.
`xc32-gcc -Os -mips16 foo.c` `xc32-g++ -Os -mips16 foo.cpp`	For this example, the command line options for optimizing for size and for MIPS16 code have been specified (that is, `-Os` and `-mips16` are being used). In this case, the `./size/mips16` subdirectories are used.

5.4.2.1. Standard Libraries

The Microchip Unified Standard C Library (MUSL) contains a standardized collection of functions, such as string, math and input/output routines. The MUSL archive `libc-musl.a` will be linked with your project when it contains C-only source and is built with the `xc32-gcc` driver. When you build a project that contains C++ code with the `xc32-g++` driver, MUSL and `libstdc++.a` libraries will be linked.

MPLAB XC32 also provides a picolibc library as an alternative small-footprint standard library. This library (`libc-pico.a`) is requested using the `-mchp-stdlibc` option. The math version of this library is called `libm-pico.a`. See Mchp-stdlibc Option for more information on this option.

5.4.2.2. User-Defined Libraries

User-defined libraries may be created and linked in with programs as required. Library files are more easy to manage and may result in faster compilation times, but must be compatible with the target device and options for a particular project. Several versions of a library may need to be created to allow it to be used for different projects.

User-created libraries that should be searched when building a project can be listed on the command line along with the source files.

As with Standard C/C++ library functions, any functions contained in user-defined libraries should have a declaration added to a header file. It is common practice to create one or more header files that are packaged with the library file. These header files can then be included into source code when required.

5.4.3. Peripheral Library Functions

For PIC32MX devices only:

Many of the peripherals of the PIC32 devices are supported by the peripheral library functions provided with the compiler tools. Please refer to the MPLAB® Harmony Libraries for new projects. For legacy support, these PLIB Libraries will be available for download from `http://www.microchip.com/pic32_peripheral_lib`.

For All PIC32M devices:

MPLAB Harmony includes a set of peripheral libraries, drivers and system services that are readily accessible for application development. For access to the peripheral header files, go to the

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Microchip web site (www.microchip.com), click on the **Design Support** tab and download MPLAB Harmony and MPLAB Code Configurator. The path to the peripheral libraries is:

For Windows: `C:\microchip\harmony\<version>\framework\peripheral`

For Mac/Linux: `~\microchip\harmony\<version>\framework\peripheral`

5.4.4. Runtime Startup Code Files

The runtime startup code is contained in multiple modules, to support architectural differences between device families. Some of the runtime code is built from source code when you build your program; in other cases, prebuilt modules are linked in to provided the appropriate functionality.

The `crt0.o` runtime object module is built from source code contained in `crt0.S` and is used for both C and C++ programs. A copy of this source file is located in each available device family pack (DFP) and is built when you use the `-mdfp` option. If this option is not used, the source file shipped with the compiler is built. If you need to see a copy of this source file, unzip the `pic32m-libs.zip` file located at `<install-directory>/pic32-libs/`. The source code can be found at `pic32m-libs/pic32m-libs/pic32m-libs/libpic32/startup/crt0.S`. If you build a project and do not specify a processor, no startup code is linked in with the program. This module contains the code that is executed at the very beginning of the C runtime startup sequence.

The `crti.o` and `crtn.o` modules also perform actions at runtime startup for C++ programs. They are located in the `<install-directory>/pic32m/lib/` directory. They contain routines to run before `main()` (contained in `.init` sections) and after `main()` (contained in `.fini` sections) respectively. The sections within these modules must be linked in a specific order after sections defined in the crt0 code. The `crtbegin.o` and `crtend.o` modules contain code that handles static constructors and destructors, and are located in the `<install-directory>/lib/gcc/pic32m/<gcc-version>/` directory.

5.4.5. Startup and Initialization

Note: Some PIC32 target devices allow you to select to boot in either the MIPS32® or microMIPS™ ISA mode via a device configuration bit (BOOTISA). On these devices, if your BOOTISA bit is set to microMIPS mode, pass the `-mmicromips` mode to the xc32-gcc/g++ compilation driver to tell it to link with the microMIPS variant of the runtime start-up code. If your BOOTISA bit is set to MIPS32 mode, pass the `-mno-micromips` option to the compilation driver so that the MIPS32 variant of the runtime start-up code is linked.

The runtime startup code performs initialization tasks that must be executed before the `main()` function in the C/C++ program is executed. For information on the tasks performed by this code, see Main, Runtime Start-up and Reset.

The compiler will select the appropriate runtime startup code, based on the selected target device and other compiler options.

- The startup code initializes the L1 cache when available.
- It enables the DSPr2 engine when available.
- It also initializes the Translation Lookaside Buffer (TLB) of the Memory Management Unit (MMU) for the External Bus Interface (EBI) or Serial Quad Interface (SQI) when available. The device-specific linker script creates a table of TLB initialization values that the startup code uses to initialize the TLB at startup.

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Important: When your target MCU is configured to use the microMIPS compressed ISA at startup (and for interrupts/exceptions), be sure to pass the `-mmicromips` option to xc32-gcc when linking, and use the `micromips` function attribute on all of your Interrupt Service Routines (ISRs). Using the `-mmicromips` option and the `micromips` attribute ensures that your startup code and ISR code are compiled for the microMIPS ISA when the **BOOTISA Configuration bit is set to micromips**. Likewise, be sure that you linkwith the MIPS32 startup code, and your ISRs are not `micromips` attributed when the `BOOTISA` bit is set to MIPS32.

For C:

There is only one start-up module, which initializes the C runtime environment. To obtain a copy of this file, follow the directions in How Do I Customize the C Runtime Startup Code?. Multilib versions of these modules exist in order to support architectural differences between device families.

For C++:

Code from five object files link sequentially to create a single initialization routine, which initializes the C++ runtime environment.

The PIC32M precompiled startup objects are located in the following location:

`<install-directory>/pic32m/lib/`

The files have the following names: `cpprt0.o`, `crti.o`, and `crtn.o`.

The GCC precompiled startup objects are located in the following location:

`<install-directory>/lib/gcc/pic32m/<gcc-version>/`.

The files have the following names: `crtbegin.o` and `crtend.o`.

Multilib variations of these modules exist in order to support architectural differences between device families and also optimization settings.

For more information about what the code in these start-up modules actual does, see Runtime Start-Up Code.

5.5. Compiler Output

There are many files created by the compiler during the compilation. A large number of these are intermediate files and some are deleted after compilation is complete, but many remain and are used for programming the device, or for debugging purposes.

5.5.1. Output Files

The compilation driver can produce output files with the following extensions, which are case-sensitive.

Table 5-3. File Names

Extensions	Definition
`file.hex`	Executable file
`file.elf`	ELF debug file
`file.o`	Object file (intermediate file)
`file.s`	Assembly code file (intermediate file)
`file.i`	Preprocessed C file (intermediate file)
`file.ii`	Preprocessed C++ file (intermediate file)
`file.map`	Map file

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The names of many output files use the same base name as the source file from which they were derived. For example the source file `input.c` will create an object file called `input.o`.

The main output file is an ELF file called `a.elf`, unless you override that name using the `-o` option.

The object files produced by the MPLAB XC32 C/C++ Compiler are compatible with third party tools; however, note that object files built from source code containing Microchip-specific features, such as the `address` attribute, will not work as expected with these tools unless the linker script and/or startup code has been appropriately customized.

If you are using an IDE, such as MPLAB X IDE, to specify options to the compiler, there is typically a project file that is created for each application. The name of this project is used as the base name for project-wide output files, unless otherwise specified by the user. However check the manual for the IDE you are using for more details.

Note: Throughout this manual, the term *project name* will refer to the name of the project created in the IDE.

The compiler is able to directly produce a number of the output file formats which are used by Microchip development tools.

The default behavior of `xc32-gcc` and `xc32-g++` is to produce an ELF output. To make changes to the file's output or the file names, see Driver Option Descriptions.

5.5.2. Diagnostic Files

Two valuable files produced by the compiler are the assembly list file, produced by the assembler, and the map file, produced by the linker.

The assembly list file contains the mapping between the original source code and the generated assembly code. It is useful for information such as how C source was encoded, or how assembly source may have been optimized. It is essential when confirming if compiler-produced code that accesses objects is atomic, and shows the region in which all objects and code are placed.

The option to create a listing file in the assembler is `-a` (or `-Wa,-a` if passed to the driver). There are many variants to this option, which may be found in the "*MPLAB® XC32 Assembler, Linker and Utilities User's Guide*" (DS50002186). To pass the option from the compiler, see Options for Assembling.

There is one list file produced for each build. There is one assembler listing file for each translation unit. This is a pre-link assembler listing so it will not show final addresses. Thus, if you require a list file for each source file, these files must be compiled separately, see Multi-Step C Compilation. This is the case if you build using MPLAB IDE. Each list file will be assigned the module name and extension `.lst`.

The map file shows information relating to where objects were positioned in memory. It is useful for confirming that user-defined linker options were correctly processed, and for determining the exact placement of objects and functions.

The option to create a map file in the linker is `-Map file` (or `-Wl,-Map=file`, if passed to the driver), which can be found in the "*MPLAB® XC32 Assembler, Linker and Utilities User's Guide*" (DS50002186). To pass the option from the compiler, see Options for Linking.

There is one map file produced when you build a project, assuming the linker was executed and ran to completion.

5.6. Compiler Messages

All compiler applications use textual messages to report feedback during the compilation process.

There are several types of messages, described below. The behavior of the compiler when encountering a message of each type is also listed.

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Warning Messages	Indicates source code or other situations that can be compiled, but is unusual and might lead to runtime failures of the code. The code or situation that triggered the warning should be investigated; however, compilation of the current module will continue, as will compilation of any remaining modules.
Error Messages	Indicates source code that is illegal or that compilation of code cannot take place. Compilation will be attempted for the remaining source code in the current module (however the cause of the initial error might trigger further errors) and compilation of the other modules in the project will take place, but the project will not be linked.
Fatal Messages	Indicates a situation in which compilation cannot proceed and which forces the compilation process to stop immediately.

Warning messages can be indivudually suppressed using the `-Wno-warning` options.

5.7. Driver Option Descriptions

Most aspects of the compilation process can be controlled using options passed to the command-line driver, `xc32-gcc`.

The GCC compiler on which the MPLAB XC32 C/C++ Compiler is based provides many options in addition to those discussed in this document. It is recommended that you avoid any option that has not been documented here, especially those that control the generation or optimization of code.

All single letter options are identified by a leading *dash* character, "-", for example, `-c`. Some single letter options specify an additional data field which follows the option name immediately and without any *whitespace*, for example, `-Idir`. Options are case sensitive, so `-c` is a different option to `-C`. All options are identified by single or double leading dash character, for example, `-c` or `--version`.

Use the `--help` option to obtain a brief description of accepted options on the command line.

If you are compiling from within the MPLAB X IDE, it will issue explicit options to the compiler that are based on the selections in the project's **Project Properties** dialog. The default project options might be different to the default options used by the compiler when running on the command line, so you should review these to ensue that they are acceptable.

5.7.1. Options Specific to PIC32M Devices

The options shown in the table below are useful when compiling for Microchip PIC32M devices with the MPLAB XC32 compiler and are discussed in the sections that follow.

Table 5-4. PIC32M Device-Specific Options

Option	Definition
`-G num`	Specify the size threshold for placing permanent storage duration objects into the small data sections.
`-mappio-debug`	Enable the APPIN/APPOUT debugging library functions for the Microchip debugger and in-circuit emulator.
`-mcci`	Enable the Microchip Common C Interface compilation mode.
`-m[no-]check-zero-division`	Specifies whether to trap on integer division by zero.
`-mcodecov=options`	Instrument the output to provide code coverage information.
`-mdfp=path`	Specifies which device family pack to use.
`-dspr2`	Specifies use of revision 2 of the MIPS DSP ASE.
`-m[no-]embedded-data`	Specifies where objects are allocated.
`-mframe-header-opt`	Allows the compiler to omit a few instructions for functions not using their incoming frame header.
`-mgen-pie-static`	Generate position-independent code suitable for statically linking into a position-independent executable.
`-mhard-float`	Use the hardware floating-point unit for floating-point calculations

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Table 5-4. PIC32M Device-Specific Options (continued)

Option	Definition
-m[no-]interlink-compressed	Generate code that is link compatible with MIPS16 and microMIPS code.
-m[no-]jals	Enable generation of microMIPS `jals` instructions, which have a shorter, 16-bit delay slot.
-mlibc-variant	Select between speed- or space-orientated string functions
-m[no-]long-calls	Disable use of the `jal` instruction.
-mmalloc-variant	Specifies the scheme of dynamic memory allocation to be used
-m[no-]memcpy	Force the use of the `memcpy()` function for non-trivial block moves.
-m[no-]micromips	Generate microMIPS code.
-[mno-]mips16	Generate MIPS16 code.
-mno-float	Do not use libraries with software floating-point.
-mno-hi-addr-opt	Disables certain optimizations associated with the access of special function registers.
-mperipheral-libs	Specifies which peripheral libraries are linked to the project.
-mprocessor	Selects the target device for which to compile.
-mreserve	Specifies the address ranges of memory to be reserved.
-msmart-io=[0|1|2]	Controls the feature set of the IO library linked in.
-mchp-stack-usage	Generation of stack usage information and warnings.
-mtext="*scn-name*"	Redirects the `.text` section into a section with a user-defined name.
-m[no-]uninit-const-in-rodata	Place uninitialized `const`-qualified objects in the read-only data section.
--nofallback	Only the selected optimization level and with no license-imposed fall back to a lesser level.

5.7.1.1. G: Specify Small Data Size Threshold Option

The `-G` *num* option specifies the size (in bytes) of the largest objects with permanent storage duration that will be will be placed into the small data or bss sections instead of the normal data or bss sections. Having objects in the small data/bss sections allows them to be accessed using a single instruction.

All modules should be compiled with the same *num* value.

5.7.1.2. Appio-debug Option

The `-mappio-debug` option enables the APPIN/APPOUT debugging library functions for the Microchip debugger and in-circuit emulator. This feature allows you to use the `DBPRINTF()` and related functions and macros as described in the *32-bit Language Tool Libraries* document (DS51685).

Enable this option only when using a target PIC32 device that supports the APPIN/APPOUT feature.

5.7.1.3. Cci Option

The `-mcci` option enables the Microchip Common C Interface (CCI) compilation mode.

Enabling this mode requests the compiler to check all source code and compiler options for compliance with the CCI. Code that complies with this interface can be more easily ported across all MPLAB XC compilers. Code or options that do not conform to the CCI will be flagged by compiler warnings.

5.7.1.4. Check-zero-division Option

The `-mcheck-zero-division` option requests the compiler to trap integer divisions by zero. This is the default action if no option is specified. The `-mno-check-zero-division` form of this option requests that no traps will take place.

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5.7.1.5. Codecov Option

The `-mcodecov=suboptions` option embeds diagnostic code into the program's output, allowing analysis of the extent to which the program's source code has been executed. See Code Coverage for more information.

A suboption must be specified and at this time, the only available suboption is `ram`.

5.7.1.6. Dfp Option

The `-mdfp=path` option indicates that device-support for the target device (indicated by the `-mprocessor` option) should be obtained from the contents of the specified Device Family Pack (DFP), where *path* is the relevant path to the folder containing the `xc32` directory within the DFP. For example, if the required DFP has been dowloaded and installed in the `Microchip` subdirectory, a build command utilizing that DFP might look like:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" main.c
```

The Microchip development environments automatically use this option to inform the compiler of which device-specific information to use.

If you are building on the command line or via a makefile, download the required DFP from packs.download.microchip.com. The `.atpack` file can be unarchived by many archive applications, but it is recommended that you use the Pack manager in the MPLAB X IDE. From within the IDE, open the Pack manager from the **Tools** > **Packs** menu, then from the **Install or Uninstall** drop down, select **Install Pack From Local Source**. Specify the path to where you save the DFP in the `-mdfp` option when you build your project.

A DFP might contain such items as device-specific header files, configuration bit data and libraries, letting you take advantage of features on new devices without you having to otherwise update the compiler. DFPs never contain executables or provide bug fixes or improvements to any existing tools or standard library functions.

If the `-mprocessor` option has been specified and the `-mdfp` option is missing or the compiler cannot find the spec file in the nominated DFP, an error will be generated. If neither the `-mprocessor` nor `-mdfp` options are provided, the compiler will run without attempting to get any information from a DFP.

5.7.1.7. Dspr2 Option

The `-mdspr2` option informs the compiler to revision 2 of the MIPS DSP Application Specific Extensions, which provided instructions designed to improve the performance of DSP and media applications. When the option is in effect, the preprocessor macros `_mips_dsp` and `mips_dspr2` are defined, and the `_mips_dsp_rev` macro is defined to be `2`. This is the default action if no option is specified.

The `-mno-dspr2` form of this option disables use of this extension.

5.7.1.8. Embedded-data Option

The `-membedded-data` option allocates `const` objects to the read-only data section (`.rodata`) first if possible, then next in the small data section (`.sdata`) if possible, otherwise in the data section (`.data`). This gives slightly slower code than the default, but reduces the amount of RAM required when executing, and thus may be preferred for some embedded systems. This option does not affect the placement of string literals. This is the default action if no option is specified.

The `-mno-embedded-data` form of this option will not allocate `const` objects to the read-only data section.

5.7.1.9. Frame-header-opt Option

The `-mframe-header-opt` option allows the compiler to omit a few instructions for each function that does not use its incoming frame header. This feature usually improves both execution speed and code size.

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5.7.1.10. Gen-pie-static Option

The `-mgen-pie-static` option generates position-independent code suitable for statically linking into a Position-Independent Executable (PIE). Such code accesses all constant addresses through a Global Offset Table (GOT). A special ELF loader, running on the target device, resolves the GOT entries and loads the final executable image into memory.

Pass this option to the `xc32-gcc` compilation driver when compiling, assembling, and linking.

5.7.1.11. Hard-float Option

The `-mhard-float` option indicates to the compiler that floating-point calculations in generated code should be performed by the hardware floating-point unit (FPU). A varient of the library that utilises hardware floating-point instructions is also selected for link time.

This option does not typically need to be specified, as the compiler will use an appropriate library and generate suitable floating-point code based on information provided by the Device Family Pack associated with the selected device.

5.7.1.12. Interlink-compressed Option

The `-minterlink-compressed` option ensures that standard (uncompressed) MIPS ISA being generated is link compatible with MIPS16 and microMIPS code. The `-mno-interlink-compressed` form of this option does not ensure this compatibility, and the generated code cannot be used with MIPS16 or microMIPS code.

5.7.1.13. Jals Option

The `-mjals` option enables the generation of microMIPS `jals` instructions, which have a shorter, 16-bit delay slot. The `jal` MIPS32 instruction requires a 32-bit instruction to fill its delay slot.

The `-mno-jals` option disables the generation of `jals` instructions. You might need to use this option if you have link errors when attempting to link a microMIPS object/library with a MIPS32 object/library.

5.7.1.14. Libc-variant Option

The `-mlibc-variant=`*`variant`* option specified whether speed- or size-orientated string functions are linked in with the program. Size-orientated functions are linked in if this option is not used.

Many of the library functions provided by `<string.h>` are available in two variants. The size-orientated functions require less code to implement. These can be explicitly selected by using a `size` argument to the option, for example `-mlibc-variant=size`. The speed-orientated functions might be larger, but they execute quickly, resulting in improved program performance. They can be selected by using a `speed` argument to the option.

All architectures implement the size-orientated function variants. Speed-orientated of the following functions are available across all device architectures: `memcmp()`, `memcpy()`, `memset()`, `strcmp()`, `strcpy()`, and `strlen()`. For cases where only the size-orientated variant is available, it will always be selected regardless of the variant specified by this option.

5.7.1.15. Long-calls Option

The `-mlong-calls` option disables the use of the `jal` instruction. Calling functions using this instruction is more efficient but requires the caller and callee functions to be in the same 256 megabyte segment. This option has no effect on abicalls code.

The `-mno-long-calls` form of this option allows the use of `jal` instructions. This is the default action if no option is specified.

5.7.1.16. Malloc-variant Option

The `-mmalloc-variant=`*`scheme`* option indicates to the compiler the scheme of dynamic memory allocation that should be employed for the program. See Dynamic Memory Allocation for more information on this type of memory allocation and the heap, from which allocation takes place.

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The `-mmalloc-variant=lite` form of this option selects a simple scheme that will yield the smallest code size. It might, however, result in a fragmented heap when freeing allocated memory, preventing further memory from being allocated at runtime. This is the default scheme if no option is specified.

The `-mmalloc-variant=binned` option uses a more sophisticated allocation scheme that will result in less fragmentation, but at the expense of increased code size.

5.7.1.17. Memcpy Option

The `-mmemcpy` option forces the compiler to use the `memcpy()` function for non-trivial block copies.

The `-mno-memcpy` form of this option allows the compiler to inline most constant-sized block copies. This is the default action if no option is specified.

5.7.1.18. Micromips Option

The `-mmicromips`driver option informs the compiler to generate code using the microMIPS™ instructions. This feature is available only in the PRO edition.

When your device is configured to boot into the microMIPS compressed Instruction Set Architecture (ISA) mode (for example, if `#pragma config BOOTISA=MICROMIPS` was specified), the `-mmicromips` option should be used when linking to select microMIPS startup code.

The `-mno-micromips` form of this option informs the compiler to use MIPS32 instructions.

The ISA can also be indicated on a per-function basis through the `micromips` and `nomicromips` attributes.

On PIC32M devices, bit 0 of the program counter indicates the ISA mode. When this bit is clear, the device is running in MIPS32 mode. When this bit is set, the device is running in either MIPS16 or microMIPS mode, depending on the core of the selected device. This means that if you execute a hard-coded jump, bit 0 must be set to the appropriate value for the destination function. Hard-coded jumps are most commonly seen when jumping from a bootloader to a bootloaded application.

5.7.1.19. Mips16/Mips16e Options

The `-mips16` driver option generates MIPS16 code, suitable for MIPS16 or microMIPS Instruction Set Architecture (ISA) mode. The `-mips16e` option is equivalent and is provided for backwards compatibility with older toolchains. These options are only available in the PRO edition.

The `-mno-mips16` option (note the slightly different 'no' form of this option, which includes an additional 'm' character) will have all code built using the MIPS32 ISA.

On PIC32M devices, bit 0 of the program counter indicates the ISA mode. When this bit is clear, the device is running in MIPS32 mode. When this bit is set, the device is running in either MIPS16 or microMIPS mode, depending on the core of the selected device. This means that if you execute a hard-coded jump, bit 0 must be set to the appropriate value for the destination function. Hard-coded jumps are most commonly seen when jumping from a bootloader to a bootloaded application.

5.7.1.20. No-float Option

The `-mno-float` driver option instructs the compiler to not link in libraries that contain software floating-point code.

5.7.1.21. No-hi-addr-opt Option

The `-mno-hi-addr-opt` option disables certain optimizations associated with the access of special function registers (SFRs).

The employs a SFR Access Efficiency feature, which adds the `address` attribute to peripheral SFRs defined in the processor header file. Compiler optimizations use this information to reduce the number of registers required to access multiple SFRs from within a single function and to remove

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redundant load instructions. This feature is enabled by default at optimization levels `-O2`, `-Os`, and `-O3`.

If you are building a static library that accesses an SFR and you want that same prebuilt library to work across devices that may have the SFRs located at a different address (for example, the `TMR1` SFR object is located at different addresses on different devices), compile your library with the `-mno-hi-addr-opt` option. This will result in larger code, but the SFR address will be determined at link time.

5.7.1.22. Peripheral-libs Option

The `-mperipheral-libs` requests that the standard peripheral libraries are linked in.

The `-mno-peripheral-libs` form of this option requests that the linked peripheral libraries are specified via the device-specific linker script. This is the default action if no option is specified.

5.7.1.23. Processor Option

The `-mprocessor=`*`device`* option selects the target device for which to compile. A list of all supported devices can be found the compiler release notes. Note that the name must be in upper case, for example, `-mprocessor=32MZ2048ECH100`.

This option selects only the target device; it does not indicate what version of the device support files to use. Additionally, use the `-mdfp` option (see Dfp Option) for this purpose.

5.7.1.24. Reserve Option

The `-mreserve=`*`ranges`* option allows you to reserve memory normally used by the program. This option has the general form:

```
-mreserve=space@start:end
```

where *`space`* names the section which will act as a placeholder and reserve the memory; and *`start`* and *`end`* are addresses, denoting the memory range to be excluded. For example, `-mreserve=data@0x80000200:0x800002FF` will reserve memory in both the kseg0 and kseg1 memory regions (that is, at starting addresses 0x80000200 and 0xa0000200) using the section `reserve_data_0x80000200` as a placeholder. The command `-mreserve=temp@0x9D001000:0x9D001003` will reserve 4 bytes in both the kseg0 and kseg1 memory regions using the section `reserve_temp_0x9d001000`.

5.7.1.25. Smart-io Option

The `-msmart-io=`*`level`* option in conjunction with the IO format string conversion specifications detected in your program control the feature set (hence size) of the library code that is linked in to perform formatted IO through functions like `printf`. See Smart IO Routines for more information on how the smart IO feature operates. This option has no effect when using the picolibc library with the `-mchp-stdlib` option.

A numerical level of operation can be specified and these have the meaning shown in the following table.

Table 5-5. Smart IO Implementation Levels

Level	Smart IO features; linked library
0	Disabled; Full-featured library (largest code size)
1	Enabled; Minimal-featured library (smallest code size)
2	Manual control; Integer-only library

When the smart IO feature is disabled (`-msmart-io=0`), a full implementation of the IO functions will be linked into your program. All features of the IO library functions will be available, and these may consume a significant amount of the available program and data memory on the target device.

The default setting is for smart IO to be enabled with a minimal feature set. This can be made explicit by using either the `-msmart-io=1` or `-msmart-io` option. When thus enabled, the compiler

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will link in the least complex variant of the IO library that implements all of the IO functionality required by the program, based on the conversion specifications detected in the program's IO function format strings. This can substantially reduce the memory requirements of your program, especially if you can eliminate in your program the use of floating-point features.

If the format string in a call to an IO function is not a string literal, the compiler will not be able to detect the exact usage of the IO function and a full-featured variant of the IO library will be linked into the program image, even with smart IO enabled.

These options should be used consistently across all program modules to ensure an optimal selection of the library routines included in the program image.

5.7.1.26. Soft-float Option

The `-msoft-float` option indicates to the compiler that floating-point calculations in generated code should be emulated rather than performed by the hardware floating-point unit (FPU). A variant of the library that does not use hardware floating-point is also selected for link time.

This option does not typically need to be specified, as the compiler will use an appropriate library and generate suitable floating-point code based on information provided by the Device Family Pack associated with the selected device.

5.7.1.27. Stack Guidance Option

The `-mchp-stack-usage` option analyzes the program and reports on the estimated maximum depth of any stack used by a program. The option can only be enabled with a PRO license.

See Stack Guidance for more information on the stack guidance reports that are produced by the compiler.

5.7.1.28. Text Option

The `-mtext="`*`scn-name[attributes]`*`"` option places text (program code) in a section named *`scn-name`*, rather than the default `.text` section. Additionally, comma-separated attributes can be specified along with the section name. No white space should appear around the = character in this option.

For example, the following command line option redirects the `.text` section into a section called `MySectionName` and specifies its link address.

```
xc32-gcc bootloader.c -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-
EC_DFP.1.4.150" -mtext="MySectionName,address(0x9D00a000)"
```

This command is useful when used to map your code in a custom linker script as part of a bootloader project.

5.7.1.29. Uninit-const-in-rodata Option

The `-muninit-const-in-rodata` option places uninitialized `const`-qualified objects in the read-only data section. This option is only meaningful in conjunction with the `-membedded-data` option.

The `-mno-uninit-const-in-rodata` form of this option places uninitialized `const`-qualified objects in a text section. This is the default action if no option is specified.

5.7.1.30. Nofallback Option

The `--nofallback` option can be used to ensure that the compiler is not inadvertently executed with optimizations below the that specified by the `-O` option.

For example, if an unlicensed compiler was requested to run with level `s` optimizations, without this option, it would normally revert to a lower optimization level and proceed. With this option, the compiler will instead issue an error and compilation will terminate. Thus, this option can ensure that builds are performed with a properly licensed compiler.

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5.7.2. Options for Controlling the Kind of Output

The options tabulated below control the kind of output produced by the compiler and are discussed in the sections that follow.

Table 5-6. Kind-of-Output Control Options

Option	Definition
`-c`	Stop compilation before the link step, producing an intermediate file.
`-E`	Stop compilation after preprocessing, producing a preprocessed file.
`--help`	Print a description of the command line options.
`-o file`	Place the output in a file with the specified name.
`-S`	Stop compilation before the assembly step, producing an assembly file output.
`-specs=file`	Overrides the standard specs file.
`-v`	Print the commands executed during each stage of compilation.
`--version`	Show version information then quit.
`-x`	Specify the language of a source file regardless of its file extension.

5.7.2.1. C: Compile To Intermediate File

The `-c` option is used to generate an intermediate file for each source file listed on the command line.

For all source files, compilation will terminate after executing the assembler, leaving behind relocatable object files with a `.o` extension.

This option is often used to facilitate multi-step builds using a make utility.

5.7.2.2. E: Preprocess Only

The `-E` option is used to generate preprocessed C/C++ source files (also called modules or translation units).

The preprocessed output is printed to `stdout`, but you can use the `-o` option to redirect this to a file.

You might check the preprocessed source files to ensure that preprocessor macros have expanded to what you think they should. The option can also be used to create C/C++ source files that do not require any separate header files. This is useful when sending files to a colleague or to obtain technical support without sending all the header files, which can reside in many directories.

5.7.2.3. Help

The `--help` option displays information on the `xc32-gcc` compiler options, then the driver will terminate.

The `--help=warning` option can be used to display a list of options relating to warning suppression.

Note that options displayed by the `--help` command that are not documented in this compiler user's guide might not supported. See the *MPLAB® XC Compiler Functional Safety Manual* for options approved for use in functional safety applications.

For example:

```
xc32-gcc --help
Microchip Language Tool Shell Version 4.20 (Build date: Sep 16 2022).
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  -omf=elf        Select elf object module format
Usage: pic32m-gcc [options] file...
Options:
  -pass-exit-codes         Exit with highest error code from a phase.
  --help                   Display this information.
  --target-help            Display target specific command line options.
```


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```
  --help={common|optimizers|params|target|warnings|[^]{joined|separate|undocumented}}[,...].
                           Display specific types of command line options.
  (Use '-v --help' to display command line options of sub-processes).
  --version                Display compiler version information.
  -dumpspecs               Display all of the built in spec strings.
  -dumpversion             Display the version of the compiler.
  -dumpmachine             Display the compiler's target processor.
  -print-search-dirs       Display the directories in the compiler's search path.
  -print-libgcc-file-name  Display the name of the compiler's companion library.
```

5.7.2.4. O: Specify Output File

The `-o` option specifies the base name and directory of the output file.

The option `-o main.elf`, for example, will place the generated output in a file called `main.elf`. The name of an existing directory can be specified with the file name, for example `-o build/main.elf`, so that the output file will appear in that directory.

This option also controls the output base name of dump and aux files.

You cannot use this option to change the type (format) of the output file.

5.7.2.5. S: Compile To Assembly

The `-S` option is used to generate an assembly file for each source file listed on the command line.

When this option is used, the compilation sequence will terminate early, leaving behind assembly files with the same basename as the corresponding source file and with a `.s` extension.

For example, the command:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -S
test.c io.c
```

will produce two assembly file called `test.s` and `io.s`, which contain the assembly code generated from their corresponding source files.

This option might be useful for checking assembly code output by the compiler without the distraction of line number and opcode information that will be present in an assembly list file. The assembly files can also be used as the basis for your own assembly coding.

5.7.2.6. Specs Option

The `-specs=`*`file`* option allows the standard specs file to be overridden.

Spec files are plain-text files used to construct spec strings, which in turn control which programs the compiler should invoke and which command-line options they need to be passed. The compiler has a standard specs file which defines the options with which the compiler's internal applications will execute.

After the compiler reads in the standard specs file, it processes *`file`* specified with this option in order to override the defaults that the `xc32-gcc` driver program uses when building the command-line options to pass to `xc32-as`, `xc32-ld`, etc. More than one `-specs` option can be specified on the command line, and they are processed in order, from left to right.

5.7.2.7. V: Verbose Compilation

The `-v` option specifies verbose compilation.

When this option is used, the name and path of the internal compiler applications will be displayed as they are executed, followed by the command-line arguments that each application was passed.

You might use this option to confirm that your driver options have been processed as you expect, or to see which internal application is issuing a warning or error.

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5.7.2.8. Version Option

The `--version` option has the compiler display the version number of the MPLAB XC32 Toolchain and the GNU copyright information. The compiler will then quit, without building any of the program source code.

5.7.2.9. X: Specify Source Language Option

The `-x` *`language`* option specifies the language for the sources files that follow on the command line.

The compiler usually uses the extension of an input file to determine the file's content. This option allows you to have the language of a file explicitly stated. The option remains in force until another language is specified with a `-x` option, or the `-x none` option, which turns off the language specification entirely for subsequent files. The allowable languages are tabulated below.

Table 5-7. Source file Language

Language	File language
`assembler`	Assembly source
`assembler-with-cpp`	Assembly with C preprocessor directives
`c`	C source
`c++`	C++ source
`cpp-output`	Preprocessed C source
`c-header`	C header file
`none`	Based entirely on the file's extension

The `-x assembler-with-cpp` language option ensures assembly source files are preprocessed before they are assembled, thus allowing the use of preprocessor directives, such as `#include`, and C-style comments with assembly code. By default, assembly files not using a `.S` extension are not preprocessed.

You can create precompiled header files with this option, for example:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -x c-
header init.h
```

will create the precompiled header called `init.h.gch`.

5.7.3. Options for Controlling the C Dialect

The options tabulated below define the type of C dialect used by the compiler and are discussed in the sections that follow.

Table 5-8. C Dialect Control Options

Option	Definition
`-ansi`	Support all (and only) ANSI-standard C programs.
`-f[no-]freestanding`	Asserts that the project will be built for a freestanding (as opposed to a hosted) environment.
`-f[no-]asm`	Restricts the recognition of certain keywords, freeing them to be used as identifiers.
`-fno-builtin` `-fno-builtin-`*`function`*	Don't recognize built-in functions that do not begin with `__builtin_` as prefix.
`-std=`*`standard`*	Specifies the language standard with which to build programs
`-f[no-]unsigned-char` `-f[no-]signed-char`	Changes the signedness of a plain `char` type.
`-f[no-]signed-bitfields` `-f[no-]unsigned-bitfields`	Changes the signedness of a plain int bit-field. By default, such a bit field is signed.

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5.7.3.1. Ansi Option

The `-ansi` option ensures the C program strictly conforms to the C90 standard.

When specified, this option disables certain GCC language extensions when compiling C source. Such extension include C++ style comments, and keywords, such as `asm` and `inline`. The macro `__STRICT_ANSI__` is defined when this option is in use. See also `-Wpedantic` for information on ensuring strict ISO compliance.

5.7.3.2. Freestanding Option

The `-ffreestanding` option asserts that the project will be built for a freestanding (as opposed to a hosted) environment.

A freestanding environment is one in which the standard library may not be fully implemented, and program start-up and termination are implementation defined.

This option is identical to the `-fno-hosted` option and implies the `-fno-builtin` option.

The `-fno-freestanding` option is identical to the `-fhosted` option and indicates that the project will be built for a hosted environment.

5.7.3.3. Asm Option

The `-fasm` option reserves the use of `asm`, `inline` and `typeof` as keywords, preventing them from being defined as identifiers. This is the default action if no option is specified.

The `-fno-asm` form of this option restricts the recognition of these keywords. You can, instead, use the keywords `__asm__`, `__inline__` and `__typeof__`, which have identical meanings.

The `-ansi` option implies `-fno-asm`.

5.7.3.4. No-builtin Option

The `-fbuiltin` option has the compiler produce specialized code that avoids a function call for many built-in functions. The resulting code is often smaller and faster, but since calls to these functions no longer appear in the output, you cannot set a breakpoint on those calls, nor can you change the behavior of the functions by linking with a different library. This is the default behavior if no option is specified.

The `-fno-builtin` option will prevent the compiler from producing special code for built-in functions that are not prefixed with `__builtin_`.

The `-fno-builtin-`*`function`* form of this option allows you to prevent a built-in version of the named function from being used. In this case, *`function`* must not begin with `__builtin_`. There is no `-fbuiltin-`*`function`* form of this option.

5.7.3.5. Signed-bitfields Option

The `-fsigned-bitfields` option control the signedness of a plain `int` bit-field type.

By default, the plain `int` type, when used as the type of a bit-field, is equivalent to `signed int`. This option specifies the type that will be used by the compiler for plain `int` bit-fields. Using `-fsigned-bitfields` or the `-fno-unsigned-bitfields` option forces a plain `int` bit-field to be signed.

Consider explicitly stating the signedness of bit-fields when they are defined, rather than relying on the type assigned to a plain `int` bit-field type.

5.7.3.6. Signed-char Option

The `-fsigned-char` option forces plain `char` objects to have a signed type.

By default, the plain `char` type is equivalent to `signed char`, unless the `-mext=cci` option has been used, in which case it is equivalent to `unsigned char`. The `-funsigned-char` (or `-fno-signed-char` option) makes this type explicit.

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The `-fsigned-char` (or `-fno-unsigned-char` option) makes it explicit that plain `char` types are to be treated as signed integers.

Consider explicitly stating the signedness of `char` objects when they are defined, rather than relying on the type assigned to a plain `char` type by the compiler.

5.7.3.7. Std Option

The `-std=`*`standard`* option specifies the C standard to which the compiler assumes source code will conform. The allowable standards are listed below.

Table 5-9. Acceptable Language Standards

Standard	Supports
`c89` or `c90`	ISO C90 (ANSI) programs
`c99`	ISO C99 programs
`c11`	ISO C11 programs
`gnu89` or `gnu90`	GNU dialect of ISO C90 programs
`gnu99`	GNU dialect of ISO C99 programs
`gnu11`	GNU dialect of ISO C11 programs
`C++98`	ISO C++98 programs
`C++03`	ISO C++03 programs
`C++11`	ISO C++11 programs
`C++14`	ISO C++14 programs
`C++17`	ISO C++17 programs
`GNU++98`	GNU dialect of ISO C++98 programs
`GNU++11`	GNU dialect of ISO C++11 programs
`GNU++14`	GNU dialect of ISO C++14 programs
`GNU++17`	GNU dialect of ISO C++17 programs

If this option is not specified, `gnu++17` is the default language standard.

5.7.3.8. Unsigned-bitfields Option

The `-funsigned-bitfields` option control the signedness of a plain `int` bit-field type.

By default, the plain `int` type, when used as the type of a bit-field, is equivalent to `signed int`. This option specifies the type that will be used by the compiler for plain `int` bit-fields. Using the `-funsigned-bitfields` or the `-fno-signed-bitfields` option forces a plain `int` to be unsigned.

Consider explicitly stating the signedness of bit-fields when they are defined, rather than relying on the type assigned to a plain `int` bit-field type.

5.7.3.9. Unsigned-char Option

The `-funsigned-char` option forces a plain `char` objects to have an unsigned type.

By default, the plain `char` type is equivalent to `signed char`, unless the `-mext=cci` option has been used, in which case it is equivalent to `unsigned char`. The `-funsigned-char` (or `-fno-signed-char` option) makes this type explicit.

Consider explicitly stating the signedness of `char` objects when they are defined, rather than relying on the type assigned to a plain `char` type by the compiler.

5.7.4. Options for Controlling the C++ Dialect

The options tabulated below define the type of C++ dialect used by the compiler and are discussed in the sections that follow. Note that the sections for those options also relevant for the C dialect are located in the Options for Controlling the C Dialect section.

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Table 5-10. C++ Dialect Control Options

Option	Definition
`-ansi`	Support all (and only) C90 programs.
`-f[no-]check-new`	Check that the pointer returned by the `new` operator is non-null.
`-f[no-]enforce-eh-specs`	Specify generation of code to check for violation of exception specifications at runtime.
`-f[no-]freestanding`	Asserts that the project will be built for a freestanding (as opposed to a hosted) environment.
`-f[no-]asm`	Restricts the recognition of certain keywords, freeing them to be used as identifiers.
`-fno-builtin` `-fno-builtin-`*function*	Don't recognize built-in functions that do not begin with `__builtin_` as prefix.
`-f[no-]rtti`	Specifies if code for Run Time Type Identification features should be generated.
`-std=`*standard*	Specifies the language standard with which to build programs
`-f[no-]unsigned-char` `-f[no-]signed-char`	Changes the signedness of a plain `char` type.
`-f[no-]signed-bitfields` `-f[no-]unsigned-bitfields`	Changes the signedness of a plain int bit-field.

5.7.4.1. Check-new Option

The `-fcheck-new` option checks that the pointer returned by `operator new` is not `NULL` before attempting to modify the storage allocated.

Typically, this check is not necessary. You can ensure that no checks are made by using the `-fno-check-new` form of this option. This is the default action if no option is specified.

5.7.4.2. Enforce-eh-specs Option

The `-fenforce-eh-specs` option generates code to check for violation of exception specifications at runtime. This is the default action if no option is specified.

The `-fno-enforce-eh-specs` form of this option omits generation of verification code, which violates the C++ standard, but doing so might reduce the code size in production builds of validated source. Even when specifying this option, the compiler will still optimize exception code based on the specifications, so throwing an unexpected exception will result in undefined behavior.

5.7.4.3. Rtti Option

The `-frtti` option enables generation of information about every class with virtual functions for use by the C++ Run Time Type Identification (RTTI) features, such as `dynamic_cast` and `typeid` operators.

The `-fno-rtti` form of this option disables generation of this information. If you don't use the RTTI features of the language, code size might be reduced by using this option. Note that exception handling uses the same information, but it will generate this information as needed. The `dynamic_cast` operator can still be used for casts that do not require RTTI, that is, casts to `void *` or to unambiguous base classes.

Ensure that the same form of this option is specified at compile time for all modules and at link time.

5.7.5. Options for Controlling Warning and Errors

Warnings are diagnostic messages that report constructions that are not inherently erroneous, but that are risky or suggest there may have been an error.

You can request many specific warnings with options beginning `-W`; for example, `-Wimplicit`, to request warnings on implicit declarations. Each of these specific warning options also has a negative form beginning `-Wno-` to turn off warnings; for example, `-Wno-implicit`. This manual lists only one of the two forms, whichever is not the default.

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The options shown in the tables below are the more commonly used warning options that control messages issued by the compile. In the (linked) sections that follow, the options that affect warnings generally are discussed.

Table 5-11. General Warning and Error Options

Option	Definition
`-fsyntax-only`	Check the code for syntax, but don't do anything beyond that.
`-pedantic`	Issue all the warnings demanded by strict ANSI C. Reject all programs that use forbidden extensions.
`-pedantic-errors`	Like `-pedantic`, except that errors are produced rather than warnings.
`-w`	Inhibit all warning messages.
`-Wall`	Enable all warnings about constructions that some users consider questionable, and that are easy to avoid, even in conjunction with macros.
`-Werror=`*`string`*	Promote warnings to errors
`-Wextra` (formerly) `-W`	Enable extra warning flags that are not enabled by `-Wall`.

Table 5-12. Warning and Error Options Implied by All Warnings

Option	Definition
`-Waddress`	Warn about suspicious uses of memory addresses. These include using the address of a function in a conditional expression, such as `void func(void)`; if `(func)`, and comparisons against the memory address of a string literal, such as if `(x == "abc")`. Such uses typically indicate a programmer error: the address of a function always evaluates to true, so their use in a conditional usually indicates that the programmer forgot the parentheses in a function call; and comparisons against string literals result in unspecified behavior and are not portable in C, so they usually indicate that the programmer intended to use `strcmp`.
`-Wno-analyzer-use-of-uninitialized-value`	Warn when automatic objects are defined without it being assigned an initial value.
`-Warray-bounds`	When combined with `-O2` or greater, warns for many instances out-of-bounds array indices and pointer offsets. This feature cannot detect all cases. Enabled with `-Wall` command.
`-Warray-compare`	Warn about equality and relational comparisons between two operands of array type, which were deprecated in C++20.
`-Warray-parameter`	Warn about redeclarations of functions involving arguments of array or pointer types of inconsistent kinds or forms, and enable the detection of out-of-bounds accesses to such parameters by warnings such as `-Warray-bounds`.
`-Wchar-subscripts`	Warn if an array subscript has type `char`.
`-Wcomment`	Warn whenever a comment-start sequence `/*` appears in a `/*`comment, or whenever a Backslash-Newline appears in a `//` comment.
`-Wdiv-by-zero`	Warn about compile-time integer division by zero. To inhibit the warning messages, use `-Wno-div-by-zero`. Floating-point division by zero is not warned about, as it can be a -legitimate way of obtaining infinities and NaNs. This is the default.
`-Wenum-int-mismatch`	Warn about mismatches between an enumerated type and an integer type in declarations.
`-Wformat`	Check calls to `printf` and `scanf`, etc., to make sure that the arguments supplied have types appropriate to the format string specified.
`-Wformat-smart-io=`*`level`*	A level of 1 disables warnings thrown by Smart IO to indicate anomalies in IO function format strings. A level of 0 enables these warnings.
`-Wimplicit`	Equivalent to specifying both `-Wimplicit-int` and `-Wimplicit-function-declaration`.
`-Wimplicit-function-declaration`	Give a warning whenever a function is used before being declared.
`-Wimplicit-int`	Warn when a declaration does not specify a type.
`-Wmain`	Warn if the type of `main` is suspicious. `main` should be a function with external linkage, returning `int`, taking either zero, two, or three arguments of appropriate types.

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Table 5-12. Warning and Error Options Implied by All Warnings (continued)

Option	Definition
`-Wmismatched-dealloc`	Warn for calls to deallocation functions with pointer arguments returned from from allocations functions for which the former isn't a suitable deallocator.
`-Wmismatched-new-delete`	Similar to `-Wmismatched-dealloc`, but warns for mismatches involving either operator `new` or operator `delete`.

`-Wmissing-braces`	Warn if an aggregate or union initializer is not fully bracketed. In the following example, the initializer for `a` is not fully bracketed, but that for `b` is fully bracketed.
	`int a[2][2] = { 0, 1, 2, 3 };`
	`int b[2][2] = { { 0, 1 }, { 2, 3 } };`

`-Wmultistatement-macros`	Warns for unsafe macro expansion as a body of a statement such as if, else, while, switch, or for. Enabled with `-Wall` command.

`-Wno-multichar`	Warn if a multi-character `character` constant is used. Usually, such constants are typographical errors. Since they have implementation-defined values, they should not be used in portable code. The following example illustrates the use of a multi-character `character` constant:
	`char`
	`xx(void)`
	`{`
	`return('xx');`
	`}`

`-Wparentheses`	Warn if parentheses are omitted in certain contexts, such as when there is an assignment in a context where a truth value is expected, or when operators are nested whose precedence people often find confusing.
`-Wreturn-type`	Warn whenever a function is defined with a return-type that defaults to `int`. Also warn about any `return` statement with no return-value in a function whose return-type is not `void`.
`-Wself-move`	Warn when a value is moved to itself with `std::move`. Such a `std::move` typically has no effect.
`-Wsequence-point`	Warn about code that may have undefined semantics because of violations of sequence point rules in the C standard. The C standard defines the order in which expressions in a C program are evaluated in terms of sequence points, which represent a partial ordering between the execution of parts of the program: those executed before the sequence point and those executed after it. These occur after the evaluation of a full expression (one which is not part of a larger expression), after the evaluation of the first operand of a `&&`, `||`, `? :` or `,` (comma) operator, before a function is called (but after the evaluation of its arguments and the expression denoting the called function), and in certain other places. Other than as expressed by the sequence point rules, the order of evaluation of subexpressions of an expression is not specified. All these rules describe only a partial order rather than a total order. For example, if two functions are called within one expression with no sequence point between them, the order in which the functions are called is not specified. However, the standards committee has ruled that function calls do not overlap. It is not specified when between sequence points modifications to the values of objects take effect. Programs whose behavior depends on this have undefined behavior. The C standard specifies that "Between the previous and next sequence point, an object shall have its stored value modified, at most once, by the evaluation of an expression. Furthermore, the prior value shall be read only to determine the value to be stored." If a program breaks these rules, the results on any particular implementation are entirely unpredictable. Examples of code with undefined behavior are `a = a++;`, `a[n] = b[n++]` and `a[i++] = i;`. Some more complicated cases are not diagnosed by this option and it may give an occasional false positive result, but in general it has been found fairly effective at detecting this sort of problem in programs.
`-Wsizeof-array-div`	Warn about divisions of two `sizeof` operators when the first one is applied to an array and the divisor does not equal the size of the array element. In such a case, the computation will not yield the number of elements in the array, which is likely what the user intended.
`-Wsizeof-pointer-div`	Warns for suspicious divisions of the size of a pointer by the size of the elements it points to, which looks like the usual way to compute the array size but won't work out correctly with pointers.

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Table 5-12. Warning and Error Options Implied by All Warnings (continued)

Option	Definition
-Wswitch	Warn whenever a switch statement has an index of enumeral type and lacks a case for one or more of the named codes of that enumeration. The presence of a default label prevents this warning. case labels outside the enumeration range also provoke warnings when this option is used.
-Wsystem-headers	Print warning messages for constructs found in system header files. Warnings from system headers are normally suppressed on the assumption that they usually do not indicate real problems and would only make the compiler output harder to read. Using this command line option tells the compiler to emit warnings from system headers as if they occurred in user code. However, note that using -Wall in conjunction with this option does not warn about unknown pragmas in system headers. For that, -Wunknown-pragmas must also be used.
-Wtrigraphs	Warn if any trigraphs are encountered (assuming they are enabled).
-Wuninitialized	Warn if an automatic variable is used without first being initialized. These warnings are possible only when optimization is enabled, because they require data flow information that is computed only when optimizing. These warnings occur only for variables that are candidates for register allocation. Therefore, they do not occur for a variable that is declared volatile, or whose address is taken, or whose size is other than 1, 2, 4 or 8 bytes. Also, they do not occur for structures, unions or arrays, even when they are in registers. Note that there may be no warning about a variable that is used only to compute a value that itself is never used, because such computations may be deleted by data flow analysis before the warnings are printed.
-Wunknown-pragmas	Warn when a #pragma directive is encountered which is not understood by the compiler. If this command line option is used, warnings will even be issued for unknown pragmas in system header files. This is not the case if the warnings were only enabled by the -Wall command line option.
-Wunused	Warn whenever a variable is unused aside from its declaration, whenever a function is declared static but never defined, whenever a label is declared but not used, and whenever a statement computes a result that is explicitly not used. In order to get a warning about an unused function parameter, both -W and -Wunused must be specified. Casting an expression to void suppresses this warning for an expression. Similarly, the unused attribute suppresses this warning for unused variables, parameters and labels.
-Wunused-function	Warn whenever a static function is declared but not defined or a non-inline static function is unused.
-Wunused-label	Warn whenever a label is declared but not used. To suppress this warning, use the unused attribute.
-Wunused-parameter	Warn whenever a function parameter is unused aside from its declaration. To suppress this warning, use the unused attribute.
-Wunused-variable	Warn whenever a local variable or non-constant static variable is unused aside from its declaration. To suppress this warning, use the unused attribute.
-Wunused-value	Warn whenever a statement computes a result that is explicitly not used. To suppress this warning, cast the expression to void.
-Wvla-parameter	Warn about redeclarations of functions involving arguments of Variable Length Array types of inconsistent kinds or forms, and enable the detection of out-of-bounds accesses to such parameters by warnings such as -Warray-bounds.
-Wzero-length-bounds	Warn about accesses to elements of zero-length array members that might overlap other members of the same object. Declaring interior zero-length arrays is discouraged because accesses to them are undefined.

The following -W options are not implied by -Wall. Some of them warn about constructions that users generally do not consider questionable, but which you might occasionally wish to check for. Others warn about constructions that are necessary or hard to avoid in some cases, and there is no simple way to modify the code to suppress the warning.

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Table 5-13. Warning and Error Options Not Implied by All Warnings

Option	Definition
`-Wabsolute-value`	Warn for C calls to standard functions that compute the absolute value of an argument when a more appropriate standard function is available. For example, calling `abs(3.14)` triggers the warning because `fabs()` is the appropriate function to call to compute the absolute value of a double argument. The option also triggers warnings when the argument in a call to such a function has an unsigned type. This warning can be suppressed with an explicit type cast and it is also enabled by `-Wextra`.
`-Waddress-of-packed-member`	Warn when the address of packed member of struct or union is taken, which usually results in an unaligned pointer value. This is enabled by default.
`-Waggregate-return`	Warn if any functions that return structures or unions are defined or called.
`-Wno-analyzer-use-of-uninitialized-value`	Warn as part of a static analysis if an automatic variable definition does not specify an initial value.
`-Wbad-function-cast`	Warn whenever a function call is cast to a non-matching type. For example, warn if `int foof()` is cast to anything `*`.
`-Wbidi-chars`	Warn about possibly misleading UTF-8 bidirectional control characters in comments, string literals, character constants, and identifiers. Such characters can change left-to-right writing direction into right-to-left (and vice versa), which can cause confusion between the logical order and visual order. This may be dangerous; for instance, it may seem that a piece of code is not commented out, whereas it in fact is. There are three levels of warning, the default being `-Wbidi-chars=unpaired`, which warns about improperly terminated bidi contexts. The `-Wbidi-chars=none` option turns the warning off. Using `-Wbidi-chars=any` warns about any use of bidirectional control characters. To warn about UCNs, use `-Wbidi-chars=unpaired,ucn` or `-Wbidi-chars=any,ucn`. Using `-Wbidi-chars=ucn` is valid, and is equivalent to `-Wbidi-chars=unpaired,ucn`, if no previous `-Wbidi-chars=any` was specified.
`-Wc++11-extensions`	Warn about C++11 constructs in code being compiled using an older C++ standard. Note that some C++11 constructs will only be diagnosed if `-Wpedantic` is used.
`-Wc++14-extensions`	Warn about C++14 constructs in code being compiled using an older C++ standard. Note that some C++14 constructs will only be diagnosed if `-Wpedantic` is used.
`-Wc++17-extensions`	Warn about C++17 constructs in code being compiled using an older C++ standard. Note that some C++17 constructs will only be diagnosed if `-Wpedantic` is used.
`-Wc++20-extensions`	Warn about C++20 constructs in code being compiled using an older C++ standard. Note that some C++20 constructs will only be diagnosed if `-Wpedantic` is used.
`-Wc++23-extensions`	Warn about C++23 constructs in code being compiled using an older C++ standard. Note that some C++23 constructs will only be diagnosed if `-Wpedantic` is used.
`-Wcast-align`	Warn whenever a pointer is cast, such that the required alignment of the target is increased. For example, warn if a `char *` is cast to an `int *`.
`-Wcast-qual`	Warn whenever a pointer is cast, so as to remove a type qualifier from the target type. For example, warn if a `const char *` is cast to an ordinary `char *`.
`-Wconversion`	Warn if a prototype causes a type conversion that is different from what would happen to the same argument in the absence of a prototype. This includes conversions of fixed point to floating and vice versa, and conversions changing the width or signedness of a fixed point argument, except when the same as the default promotion. Also, warn if a negative integer constant expression is implicitly converted to an unsigned type. For example, warn about the assignment `x = -1` if `x` is unsigned. But do not warn about explicit casts like `(unsigned) -1`.
`-Wctad-maybe-unsupported`	Warn when C++ code performs class template argument deduction (CTAD) on a type with no explicitly written deduction guides. This warning will point out cases where CTAD succeeded only because the compiler synthesized the implicit deduction guides, which might not be what you intended.
`-Wdangling-reference`	Warn when a reference in C++ code is bound to a temporary whose lifetime has ended.
`-Wdeprecated-enum-enum-conversion`	Warn about the case when the usual arithmetic conversions are applied on operands where one is of enumeration type and the other is of a different enumeration type. This conversion was deprecated in C++20.

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Table 5-13. Warning and Error Options Not Implied by All Warnings (continued)

Option	Definition
`-Wdeprecated-enum-float-conversion`	Warn about the case when the usual arithmetic conversions are applied on operands where one is of enumeration type and the other is of a floating-point type. This conversion was deprecated in C++20.
`-Winline`	Warn if a function can not be inlined, and either it was declared as inline, or else the `-finline-functions` option was given.
`-Wlarger-than-len`	Warn whenever an object of larger than `len` bytes is defined.
`-Wlong-long` `-Wno-long-long`	Warn if `long long` type is used. This is default. To inhibit the warning messages, use `-Wno-long-long`. Flags `-Wlong-long` and `-Wno-long-long` are taken into account only when `-pedantic` flag is used.
`-Wmissing-declarations`	Warn if a global function is defined without a previous declaration. Do so even if the definition itself provides a -prototype.
`-Wmissing-format-attribute`	If `-Wformat` is enabled, also warn about functions that might be candidates for format attributes. Note these are only possible candidates, not absolute ones. This option has no effect unless `-Wformat` is enabled.
`-Wmissing-noreturn`	Warn about functions that might be candidates for attribute `noreturn`. These are only possible candidates, not absolute ones. Care should be taken to manually verify functions. In fact, do not ever return before adding the `noreturn` attribute, otherwise subtle code generation bugs could be introduced.
`-Wmissing-prototypes`	Warn if a global function is defined without a previous prototype declaration. This warning is issued even if the definition itself provides a prototype (this option can be used to detect global functions that are not declared in header files).
`-Wmissing-requires`	Warns about a concept-id appearing as a C++20 simple-requirement.
`-Wnested-externs`	Warn if an `extern` declaration is encountered within a function.
`-Wno-deprecated-declarations`	Do not warn about uses of functions, variables and types marked as deprecated by using the `deprecated` attribute.
`-Wpadded`	Warn if padding is included in a structure, either to align an element of the structure or to align the whole structure.
`-Wpointer-arith`	Warn about anything that depends on the size of a function type or of `void`. The compiler assigns these types a size of 1, for convenience in calculations with `void *`pointers and pointers to functions.
`-Wrange-loop-construct`	Warn when a C++ range-based for-loop is creating an unnecessary copy, which can happen when the range declaration is not a reference, but probably should be.
`-Wredundant-decls`	Warn if anything is declared more than once in the same scope, even in cases where multiple declaration is valid and changes nothing.
`-Wshadow`	Warn whenever a local variable shadows another local variable.
`-Wsign-compare` `-Wno-sign-compare`	Warn when a comparison between signed and unsigned values could produce an incorrect result when the signed value is converted to unsigned. This warning is also enabled by `-W`. To get the other warnings of `-W` without this warning, use `-W -Wno-sign-compare`.
`-Wstrict-prototypes`	Warn if a function is declared or defined without specifying the argument types (an old-style function definition is permitted without a warning if preceded by a declaration which specifies the argument types).
`-Wstring-compare`	Warn when calls to `strcmp()` or `strncmp()` are compared to zero or non-zero and the length of one argument is greater than the size of the array holding the other (or the bound in the case of `strncmp()`). As the result of such comparisons are known irrespective of the strings, this could indicate a mistake in the code.
`-Wstringop-overread`	Warn for calls to string manipulation functions such as `memchr()`, or `strcpy()` that are determined to read past the end of the source sequence.

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Table 5-13. Warning and Error Options Not Implied by All Warnings (continued)

Option	Definition
`-Wtraditional`	Warn about certain constructs that behave differently in traditional and ANSI C. • Macro arguments occurring within string constants in the macro body. These would substitute the argument in traditional C, but are part of the constant in ANSI C. • A function declared external in one block and then used after the end of the block. • A switch statement has an operand of type `long`. • A nonstatic function declaration follows a static one. This construct is not accepted by some traditional C compilers.
`-Wtrivial-auto-var-init`	Warn when the `-ftrivial-auto-var-init` option is in effect and an automatic variable cannot be initialized. This might occur when the automatic variable is declared between the controlling expression and the first `case` label of a `switch` statement.
`-Wundef`	Warn if an undefined identifier is evaluated in an `#if` -directive.
`-Wvexing-parse`	Warn about the most vexing parse syntactic ambiguity. This warns about the cases when a declaration looks like a variable definition, but the C++ language requires it to be interpreted as a function declaration. The warning will suggest options how to deal with such an ambiguity
`-Wwrite-strings`	Give string constants the type `const char[length]` so that copying the address of one into a non-const `char *` pointer gets a warning. At compile time, these warnings help you find code that you can try to write into a string constant, but only if you have been very careful about using `const` in declarations and prototypes. Otherwise, it's just a nuisance, which is why `-Wall` does not request these warnings.
`-Wxor-used-as-pow`	Warn where the ^ exclusive OR operator was used in situations where exponentiation was more likely intended. Specifically, the warning occurs when the left-hand side is the decimal constant 2 or 10 and the right-hand side is also a decimal constant.

5.7.5.1. Syntax-only Option

The `-fsyntax-only` option checks the C source code for syntax errors, then terminates the compilation.

The `-fno-syntax-only` form of this option performs a full compilation, which is the default action if this option is not specified.

5.7.5.2. Pedantic Option

The `-pedantic` option ensures that programs do not use forbidden extensions and that warnings are issued when a program does not follow ISO C.

5.7.5.3. Pedantic-errors Option

The `-pedantic-errors` option works in the same way as the `-pedantic` option, only errors, instead of warnings, are issued when a program is not ISO compliant.

5.7.5.4. W: Disable all Warnings Option

The `-w` option inhibits all warning messages, and thus should be used with caution.

5.7.5.5. Wall Option

The `-Wall` option enables all the warnings about easily avoidable constructions that some users consider questionable, even in conjunction with macros.

Note that some warning flags are not implied by `-Wall`. Of these warnings, some relate to constructions that users generally do not consider questionable, but which you might occasionally wish to check. Others warn about constructions that are necessary or hard to avoid in some cases and there is no simple way to modify the code to suppress the warning. Some of these warnings can be enabled using the `-Wextra` option, but many of them must be enabled individually.

5.7.5.6. Werror Option

The `-Werror` option can be used to promote compiler warnings into errors. As with any other error, these promoted messages will prevent the project from building.

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The `-Werror` form of this option promotes all issued compiler warning messages into errors. This option might be useful when debugging projects or for applications where warnings are not permitted for functional safety reasons. Note, however, that the use of this option will essentially tie a project's source code to a particular compiler version and is not recommended for production builds. If you build a project using this option with a newer compiler version, new diagnostic messages might appear due to improvements or different handling of questionable code. Any new warnings will stop the project from building.

The `-Werror=`*`string`* form of this option promotes warnings identified by the string argument into errors. For example, `-Werror=return-type` will promote the warning `control reaches end of non-void function [-Wreturn-type]` to an error. Only one string may be specified with this option; however, you may use this option as many times as required.

The `-Wno-error=`*`string`* form of this option ensures that the warnings identified are never promoted to an error, even if the `-Werror` form of this option is in effect.

5.7.5.7. Wextra Option

The `-Wextra` option generates extra warnings in the following situations.

- A nonvolatile automatic variable might be changed by a call to longjmp. These warnings are possible only in optimizing compilation. The compiler sees only the calls to `setjmp`. It cannot know where `longjmp` will be called. In fact, a signal handler could call it at any point in the code. As a result, a warning may be generated even when there is in fact no problem, because `longjmp` cannot in fact be called at the place that would cause a problem.
- A function could exit both via `return` *`value`*`;` and `return;`. Completing the function body without passing any return statement is treated as `return;`.
- An expression-statement or the left-hand side of a comma expression contains no side effects. To suppress the warning, cast the unused expression to `void`. For example, an expression such as `x[i,j]` causes a warning, but `x[(void)i,j]` does not.
- An unsigned value is compared against zero with < or <=.
- A comparison like `x<=y<=z` appears. This is equivalent to `(x<=y ? 1 : 0) <= z`, which is a different interpretation from that of an ordinary mathematical notation.
- Storage-class specifiers like `static` are not the first things in a declaration. According to the C Standard, this usage is obsolescent.
- If `-Wall` or `-Wunused` is also specified, warn about unused arguments.
- A comparison between signed and unsigned values could produce an incorrect result when the signed value is converted to unsigned (but won't warn if `-Wno-sign-compare` is also specified).
- An aggregate has a partly bracketed initializer. For example, the following code would evoke such a warning, because braces are missing around the initializer for `x.h`:

```
struct s { int f, g; };
struct t { struct s h; int i; };
struct t x = { 1, 2, 3 };
```

- An aggregate has an initializer that does not initialize all members. For example, the following code would cause such a warning, because `x.h` would be implicitly initialized to zero:

```
struct s { int f, g, h; };
struct s x = { 3, 4 };
```

5.7.6. Options for Debugging

The options tabulated below control the debugging output produced by the compiler and are discussed in the sections that follow.

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Table 5-14. Debugging Options

Option	Definition
`-dA`	Add extra debug information to generated assembly.
`-fdiagnostics-show-caret`	Controls information shown in diagnostics.
`-f[no-]eliminate-unused-debug-symbols`	Eliminate debug information associated with any C/C++ symbol that has not been used in the program.
`-fframe-base-loclist`	Include a frame-base location list in debugging information.
`-g`	Produce debugging information.
`-mno-info-linker`	Suppresses some linker advisory messages.
`-Q`	Print function names and statistics from each pass.
`-save-temps[=dir]`	Don't delete intermediate files.
`-msemihost`	Redirect output from `stdout` functions to the host PC when debugging

5.7.6.1. Da Option

The `-dA` option adds extra diagnostic information to the generated assembly code. Since this assembly code is output to a temporary file that is normally deleted after compilation, you can use the `-save-temps` option to preserve it for later inspection.

5.7.6.2. Diagnostics-show-caret Options

The `-fdiagnostics-show-caret` option has each diagnostic include the original source line and a caret character, '^', indicating the column. This is the default action if no option is specified.

The `-fno-diagnostics-show-caret` form of this option suppresses the source line and caret from all diagnotics.

5.7.6.3. Eliminate-unused-debug-symbols Option

The `-feliminate-unused-debug-symbols` option eliminates the debug information associated with any C/C++ symbol that has not been used in the program. This is also the default action if no option has been specified. Eliminating this information will reduce the size and load time of output files.

Use the `-fno-eliminate-unused-debug-symbols` form of this option if you want debug information generated for all symbols.

5.7.6.4. Frame-base-loclist Option

The `-fframe-base-loclist` option includes a frame-base location list in debugging information produced by the compiler. The MPLAB X IDE supports frame-base location lists in the DWARF content of ELF files, and this option can be used when debugging with this IDE.

The `-fno-frame-base-loclist` form of this option prevents these lists from being generated, making the compiler debug information compatible with older IDEs that do not support this feature. This is the default action if no option is specified.

5.7.6.5. G: Produce Debugging Information Option

The `-g` option instructs the compiler to produce additional information, which can be used by hardware tools to debug your program.

The option can be used with `-O`, making it possible to debug optimized code. The shortcuts taken by optimized code may occasionally produce surprising results:

- Some declared variables may not exist at all
- Flow of control may briefly move unexpectedly
- Some statements may not be executed because they compute constant results or their values were already at hand
- Some statements may execute in different places because they were moved out of loops

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Nevertheless it proves possible to debug optimized output. This makes it reasonable to use the optimizer for programs that might have bugs.

5.7.6.6. No-info-linker Option

The `-mno-info-linker` option suppresses some advisory messages issued by the linker. Such messages might indicate the location of the linker script being used, for example.

5.7.6.7. Q: Print Function Information Option

The `-Q` option instructs the compiler to print out each function name as it is compiled, and print statistics about each pass when it finishes.

5.7.6.8. Save-temps Option

The `-save-temps` option instructs the compiler to keep temporary files after compilation has finished. You might find the generated `.i` and `.s` temporary files particularly useful for troubleshooting and they are often used by the Microchip Support team when you enter a support ticket.

The intermediate files will be placed in the current directory and have a name based on the corresponding source file. Thus, compiling `foo.c` with `-save-temps` would produce `foo.i`, `foo.s` and the `foo.o` object file.

This option can be used to override the default location of aux and dump files.

The `-save-temps=cwd` option is equivalent to `-save-temps`.

The `-save-temps=obj` form of this option is similar to `-save-temps`, but if the `-o` option is specified, the temporary files are placed in the same directory as the output object file. If the `-o` option is not specified, the `-save-temps=obj` switch behaves like `-save-temps`.

The following example will create `dir/xbar.i`, `dir/xbar.s`, since the `-o` option was used.

```
xc32-gcc -save-temps=obj -c bar.c -o dir/xbar.o
```

5.7.6.9. Semihost Option

The `-msemihost` option links in a library that allows the redirection of output from `stdout` functions, such as `printf()`, to the host PC when debugging.

With this option enabled, the debugger will break execution whenever data is detected in the `stdout` stream. With appropriate configuration of your source code and the IDE project, this data can be sent to the **Output** view in the IDE. See the *Step-by-step guide to enable semihosting in your application* section in the MPLAB X IDE User's Guide for more information.

5.7.7. Options for Controlling Optimization

The options tabulated below control compiler optimizations and are described in the sections that follow.

Use of an option is permitted and has an effect with an unlicensed compiler (Free edition), if that option is enabled by default, when using optimization level 2 or lower. Any form of option that disables an optimization is available unconditionally.

Table 5-15. Optimization Options

Option	Edition	Controls
`-O0`	All	Do not optimize.
`-O` `-O1`	All	Optimization level 1.
`-O2`	All	Optimization level 2.
`-O3`	PRO only	Speed-orientated optimizations.

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Table 5-15. Optimization Options (continued)

Option	Edition	Controls
-Os	PRO only	Size-orientated optimizations.
-f[no-]align-functions=*n*	All	Alignment of the start of functions.
-f[no-]align-jumps=*n*	All	Alignment of jump targets
-f[no-]align-labels=*n*	All	Alignment of all branch targets.
-f[no-]align-loops=*n*	All	Alignment of loops.
-f[no-]caller-saves	All	Allocation into registers clobbered by function calls.
-f[no-]cse-follow-jumps	All	Customization of common subexpression elimination optimizations.
-f[no-]cse-skip-blocks	All	Customization of common subexpression elimination optimizations.
-f[no-]data-sections	All	Placement of objects into a section in the output file.
-f[no-]defer-pop	All	When arguments to function calls are popped.
-f[no-]expensive-optimizations	All	Minor optimizations that are relatively expensive.
-ffat-lto-objects	All	Requests that the compiler generate fat object files.
-f[no-]function-cse	All	Placement of function addresses.
-f[no-]function-sections	All	Placement of functions into a section in the output file.
-f[no-]gcse	All	The global common subexpression elimination pass.
-f[no-]gcse-lm	All	Customization of common subexpression elimination dealing with loads.
-f[no-]gcse-sm	All	Customization of common subexpression elimination dealing with stores.
-finline	All	Inlining of functions marked with the inline specifier
-f[no-]inline-functions	All	Integration of all simple functions into their callers.
-f[no-]inline-limit=*n*	All	The size limit for inlining functions.
-finline-small-functions	All	Integration of all simple functions into their callers.
-f[no-]keep-inline-functions	All	Output of a separate run-time-callable version of inlined functions.
-f[no-]keep-static-consts	All	Output of `static const` objects.
-f[no-]lto	PRO only	The standard link-time optimizer.
-flto-partition=*algorithm*	PRO only	The link-time optimizer algorithm used to partition object files.
-f[no-]omit-frame-pointer	All	Reservation of the Frame Pointer in a register for functions that don't need one.
-f[no-]optimize-register-move -f[no-]regmove	All	Reassign of register numbers in move and other instructions.
-f[no-]optimize-sibling-calls	All	Optimization of sibling and tail recursive calls.
-fpeel-loops	All	Reconfigure loops in the source code.
-f[no-]peephole -f[no-]peephole2	All	Machine-specific peephole optimizations.
-f[no-]rename-registers	All	Use of free registers to avoid false dependencies in scheduled code.
-f[no-]rerun-cse-after-loop	All	When common subexpression elimination optimizations should be performed.
-f[no-]rerun-loop-opt	All	How often to run the loop optimizer.
-f[no-]schedule-insns -f[no-]schedule-insns2	All	Reordering instructions to eliminate instruction stalls.
-f[no-]strength-reduce	All	Loop strength reduction and elimination of iteration variables.
-f[no-]strict-aliasing	All	Assumption of the strictest aliasing rules applicable to the language being compiled.
-f[no-]thread-jumps	All	Jump-to-branch optimizations.
-f[no-]toplevel-reorder	All	Reordering of top-level functions, variables, and `asm` statements.
-ftracer	All	Perform tail duplication.

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Table 5-15. Optimization Options (continued)

Option	Edition	Controls
`-ftree-vrp`	All	Perform value range propagation.
`-ftrivial-auto-var-init=`*choice*	All	Initialize automatic variables that have not been explicitly initialized in the source code
`-f[no-]unroll-loops` `-f[no-]unroll-all-loops`	All	Loop unrolling.
`-fuse-linker-plugin`	All	Enable use of a linker plugin during link-time optimization plugin.
`-f[no-]whole-program`	PRO only	More aggressive interprocedural optimizations.
`-fzero-call-used-regs=`*choice*	All	Overwriting "call-used" registers associated with functions when they return

5.7.7.1. O0: Level 0 Optimizations

The `-O0` option performs only rudimentary optimization. This is the default optimization level if no `-O` option is specified.

With this optimization level selected, the compiler's goal is to reduce the cost of compilation and to make debugging produce the expected results.

Statements are independent when compiling with this optimization level. If you stop the program with a breakpoint between statements, you can then assign a new value to any variable or change the program counter to any other statement in the function and get exactly the results you would expect from the source code.

The compiler only allocates variables declared `register` in registers.

5.7.7.2. O1: Level 1 Optimizations

The `-O1` or `-O` options request level 1 optimizations.

The optimizations performed when using `-O1` aims to reduce code size and execution time, but still allows a reasonable level of debugability.

This level is available for unlicensed as well as licensed compilers.

5.7.7.3. O2: Level 2 Optimizations Option

The `-O2` option requests level 2 optimizations.

At this level, the compiler performs nearly all supported optimizations that do not involve a space-speed trade-off.

This level is available for unlicensed as well as licensed compilers.

5.7.7.4. O3: Level 3 Optimizations Option

The `-O3` option requests level 3 optimizations.

This option requests all supported optimizations that reduces execution time but which might increase program size.

This level is available only for licensed compilers.

5.7.7.5. Os: Level s Optimizations Option

The `-Os` option requests space-orientated optimizations.

This option requests all supported optimizations that do not typically increase code size.

This level is available only for licensed compilers.

5.7.7.6. Align-functions Option

The `-falign-functions=`*n* option aligns the start of functions to the next power of two greater than *n*.

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The `-fno-align-functions` form of this option is equivalent to `-falign-functions=1`, which implies that the function is not aligned. If *n* is not specified or is zero, a default of alignment of 4 bytes is used for both MIPS32 and MIPS16 instruction sets. If *n* is not a power of 2, the alignment value is rounded up.

For instance, `-falign-functions=32` aligns functions to the next 32-byte boundary; `-falign-functions=24` aligns functions to the next 32-byte boundary but only if this can be done by skipping no more than 23 bytes.

This option is automatically enabled at optimization levels `-O2` and `-O3`.

5.7.7.7. Align-jumps Option

The `-falign-jumps=`*n* option aligns branch targets, where the targets can only be reached by jumping, to the next power of two greater than *n*. For instance, `-falign-jumps=32` aligns targets to the next 32-byte boundary; `-falign-jumps=24` aligns targets to the next 32-byte boundary but only if this can be done by skipping no more than 23 bytes.

The `-fno-align-jumps` form of this option is equivalent to `-falign-jumps=1`, which implies that the target is not aligned. If *n* is not specified or is zero, , a default of alignment of 1 byte is used, which implies that the target is not aligned. If *n* is not a power of 2, the alignment value is rounded up.

For instance, `-falign-jumps=32` aligns targets to the next 32-byte boundary; `-falign-jumps=24` aligns targets to the next 32-byte boundary but only if this can be done by skipping no more than 23 bytes.

This option is automatically enabled at optimization levels `-O2` and `-O3`.

If the alignment values specified by `-falign-labels` is greater than that specified with this option, then its value is used to align jumps instead.

5.7.7.8. Align-labels Option

The `-falign-labels=`*n* option aligns all branch targets to the next power of two greater than *n*. For instance, `-falign-labels=8` aligns labels to the next 8-byte boundary; `-falign-labels=9` aligns labels to the next 16-byte boundary but only if this can be done by skipping no more than 9 bytes.

. The `-fno-align-labels` form of this option is equivalent to `-falign-labels=1`, which implies that the label is not aligned. If *n* is not specified or is zero, a default of alignment of 1 byte is used, which implies that the label is not aligned. If the options `-falign-loops` or `-falign-jumps` have also been specified and either of their arguments are greater than *n*, their argument values are used to determine the label alignment instead. If *n* is not a power of 2, the alignment value is rounded up.

For instance, `-falign-labels=32` aligns labels to the next 32-byte boundary; `-falign-labels=24` aligns labels to the next 32-byte boundary but only if this can be done by skipping no more than 23 bytes.

This option can easily make code slower, because it must insert dummy operations for when the branch target is reached in the usual flow of the code.

If the options `-falign-loops` or `-falign-jumps` have been used and either of their arguments are greater than *n*, then their argument values are used to determine the label alignment instead.

This option is automatically enabled at optimization levels `-O2` and `-O3`.

The `-fno-align-labels` form of this option is equivalent to `-falign-labels=1` and implies that labels are not aligned. The `-falign-labels` form of this option (with no argument) also performs no alignment.

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5.7.7.9. Align-loops Option

The `-falign-loops=n` option aligns loops to the next power of two greater than `n`. For instance, `-falign-loops=32` aligns loops to the next 32-byte boundary; `-falign-loops=24` aligns loops to the next 32-byte boundary but only if this can be done by skipping no more than 23 bytes.

The `-fno-align-loops` form of this option is equivalent to `-falign-loops=1`, which implies that the loop is not aligned. If `n` is not specified or is zero, a default of alignment of 1 byte is used, which implies that the loop is not aligned. If `n` is not a power of 2, the alignment value is rounded up.

For instance, `-falign-loops=32` aligns loops to the next 32-byte boundary; `-falign-loops=24` aligns loops to the next 32-byte boundary but only if this can be done by skipping no more than 23 bytes.

If the loops are executed many times, this makes up for any execution of the dummy padding instructions.

If the alignment values specified by `-falign-labels` is greater than that specified with this option, then its value is used to align loops instead.

5.7.7.10. Caller-saves Option

The `-fcaller-saves` option allows the compiler to allocate values to registers that are clobbered by function calls. If allocation to these registers takes place, extra code to save and restore the clobbered registers is generated around function calls. Allocation is performed only when better performing code is expected than would otherwise be produced.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-caller-saves` form of this option never allocates values to registers that are clobbered by functions.

5.7.7.11. Cse-follow-jumps Option

The `-fcse-follow-jumps` option instructs the common subexpression elimination (CSE) optimizations to scan through jump instructions when the target of the jump is not reached by any other path. For example, when CSE encounters an `if()` statement with an `else` clause, CSE follows the jump when the condition tested is false.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-cse-follow-jumps` form of this option does not perform this scan.

5.7.7.12. Cse-skip-blocks Option

The `-fcse-skip-blocks` option performs a similar task to the `-fcse-follow-jumps` option but instructs the common subexpression elimination (CSE) optimizations to follow jumps that conditionally skip over blocks. When CSE encounters a simple `if()` statement with no `else` clause, it will follow the jump around the body of the `if()`.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-cse-skip-blocks` form of this option does not perform this scan.

5.7.7.13. Data-sections Option

The `-fdata-sections` option places each object in its own section to assist with garbage collection and potential code size reductions.

When enabled, this option has each object placed in its own section named after the object. When used in conjunction with garbage collection performed by the linker (enabled using the `-Wl,--gc-sections` driver option) the final output might be smaller. It can, however, negatively impact other code generation optimizations, so confirm whether this option is of benefit with each project.

The `-fno-data-sections` form of this option does not force each object to a unique section. This is the default action if no option is specified.

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5.7.7.14. Defer-pop Option

The `-fdefer-pop` option specifies that the compiler should let function arguments accumulate on the stack for several function calls before they are popped off the stack in one step.

This option is automatically enabled at optimization levels `-O1`, `-O2`, `-O3`, and `-Os`.

The `-fno-defer-pop` form of this option has the compiler pop the arguments to each function call as soon as that function returns.

5.7.7.15. Expensive-optimizations Option

The `-fexpensive-optimizations` options has the compiler perform a number of optimizations that have minimal effect but that are relatively expensive to perform.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-expensive-optimizations` form of this option does not perform these optimizations.

5.7.7.16. Fat-lto-objects Option

The `-ffat-lto-objects` option requests that the compiler generate fat object files, which contain both object code and GIMPLE (one of GCC's internal representations), written to unique ELF sections. Such objects files are useful for library code that could be linked with projects that do and do not use the standard link-time optimizer, controlled by the `-flto` option.

The `-fno-fat-lto-objects` form of this option, which is the default if no option is specified, suppresses the inclusion of the object code into object files, resulting in faster builds. However, such object files must always be linked using the standard link-time optimizer.

5.7.7.17. Function-cse Option

The `-ffunction-cse` form of this option allows the address of called functions to be held in registers. This is the default action if no option is specified.

The `-fno-function-cse` form of this option will not place function addresses in registers. Each instruction that calls a constant function contain the function's address explicitly. This option results in less efficient code, but some strange hacks that alter the assembler output may be confused by the optimizations performed when this option is not used.

5.7.7.18. Function-sections Option

The `-ffunction-sections` option places each function in its own section to assist with garbage collection and potential code size reductions.

When enabled, this option has each function placed in its own section named after the function. When used in conjunction with garbage collection performed by the linker (enabled using the `-Wl,--gc-sections` driver option) the final output might be smaller. The `-ffunction-sections` option can, however, hamper other code generation optimizations, so confirm whether this option is of benefit with each project.

Note also that if functions are removed, their debugging information will remain in the ELF file, potentially imperiling the debuggability of code. When displaying source code information, the debugger looks for associations between addresses and the functions whose code resides at those locations, and it might wrongly consider that an address belongs to a removed function. As removed functions are not allocated memory, their "assigned" address will not change from being 0, thus the debugger is more likely to show references to a removed function when interpreting addresses closer to 0.

The `-fno-function-sections` form of this option does not force each function into a unique section. This is the default action if no option is specified.

5.7.7.19. Gcse Option

The `-fgcse` option perform a global common subexpression elimination pass. This pass also performs global constant and copy propagation.

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This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-gcse` form of this option does not perform this pass.

5.7.7.20. Gcse-lm Option

The `-fgcse-lm` option attempts to have the global common subexpression elimination optimizations move load sequences that are only killed by stores into themselves. This allows a loop containing a load/store sequence to change to a load outside the loop, and a copy/store within the loop.

The option is enabled when `-fgcse` is enabled.

The `-fno-gcse-lm` form of this option does not move these sequences.

5.7.7.21. Gcse-sm Option

The `-fgcse-sm` option runs a store motion pass after the global common subexpression elimination optimizations. This pass attempts to move stores out of loops. When used in conjunction with `-fgcse-lm`, loops containing a load/store sequence can change to a load before the loop and a store after the loop.

The option is not automatically enabled at any optimization level.

The `-fno-gcse-sm` form of this option does not move these sequences.

5.7.7.22. Inline Option

The `-finline` option allows the compiler to expand functions using the `inline` keyword. This is the default action if no option is specified.

The `-fno-inline` form of this option will never inline functions, even if they have been marked as `inline`.

5.7.7.23. Inline-functions Option

The `-finline-functions` option considers all functions for inlining, even if they are not declared `inline`.

If all calls to a given function are inlined, and the function is declared `static`, then the function is normally not output as a stand-alone assembler routine.

This option is automatically enabled at optimization levels `-O3` and `-Os`.

The `-fno-inline-functions` form of this option will never inline function that have not been marked as `inline`.

5.7.7.24. Inline-limit Option

The `-finline-limit=`*n* option controls the inlining size limit for functions marked `inline`. The argument, *n*, is a number of pseudo instructions (not counting parameter handling) being an abstract measurement of a function's size. In no way does this value represent a count of assembly instructions and as such, its exact meaning might change from one release of the compiler to an another. The default value of *n* is 10000.

Increasing the inlining limit can result in more inlined code at the cost of compilation time and memory consumption.

5.7.7.25. Inline-small-functions Options

The `-finline-small-functions` option integrates the body of functions into its callers when a function's code size is expected to be smaller than the size of the call/return sequence that would otherwise be required to call that function. The compiler heuristically decides which functions are simple enough to integrate in this way so as to reduce the size of the program. This inlining applies to all functions, even those not declared `inline`. Automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-inline-small-functions` form of this option suppresses this optimization.

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5.7.7.26. Keep-inline-functions Option

The `-fkeep-inline-functions` option ensures that separate run-time-callable assembly code for functions is output, even if all calls to a given function are inlined and the function is declared `static`. This switch does not affect the output of `extern inline` functions.

The `-fno-keep-inline-functions` form of this option will not emit output for `static` functions where all calls to it have been inlined. This is the default action if no option has been specified.

5.7.7.27. Keep-static-consts Option

The `-fkeep-static-consts` option emits `static const` objects when the optimizers are disabled, even if the objects are not referenced. This is the default action if no option is specified.

The `-fno-keep-static-consts` form of this option forces the compiler to emit the object only when referenced, regardless of whether the optimizers are enabled.

5.7.7.28. Lto Option

This `-flto` option runs the standard link-time optimizer. This feature can only be enabled when using a licensed compiler.

When invoked with source code, the compiler adds an internal bytecode representation of the code to special sections in the object file. When the object files are linked together, all the function bodies are read from these sections and instantiated as if they had been part of the same translation unit. Link time optimizations do not require the presence of the whole program to operate.

To use the link-timer optimizer, specify `-flto` both at compile time and during the final link. For example:

```
xc32-gcc -c -O3 -flto -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-
EC_DFP.1.4.150" foo.c
xc32-gcc -c -O3 -flto -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-
EC_DFP.1.4.150" bar.c
xc32-gcc -o myprog.elf -flto -O3 -mprocessor=32MZ2048ECH100 -mdfp="Microchip/
Microchip.PIC32MZ-EC_DFP.1.4.150" foo.o bar.o
```

Another (simpler) way to enable link-time optimization is:

```
xc32-gcc -o myprog.elf -flto -O3 -mprocessor=32MZ2048ECH100 -mdfp="Microchip/
Microchip.PIC32MZ-EC_DFP.1.4.150" foo.c bar.c
```

Important: Object and library archive files built with LTO enabled are versioned, and there is a strict version check, so those files generated in one version of the compiler might not work with a different version. Additionally, any object or library archive built with LTO enabled can only be used with projects built on the same platform. For example, a library built with LTO on the Windows platform can only be used with other projects that will be built on Windows.

The `-fno-lto` form of this option does not run the standard link-time optimizer. This is the default action if this option is not specified.

5.7.7.29. Lto-partition Option

The `-flto-partition=`*`algorithm`* option controls the algorithm used to partition object files when running the link-time optimizer. Multiple partitions can be optimized in parallel, which might reduce the memory and processing time required by the compiler.

The argument `none` disables partitioning entirely and executes the link-time optimization step directly from the whole program analysis (WPA) phase. This mode of operation will produce the most optimal results at the expense of larger compiler memory requirements and longer build times, although this is unlikely to be an issue with small programs.

The `one` algorithm argument specifies that link-time optimizations should be performed on the whole program as a single unit, rather than splitting it into smaller partitions. This can result in

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better optimization opportunities, especially for interprocedural analysis and transformations, but it also requires the most memory and computational time during the link phase.

Selecting the option argument to `1to1` splits the program so that each original compilation unit becomes a separate partition. This can reduce the computational memory and time requirements significantly but might also reduce the runtime performance benefits of the optimization.

The default argument is `balanced`, which specifies partitioning into a given number of parts of roughly the same size, based on the call graph. This algorithm tries to balance the trade-off between computational memory and time, as well as runtime performance.

5.7.7.30. Omit-frame-pointer Option

The `-fomit-frame-pointer` option instructs the compiler to directly use the stack pointer to access objects on the stack and, if possible, omit code that saves, initializes, and restores the frame register. It is enabled automatically at all non-zero optimization levels.

Negating the option, using `-fno-omit-frame-pointer`, might assist debugging optimized code; however, this option does not guarantee that the frame pointer will always be used.

5.7.7.31. Optimize-register-move/regmove Option

The `-foptimize-register-move` option and its alias, `-fregmove`, have no effect, but are accepted for backward compatibility.

5.7.7.32. Optimize-sibling-calls Option

The `-foptimize-sibling-calls` option optimizes sibling calls (where the last action of a function is a call to another function whose stack footprint is compatible with the callee) and tail recursive calls (where the last action of a function is a call to itself).

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-foptimize-sibling-calls` form of this option will not enable these optimizations.

5.7.7.33. Peel-loops Option

The `-fpeel-loops` option peels loops in the source code, which involves reconfiguring the loop where possible so that a number of the early iterations are excluded from the loop and are executed explicitly before the loop starts. Doing so might mean that the remaining loop body can be executed more efficiently. This option also turns on complete loop peeling (i.e. complete removal of loops that will execute a small, constant number of iterations). This option is automatically enabled when selecting level `-O3` optimizations.

The `-fno-peel-loops` form of this option does not perform loop peeling. This is the default action if this option is not specified and level `-O3` optimizations have not been selected.

5.7.7.34. Peephole/peephole2 Options

The `-fpeephole` option enables machine-specific peephole optimizations. Peephole optimizations occur at various points during the compilation. This is the default action if no option is specified.

The `-fpeephole2` form of this option enables high-level peephole optimizations. This option is enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-peephole` and `-fno-peephole2` form of these options disables standard and high-level peephole optimizations, respectively. Both options should be used to entirely disable peephole optimizations.

5.7.7.35. Rename-registers Option

The `-frename-registers` option attempts to avoid false dependencies in scheduled code by making use of registers leftover after register allocation. This optimization most benefits processors with many registers, but it can reduce the debugability of code, since variables might no longer be allocated to a “home register.”

This option is automatically enabled when using `-funroll-loops`.

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The `-fno-rename-registers` form of this option does not use leftover registers. This is the default action if no option has been specified and the `-funroll-loops` option has not been used.

5.7.7.36. Rerun-cse-after-loop Option

The `-frerun-cse-after-loop` option reruns common subexpression elimination (CSE) optimizations after loop optimizations has been performed.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-rerun-cse-after-loop` form of this option does not rerun the CSE optimizations.

5.7.7.37. Rerun-loop-opt Option

The `-frerun-loop-opt` option no longer has any effect and is ignored for compatibility with legacy projects.

5.7.7.38. Schedule-insns/schedule-insns2 Options

The `-fschedule-insns` option attempts to reorder instructions to eliminate instruction stalls due to required data being unavailable.

This option is automatically enabled at optimization levels `-O2` and `-O3`.

The `-fschedule-insns2` form of this option is similar to `-fschedule-insns`, but it requests an additional pass of instruction scheduling after register allocation has been performed.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-schedule-insns` and `-fno-schedule-insns2` forms of these options do not reorder instructions.

5.7.7.39. Strength-reduce Option

The `-fstrength-reduce` option no longer has any effect and is ignored for compatibility with legacy projects.

5.7.7.40. Strict-aliasing Option

The `-fstrict-aliasing` option allows the compiler to assume the strictest aliasing rules applicable to the language being compiled. For C, this activates optimizations based on the type of expressions. In particular, an object of one type is assumed never to reside at the same address as an object of a different type, unless the types are almost the same.

For example, an `unsigned int` can alias an `int`, but not a `void *` or a `double`. A character type may alias any other type.

Pay special attention to code like this:

```
union a_union {
  int i;
  double d;
};
int f() {
  union a_union t;
  t.d = 3.0;
  return t.i;
}
```

The practice of reading from a different union member than the one most recently written to (called “type-punning”) is common. Even with `-fstrict-aliasing`, type-punning is allowed, provided the memory is accessed through the `union` type. The code above works as expected. However, this code might not:

```
int f() {
  a_union t;
  int * ip;
  t.d = 3.0;
  ip = &t.i;
  return *ip;
}
```


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This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

`-fno-strict-aliasing` form of this option relaxes the aliasing rules, preventing some optimizations from being performed.

5.7.7.41. Thread-jumps Option

The `-fthread-jumps` option enables checks to determine if the branch destinations of comparisons are further comparisons that have been subsumed by the first. If so, the first branch is redirected to either the destination of the second branch or a point immediately following it, depending on whether the second branch condition is known to be true or false.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-thread-jumps` form of this option does not perform these checks.

5.7.7.42. Toplevel-reorder Option

The `-ftoplevel-reorder` option allows the compiler to reorder top-level functions, variables, and `asm` statements, in which case, they might not be output in the same order that they appear in the input file. This option also allows the compiler to remove unreferenced `static` variables.

Enabled at level `-O0`. When disabled explicitly using the `-fno-toplevel-reorder` option, it also implies `-fno-section-anchors`, which is otherwise enabled at `-O0` on some targets.

5.7.7.43. Tracer Option

The `-ftracer` option performs tail duplication, a transformation that can increase basic block (trace) sizes by duplicating code after a control flow merge point. Such transformations can facilitate many other optimizations, particularly speed-orientated optimizations aimed at reducing cache misses and the overhead of branches and indirect jumps.

The `-fno-tracer` form of this option disables this transformation, and is the default action if no option is specified.

5.7.7.44. Tree-vrp Option

The `-ftree-vrp` option controls Value Range Propagation (VRP), which determines what subranges a variable can contain and uses that information to eliminate unnecessary range checks, like array bound checks and null pointer checks. This in turn makes programs smaller and run faster.

This option is automatically enabled at optimization levels `-O2`, `-O3`, and `-Os`.

The `-fno-tree-vrp` form of this option does not perform VRP.

5.7.7.45. Trivial-auto-var-init Option

The `-ftrivial-auto-var-init=`*`choice`* option instructs the compiler to initialize automatic variables that have not been explicitly initialized in the source code with either a pattern or with zeroes. Doing so can increase the security and predictability of a program by preventing uninitialized memory disclosure and use. Even with this feature in effect, automatic variables that do not have an explicit initializer are treated as uninitialized. The `-Wuninitialized` and `-Wanalyzer-use-of-uninitialized-value` options will still report warning messages against such automatic variables and the compiler will perform optimization as if the variable were uninitialized. This feature also initializes padding of automatic structure or union objects to zero. However, automatic variables that are declared between the controlling expression and the first case of a switch statement are not initialized. Use the `-Wtrivial-auto-var-init` option to report all such cases.

The three values of choice are:

`uninitialized`	Do not initialize any automatic variables. This choice results in the fastest execution of the program.
`pattern`	Initialize automatic variables with the value 0xFE. This value is chosen so that logic bugs in the program will more likely result in obvious program crashes, it is easily recognized in crash dumps, and is not a value that programmers rely on for useful program semantics.

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Note, however, that the value or values used for pattern initialization might changed in future implementations.

zero Initialize automatic variables with zeroes.

If this option is not specified, the default action is to not initialize automatic variables, as if the `uninitialized` choice had been selected.

You can control this behavior for a specific variable by using the `uninitialized` variable attribute (see Specifying Attributes of Variables).

5.7.7.46. Unroll-loops/unroll-all-loops Options

The `-funroll-loops` and `-funroll-all-loops` options control speed-orientated optimizations that attempt to remove branching delays in loops. Unrolled loops typically increase the execution speed of the generated code, at the expense of larger code size.

The `-funroll-loops` option unrolls loops where the number of iterations can be determined at compile time or when code enters the loop. This option is enabled with `-fprofile-use`. The `-funroll-all-loops` option is more aggressive, unrolling all loops, even when the number of iterations is unknown. It is typically less effective at improving execution speed than the `-funroll-loops` option.

Both options imply `-frerun-cse-after-loop`, `-fweb` and `-frename-registers`.

The `-fno-unroll-loops` and `-fno-unroll-all-loops` forms of these options do not unroll any loops and are the default actions if no options are specified.

5.7.7.47. Use-linker-plugin Option

The `-fuse-linker-plugin` option enables the use of a linker plugin during link-time optimization, improving the quality of optimization by exposing more code to the link-time optimizer. This is the default action if no option is specified. The `-fwhole-program` option should not be used with the `-fuse-linker-plugin` option.

The `-fno-use-linker-plugin` option disables the use of a linker plugin during link-time optimization.

5.7.7.48. Whole-program Optimizations Option

The `-fwhole-program` option runs more aggressive interprocedural optimizations.

The option assumes that the current compilation unit represents the whole program being compiled. All public functions and variables, with the exception of `main()` and those merged by attribute `externally_visible`, become `static` functions and in effect are optimized more aggressively by interprocedural optimizers. While this option is equivalent to proper use of the `static` keyword for programs consisting of a single file, in combination with option `-flto`, this flag can be used to compile many smaller scale programs since the functions and variables become local for the whole combined compilation unit, not for the single source file itself.

The `-fno-whole-program` form of this option disables these optimizations and this is the default action if no option is specified.

5.7.7.49. Zero-call-used-regs Option

The `-fzero-call-used-regs=`*`choice`* option instructs the compiler to zero out a subset of the "call-used" registers associated with each function when those functions return. Call-used registers are those registers that can be altered by a function call. This action can enhance program security by reducing the risk of return-oriented programming (ROP) attacks or preventing information leakage through registers.

To balance security needs with runtime performance, the *`choice`* argument allows you to select which subset of call-used registers should be zeroed. The four basic options for *`choice`* are:

skip No call-used registers are zeroed.

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used Only call-used registers that have been set or referenced in the function are zeroed.
all All call-used registers are zeroed.

The `used` and `all` options can be further refined with the following suffixes:

-gpr Limits zeroing to general-purpose registers.
-arg Limits zeroing to function argument registers, as defined by the platform's calling convention.

You can use these suffixes individually or together. If both are used, they must appear in the above order. For example, `used-gpr` zeros only general-purpose call-used registers that have been set or referenced in the function; `used-arg` zeros only call-used registers used for function arguments that have been set or referenced; and `used-gpr-arg` zeros only general-purpose call-used registers used for function arguments that have been set or referenced.

Choices like `used-arg`, `used-gpr-arg`, `all-arg`, and `all-gpr-arg` are primarily used for ROP mitigation.

The compiler's encoding of individual functions can be controlled by the `zero_call_used_regs` attribute, which overrides this option. See Zero_call_used_regs Function Attribute.

5.7.8. Options for Controlling the Preprocessor

The options tabulated below control the preprocessor and are discussed in the sections that follow.

Table 5-16. Preprocessor Options

Option	Definition
`-C`	Preserve comments.
`-d`*letters*	Make debugging dumps of preprocessor macros.
`-Dmacro[=defn]`	Define a macro.
`-H`	Print the name of each header file used.
`-imacros file`	Include file macro definitions only.
`-include file`	Process file as input before processing the regular input file.
`-M`	Generate make rule.
`-MD`	Write dependency information to file.
`-MF file`	Specify dependency file.
`-MG`	Ignore missing header files.
`-MM`	Generate make rule for quoted headers.
`-MMD`	Generate make rule for user headers.
`-MP`	Add phony target for dependency.
`-MQ`	Change rule target with quotes.
`-MT` *target*	Change rule target.
`-nostdinc`	Omit system directories from header search.
`-P`	Don't generate #line directives.
`-f[no-]show-column`	Omit column numbers in diagnostics.
`-trigraphs`	Support ANSI C trigraphs.
`-Umacro`	Undefine a macro.
`-undef`	Do not predefine any nonstandard macros.

5.7.8.1. C: Preserve Comments Option

The `-C` option tells the preprocessor not to discard comments from the output. Use this option with the `-E` option to see commented yet preprocessed source code.

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5.7.8.2. d: Preprocessor Debugging Dumps Option

The `-dletters` option has the preprocessor produce debugging dumps during compilation as specified by *letters*. This option should be used in conjunction with the `-E` option.

The `-dM` option generates a list of `#define` directives for all the macros defined during the execution of the preprocessor, including predefined macros. These will indicate the replacement string if one was defined. For example, the output might include:

```
#define _CP0_BCS_TAGLO(c,s) _bcsc0(_CP0_TAGLO, _CP0_TAGLO_SELECT, c, s)
#define PORTE PORTE
#define _LATE_LATE1_LENGTH 0x00000001
#define _IPC22_w_POSITION 0x00000000
```

You can use this option to show those macros which are predefined by the compiler or header files.

The acceptable letter arguments to `-d` are tabulated below.

Table 5-17. Preprocessor Debugging Information

Letter	Produces
`D`	Similar output to `-dM` but lacking predefined macros. The normal preprocessor output is also included in this output.
`M`	Full macro output, as described in the main text before this table.
`N`	Similar output to `-dD` but only the macro names are output with each definition.

5.7.8.3. D: Define a Macro

The `-Dmacro` option allows you to define a preprocessor macro and the `-Dmacro=text` form of this option additionally allows a user-define replacement string to be specified with the macro. A space may be present between the option and macro name.

When no replacement text follows the macro name, the `-Dmacro` option defines a preprocessor macro called *macro* and specifies its replacement text as `1`. Its use is the equivalent of placing `#define macro 1` at the top of each module being compiled.

The `-Dmacro=text` form of this option defines a preprocessor macro called *macro* with the replacement text specified. Its use is the equivalent of placing `#define macro text` at the top of each module being compiled.

Either form of this option creates an identifier (the macro name) whose definition can be checked by `#ifdef` or `#ifndef` directives. For example, when using the option, `-DMY_MACRO` (or `-D MY_MACRO`) and building the following code:

```
#ifdef MY_MACRO
int input = MY_MACRO;
#endif
```

the definition of the `int` variable `input` will be compiled, and the variable assigned the value `1`.

If the above example code was instead compiled with the option `-DMY_MACRO=0x100`, then the variable definition that would ultimately be compiled would be: `int input = 0x100;`

See Preprocessor Arithmetic for clarification of how the replacement text might be used.

Defining macros as C string literals requires escaping the quote characters (`" "`) used by the string. If a quote is intended to be included and passed to the compiler, it should be escaped with a backslash character (`\`). If a string includes a space character, the string should have additional quotes around it.

For example, to pass the C string, `"hello world"`, (including the quote characters and the space in the replacement text), use `-DMY_STRING="\"hello world\""`. You could also place quotes around the entire option: `"-DMY_STRING=\"hello world\""`. These formats can be used on any

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platform. Escaping the space character, as in `-DMY_STRING=\"hello\ world\"` is only permitted with macOS and Linux systems and will not work under Windows, and hence it is recommended that the entire option be quoted to ensure portability.

5.7.8.4. H: Print Header Files Option

The `-H` option prints to the console the name of each header file used, in addition to other normal activities.

5.7.8.5. Imacros Option

The `-imacros` *`file`* option processes the specified file in the same way the `-include` option would, except that any output produced by scanning the file is thrown away. The macros that the file defines remain defined during processing. Because the output generated from the file is discarded, the only effect of this option is to make the macros defined in file available for use in the main input.

Any `-D` and `-U` options on the command line are always processed before an `-imacros` option, regardless of the order in which they are placed. All the `-include` and `-imacros` options are processed in the order in which they are written.

5.7.8.6. Include Option

The `-include` *`file`* option processes *`file`* as if `#include "file"` appeared as the first line of the primary source file. In effect, the contents of *`file`* are compiled first. Any `-D` and `-U` options on the command line are always processed before the `-include` option, regardless of the order in which they are written. All the `-include` and `-imacros` options are processed in the order in which they are written.

5.7.8.7. M: Generate Make Rule

The `-M` option tells the preprocessor to output a rule suitable for `make` that describes the dependencies of each object file.

For each source file, the preprocessor outputs one make-rule whose target is the object file name for that source file and whose dependencies are all the header files it includes. This rule may be a single line or may be continued with a backslash-newline sequence if it is lengthy.

The list of rules is printed on standard output instead of the preprocessed C program.

The `-M` option implies `-E`.

5.7.8.8. MD: Write Dependency Information To File Option

The `-MD` option writes dependency information to a file.

This option is similar to `-M` but the dependency information is written to a file and compilation continues. The file containing the dependency information is given the same name as the source file with a `.d` extension.

5.7.8.9. MF: Specify Dependency File Option

The `-MF` *`file`* option specifies a file in which to write the dependencies for the `-M` or `-MM` options. If no `-MF` option is given, the preprocessor sends the rules to the same place it would have sent preprocessed output.

When used with the driver options, `-MD` or `-MMD`, `-MF`, overrides the default dependency output file.

5.7.8.10. MG: Ignore Missing Header Files Option

The `-MG` option treats missing header files as generated files and adds them to the dependency list without raising an error.

The option assumes the missing files live in the same directory as the source file. If `-MG` is specified, then either `-M` or `-MM` must also be specified. This option is not supported with `-MD` or `-MMD`.

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5.7.8.11. MM: Generate Make Rule For Quoted Headers Option

The `-MM` option performs the same tasks as `-M`, but system headers are not included in the output.

5.7.8.12. MMD: Generate Make Rule For User Headers Option

The `-MMD` option performs the same tasks as `-MD`, but only user header files are included in the output.

5.7.8.13. MP: Add Phony Target For Dependency Option

The `-MP` option instructs the preprocessor to add a phony target for each dependency other than the main file, causing each to depend on nothing. These MP rules work around make errors if you remove header files without updating the make-file to match.

This is typical output:

```
test.o: test.c test.h
test.h:
```

5.7.8.14. MQ: Change Rule Target With Quotes Option

The `-MQ` option is similar to `-MT`, but it quotes any characters which are considered special by `make`.

```
-MQ '$(objpfx)foo.o' gives $$(objpfx)foo.o: foo.c
```

The default target is automatically quoted, as if it were given with `-MQ`.

5.7.8.15. MT: Change Rule Target Option

The `-MT` target option changes the target of the rule emitted by dependency generation.

By default, the preprocessor takes the name of the main input file, including any path, deletes any file suffix such as `.c`, and appends the platform's usual object suffix. The result is the target. An `-MT` option sets the target to be exactly the string you specify. If you want multiple targets, you can specify them as a single argument to `-MT`, or use multiple `-MT` options.

For example:

```
-MT '$(objpfx)foo.o' might give $(objpfx)foo.o: foo.c
```

5.7.8.16. Nostdinc Option

The `-nostdinc` option prevents the standard system directories for header files being searched by the preprocessor. Only the directories you have specified with `-I` options (and the current directory, if appropriate) are searched.

By using both `-nostdinc` and `-iquote`, the include-file search path can be limited to only those directories explicitly specified.

5.7.8.17. P: Don't Generate #line Directives Option

The `-P` option tells the preprocessor not to generate `#line` directives in the preprocessed output. Used with the `-E` option.

5.7.8.18. Show-column Option

The `-show-column` option will print column numbers in diagnostics. This is the default action if no option is specified.

The `-no-show-column` form of this option will not print column numbers in diagnostics. This may be necessary if diagnostics are being scanned by a program that does not understand the column numbers, such as DejaGnu.

5.7.8.19. Trigraphs Option

The `-trigraphs` option turns on support for ANSI C trigraphs. The `-ansi` option also has this effect.

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5.7.8.20. U: Undefine Macros

The `-Umacro` option undefines the macro `macro`.

Any builtin macro or macro defined using `-D` will be undefined by the option. All `-U`and `-D` options are evaluated in the same order in which they appear on the command line, but before any `-include` and `-imacros` options.

5.7.8.21. Undef Option

The `-undef` option prevents any system-specific or GCC-specific macros being predefined (including architecture flags).

5.7.9. Options for Assembling

The option tabulated below control assembler operations and is discussed in the section that follows.

Table 5-18. Assembly Options

Option	Definition
`-Wa,option`	Pass options to the assembler.

5.7.9.1. Wa: Pass Option To The Assembler, Option

The `-Wa,option` option passes its `option` argument directly to the assembler. If `option` contains commas, it is split into multiple options at the commas. For example `-Wa,-a` will pass the `-a` option to the assembler, requesting that an assembly list file be produced.

5.7.10. Options for Linking

The options tabulated below control linker operations and are discussed in the sections that follow. If any of the options `-c`, `-S` or `-E` are used, the linker will not be executed.

Table 5-19. Linking Options

Option	Definition
`-Wl,--dinit-compression=level`	Linker option that applies optimizations of the specified level to the data initialization template, which initializes objects and `ramfunc` functions in RAM.
`--fill=options`	A memory-fill option to be passed on to the linker.
`-llibrary`	Search the library named `library` when linking.
`--mchp-stdlibc=library`	Specify the standard library to use
`-nodefaultlibs`	Do not use the standard system libraries when linking.
`-mno-info-linker`	Suppresses some linker advisory messages.
`-nostdlib`	Do not use the standard system start-up files or libraries when linking.
`-nostdlib++`	Do not use the standard C++ system start-up files or libraries when linking.
`-relaxed-math`	Link in a relaxed-compliance math library.
`-s`	Remove all symbol table and relocation information from the output.
`-T script`	Specify linker script.
`-u symbol`	Add an undefined symbol that will be present at link stage.
`-Wl,option`	Pass options to the linker.
`-Xlinker option`	Pass system-specific options to the linker.

5.7.10.1. Dinit-compression Option

The `-Wl,--dinit-compression=level` option enables optimization to the specified level of the data initialization template, which initializes objects and `ramfunc`-attributed functions in RAM. See Initialize Objects and RAM Functions for more information on the operation of the data initialization template and record formats.

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When the argument *level* is set to 0, the compiler uses the unoptimized legacy .dinit format used by v4.10 and prior compilers.

Level 1 merges those initialized objects in contiguous memory under the same .dinit record.

Level 2 performs level 1 optimizations but additionally groups the same (non-zero) initial value in a record of format #2 or #3 (as described in Initialize Objects and RAM Functions), specifying respectively a single 16- or 32-bit initial value that will be copied multiple times. A format #2 record is chosen when there is a 16-bit repeated value in the initial value sequence (e.g. 0x13571357...); a format #3 record is chosen when there is a 32-bit repeated value in the initial value sequence (e.g. 0x6701238067012380...). This option adds size to runtime startup code.

Level 3 can perform any of the optimizations available in the lower levels and can additionally perform a PackBits-based run-length encoding compression to objects and ramfunc functions, storing this in record format #4. The pack-bits decompression algorithm will only be used if it saves an amount of space equal to or larger than the size of the decompression algorithm that needs to be additionally linked in; however, any repeated values initialized (as described above) might add to the size of the runtime startup routine. This is the default level if no option is specified.

5.7.10.2. Fill Option

The -fill option is used for filling unused (unspecified) memory locations in the output with a known value. The usage of this option is:

```
--fill=[wwidth:]fill_expr@address:end_address
```

where the arguments have the following meaning:

wwidth signifies the decimal width of each constant in the *fill_expr* and can range from 1 thru 9. If this width is not specified, the default value is two bytes. For example, --fill=w1:0x55@0:0xF with fill every unused byte between address 0 and 0xF with the byte value 0x55, whereas --fill=w2:0x55@0:0xF with fill every unused byte between the same addresses with the value 0x0055.

fill_expr defines the values to fill and consists of *const*, which is a base value to place in the first memory location and optionally with *increment*, which indicates how this base value should change after each use. If the base value specifies more than one byte, these are stored in little-endian byte order. These following show the possible fill expressions:

- *const* fill memory with a repeating constant; i.e., --fill=0xBEEF@0-0x1FF fills unused locations starting at address 0 with the values 0xBEEF, 0xBEEF, 0xBEEF, 0xBEEF, etc.
- *const*+=*increment* fill memory with an incrementing constant; i.e., --fill=0xBEEF+=1@0:0x1FF attempts to fills with the values 0xBEEF, 0xBEF0, 0xBEF1, 0xBEF2, etc. Note that *const* increments with each location scanned, regardless of whether that location is populated or unused.
- *const*-=*increment* fill memory with a decrementing constant; i.e.,--fill=0xBEEF-=0x10@0:0x1FF attempts to fills with the values 0xBEEF, 0xBEDF, 0xBECF, 0xBEBF, etc. Note that *const* decrements with each location scanned, regardless of whether that location is populated or unused.
- *const*,*const*,...,*const* fill memory with a list of repeating constants; i.e., --fill=0xDEAD,0xBEEF@0:0x1FF fills with 0xDEAD, 0xBEEF, 0xDEAD, 0xBEEF, etc.

@address:end_address fills a specific address range with *fill_expr*; for example, --fill=0xBEEF@0x1000:0x1001 puts the byte value 0xEF at addresses 0x1000; and --fill=0xBEEF@0xF0:0xFF puts 0xBEEF in unused addresses between 0 and 0xFF, inclusive.

5.7.10.3. L: Specify Library File Option

The -l*library* option scans the named library file for unresolved symbols when linking.

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When this option is used, the linker will search a standard list of directories for the library with the name *library*.a. The directories searched include the standard system directories, plus any that you specify with the -L option.

The linker processes libraries and object files in the order they are specified, so it makes a difference where you place this option in the command. The options (and in this order), foo.o -llibz bar.o search library libz.a after file foo.o but before bar.o. If bar.o refers to functions in libz.a, those functions may not be loaded.

Normally the files found this way are library files (archive files whose members are object files). The linker handles an archive file by scanning through it for members which define symbols that have been referenced but not defined yet. But if the file found is an ordinary object file, it is linked in the usual fashion.

The only difference between using an -l option (e.g., -lmylib) and specifying a file name (e.g., mylib.a) is that the compiler will search for a library specified using -l in several directories, as specified by the -L option.

By default the linker is directed to search <install-path>/lib for libraries specified with the -l option. This behavior can be overridden using environment variables.

See also the INPUT and OPTIONAL linker script directives.

5.7.10.4. Mchp-dinit Option

The --mchp-dinit=*type* option indicates which form of initialization will be used for data. The *type* argument can be either word, which forces the runtime startup routines to initialize memory using only word-sized and word-aligned writes, or original, which uses a regular byte-orientated intialization sequence.

Use of the --mchp-dinit=word option will issue to the linker the --word-dinit option, which is described in the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*, along with more detailed information on the word-initialization feature.

5.7.10.5. Mchp-stdlibc Option

The -mchp-stdlibc=*library* option indicates which standard C library will be linked with the project. The *library* argument can be either musl, which is the Microchip Unified Standard Library and the default selection if this option is not used, or picolibc, which has been specifically designed for smaller embedded systems with limited memory. The option aliases -mmusl and -mpicolibc can be used to indicate the default or Picolibc libraries respectively. This option must be used when both compiling and linking projects.

When using a debugging environment that supports semihosting, you can combine the Picolibc library with the semihosting library (see Semihost Option).

For more on the standard library functions, see the *Microchip Unified Standard Library Reference Guide*. Specific information on the Picolibc library can be found in Picolibc Library.

5.7.10.6. Nodefaultlibs Option

The -nodefaultlibs option will prevent the standard system libraries being linked into the project. Only the libraries you specify are passed to the linker.

The compiler may generate calls to memcmp, memset and memcpy, even when this option is specified. As these symbols are usually resolved by entries in the standard compiler libraries, they should be supplied through some other mechanism when this option is specified.

5.7.10.7. No-info-linker Option

The -mno-info-linker option suppresses some advisory messages issued by the linker. Such messages might indicate the location of the linker script being used, for example.

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5.7.10.8. Nostdlib Option

The `-nostdlib` option will prevent the standard system startup files and libraries being linked into the project. No startup files and only the libraries you specify are passed to the linker.

The compiler may generate calls to `memcmp()`, `memset()` and `memcpy()`. These entries are usually resolved by entries in standard compiler libraries. These entry points should be supplied through some other mechanism when this option is specified.

5.7.10.9. Nostdlib++ Option

The `-nostdlib++` option will prevent the standard C++ system startup files and libraries being linked into the project. No startup files and only the libraries you specify are passed to the linker.

5.7.10.10. Relaxed-math Option

The `-relaxed-math` option links in a relaxed-compliance math library.

This library provides alternative floating-point support routines that are faster and smaller than the default math routines, but make some sacrifices in compliance. For instance, it does not do all of the infinity, overflow and NaN checking, etc., of a fully-compliant library. It does not return all of the detailed feedback from that checking. However, this reduced compliance is usually sufficient for most applications.

5.7.10.11. S: Remove Symbol Information Option

The `-s` option removes all symbol table and relocation information from the output.

5.7.10.12. T: Use Linker Script Option

The `-T` *`script`* option specifies a linker script to use when linking.

Ordinarily, the linker will use a default linker script obtained from the compiler installationor when building with the `-mdfp` option, a linker script packaged in the specified device family pack (DFP). The `-T` option allows you to specify an application-specific linker script to use. The MPLAB X IDE uses this option when you add a linker script to your project.

5.7.10.13. U: Add Undefined Symbol Option

The `-u` *`symbol`* option adds an undefined symbol that will be present at the link stage. To resolve the symbol, the linker will search library modules for its definition, thus this option is useful if you want to force a library module to be linked in. It is legitimate to use this option multiple times with different symbols to force loading of additional library modules.

5.7.10.14. Wl: Pass Option To The Linker, Option

The `-Wl,`*`option`* option passes *`option`* to the linker application where it will be interpreted as a linker option. If *`option`* contains commas, it is split into multiple options at the commas. Any linker option specified will be added to the default linker options passed by the driver and these will be executed before the default options by the linker.

5.7.10.15. Xlinker Option

The `-Xlinker` *`option`* option pass *`option`* to the linker where it will be interpreted as a linker option. You can use this to supply system-specific linker options that the compiler does not know how to recognize.

5.7.11. Options for Directory Search

The options tabulated below control directories searched operations and are discussed in the sections that follow.

Table 5-20. Directory Search Options

Option	Definition
-Bprefix	This option specifies where to find executables, libraries, include files and compiler data files.

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Table 5-20. Directory Search Options (continued)

Option	Definition
`-I dir`	Add directory to search for header files.
`-Idirafter dir`	Add directory to search for header files after all other paths are exhausted.
`-Iquote dir`	Add directory to search for “quoted” header files before processing -I option directories.
`-Ldir`	Specify additional library search directories.

5.7.11.1. B: Specify Compiler Component Search Path Option

The `-Bprefix` option specifies a path where executables, libraries, include files and compiler data files can be found.

The compiler driver runs one or more of the internal applications `xc32-cpp`, `xc32-as` and `xc32-ld`. It tries *prefix* as a prefix for each application it tries to run.

For each application to be run, the compiler driver first tries adding *prefix*. If the application cannot be found, the driver searches the search paths specified by the `PATH` environment variable for the application.

If *prefix* specifies a directory name, this path also applies to libraries used by the linker, because the driver translates this into `-L` options for the linker. This also applies to include file search paths, because the compiler translates these options into `-isystem` options for the preprocessor. In this case, the compiler appends `include` to the prefix.

5.7.11.2. I: Specify Include File Search Path Option

The `-Idir` option adds the directory *dir* to the head of the list of directories to be searched for header files. A space may be present between the option and directory name.

The option can specify either an absolute or relative path and it can be used more than once if multiple additional directories are to be searched, in which case they are scanned from left to right. The standard system directories are searched after scanning the directories specified with this option.

Under the Windows OS, the use of the directory backslash character may unintentionally form an escape sequence. To specify an include file path that ends with a directory separator character and which is quoted, use `-I "E:\\"`, for example, instead of `-I "E:\"`, to avoid the escape sequence `\"`. Note that MPLAB X IDE will quote any include file path you specify in the project properties and that search paths are relative to the output directory, not the project directory.

Note: Do not use this option to specify any MPLAB XC32 system include paths. The compiler drivers automatically select the default language libraries and their respective include-file directory for you. Manually adding a system include path may disrupt this mechanism and cause the incorrect files to be compiled into your project, causing a conflict between the include files and the library. Note that adding a system include path to your project properties has never been a recommended practice.

5.7.11.3. Idirafter Option

The `-idirafter dir` option adds the directory *dir* to the list of directories to be searched for header files during preprocessing. The directory is searched only after all other search paths (including the standard search directories as well as those specified by the `-I` and `-Iquote` options) have been searched. If this option is used more than once, the directories they specify are searched in a left-to-right order as they appear on the command line.

5.7.11.4. Iquote Option

The `-iquote dir` option adds the directory *dir* to the list of directories to be searched for header files during preprocessing. Directories specified with this option apply only to the quoted form of the directive, for example `#include "file"`, and the directory is searched only after the current working directory has been searched. If this option is used more than once, the directories they specify are searched in a left-to-right order as they appear on the command line.

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5.7.11.5. L: Specify Library Search Path Option

The `-Ldir` option allows you to specify an additional directory to be searched for library files that have been specified by using the `-l` option. The compiler will automatically search standard library locations, so you only need to use this option if you are linking in your own libraries.

5.7.12. Options for Code Generation Conventions

The options tabulated below control machine-independent conventions used when generating code and are discussed in the sections that follow.

Table 5-21. Code Generation Convention Options

Option	Definition

`-fargument-alias`
`-fargument-noalias`
`-fargument-noalias-global`
	Specify the possible relationships among parameters and between parameters and global data.

`-fcall-saved-reg`	Treat *reg* as an allocatable register saved by functions.
`-fcall-used-reg`	Treat *reg* as an allocatable register that is clobbered by function calls.
`-f[no-]common`	Controls the placement of global variables defined without an initializer.
`-f[no-]exceptions`	Generate extra code to propagate exceptions.
`-ffixed-reg`	Treat*reg* as a fixed register that will not be used in code.
`-f[no-]ident`	Ignore the `#ident` directive.
`-fpack-struct`	Pack all structure members together without memory holes.
`-f[no-]pcc-struct-return`	Return short `struct` and `union` values in memory, rather than in registers.
`-f[no-]short-enums`	Specify the size of `enum` types.
`-f[no-]verbose-asm`	Put extra commentary information in the generated assembly code to make it more readable.

5.7.12.1. Argument-alias Options

This set of options specify the possible relationships among parameters, and between parameters and global data.

The `-fargument-alias` option specifies that parameters might alias each other and might alias global storage.

The `-fargument-noalias` option specifies that parameters do not alias each other, but they might alias global storage.

The `-fargument-noalias-global` option specifies that parameters do not alias each other and do not alias global storage.

Each language automatically uses the appropriate option is required by the language standard, so you should not need to use these options yourself.

5.7.12.2. Call-saved-reg Option

The `-fcall-saved-reg` option will have the compiler treat the register named *reg* as an allocatable register that is saved by functions. Functions compiled with this option in effect save and restore the specified register if they use it.

The register specified in this option might be allocated for objects or temporary objects whose duration extends over a function call.

It is an error to specify the Frame Pointer or Stack Pointer registers with this option. Use of this option to specify other registers that have fixed pervasive roles in the machine's execution model might result in code failure. The same is also true if this option specifies a register in which function values are returned.

This option should be used consistently with all project modules.

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5.7.12.3. Call-used-reg Option

The `-fcall-used-reg` option will have the compiler treat the register named *reg* as an allocatable register that is clobbered by functions. Functions compiled with this option in effect will not save and restore the specified register if they use it, meaning that the register's content might be lost.

The register specified in this option might be allocated for objects or temporary objects whose duration does not extend over a function call.

It is an error to specify the Frame Pointer or Stack Pointer registers with this option. Use of this option to specify other registers that have fixed pervasive roles in the machine's execution model might result in code failure. The same is also true if this option specifies a register in which function values are returned.

This option should be used consistently with all project modules.

5.7.12.4. Common Option

The `-fcommon` option tells the compiler to allow merging of tentative definitions by the linker.

The definition for a file-scope object without a storage class specifier or initializer is known as a tentative definition in the C standard. Such definitions are treated as external references when the `-fcommon` option is specified and will be placed in a common block. As such, if another compilation unit has a full definition for an object with the same name, the definitions are merged and storage allocated. If no full definition can be found, the linker will allocate unique memory for the object tentatively defined. Tentative definitions are thus distinct from declarations of a variable with the `extern` keyword, which never allocate storage.

In the following code example:

extra.c
```
int a = 42;  /* full definition */
```

main.c
```
int a;       /* tentative definition */
int main(void) {
  ...
}
```

The object `a` is defined in `extra.c` and tentatively defined in `main.c`. Such code will build when using the `-fcommon` option, since the linker will resolve the tentative definition for `a` with the full definition in `extra.c`.

The `-fno-common` form of this option inhibits the merging of tentative definitions by the linker, treating tentative definitions as a full definition if the end of the translation unit is reached and no definition has appeared with an initializer. This is the default action if no option is specified. Building the above code, for example, would result in a `multiple definition of 'a'` error, since the tentative definition and initialized definition would both attempt to allocate storage for the same object. If you are using this form of the option, the definition of `a` in `main.c` should be written `extern int a;` to allow the program to build.

5.7.12.5. Exceptions option

The `-fexceptions` option generates extra code needed to propagate exceptions. This option might need to be specified when compiling C code that needs to inter-operate properly with exception handlers written in C++.

The `-fno-exceptions` form of this option disables exception handling. This is the default action if no option is specified.

Ensure that the same form of this option is specified at compile time for all modules and at link time. When used additionally at link time, the option allows the linker to select a variant of the libraries that are built with C++ exceptions disabled, reducing code size.

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5.7.12.6. Fixed-reg Option

The `-ffixed-reg` option has the compiler treat the register named *reg* as a fixed register. Code generated by the compiler will never make use of this register (except in cases where the register has some fixed role, like as a Stack Pointer or Frame Pointer).

The register name can be a register number, for example `-ffixed-3` to refer to r3.

5.7.12.7. Ident option

The `-fident` option forces the compiler to process any occurrence of the `#ident` directive, which places the string constant argument to the directive into a special segment of the object file. This is the default action if no option is specified.

The `-fno-ident` form of this option forces the compiler to ignore any occurrence of this directive.

5.7.12.8. Pack-struct Option

The `-fpack-struct` option packs all structure members together without padding bytes between them. Typically, this option is not used, since the structure members might become unaligned and the code required to access them becomes sub-optimal. Additionally, the offsets of members within such structures won't agree with those for unpacked (aligned) structures in system libraries.

The `-fno-pack-struct` option chooses a structure arrangement that will produce optimal code, potentially placing padding bytes between members to ensure they are properly aligned for the device. This is the default action if no option is specified.

5.7.12.9. Pcc-struct-return Option

The `-fpcc-struct-return` option forces the compiler to return small `struct` and `union` objects (whose size and alignment match that of an integer type) in memory, rather than in registers. This convention is less efficient but allows compatibility with files compiled using other compilers.

The `-fno-pcc-struct-return` form of this option returns small `struct` and `union` objects in registers. This is the default action no option is specified.

5.7.12.10. Short-enums Option

The `-fshort-enums` option allocates the smallest possible integer type (with a size of 1, 2, or 4 bytes) to an `enum` such that the range of possible values can be held.

The `-fno-short-enums` form of this option forces each `enum` type to be 4-bytes wide (the size of the `int` type). This is the default action if no option is specified. When using this option, generated code is not binary compatible with code generated without the option.

5.7.12.11. Verbose-asm Option

The `-fno-verbose-asm` option places extra commentary information in the generated assembly code to make it more readable.

The `-fno-verbose-asm` form of this option omits this extra information and is useful when comparing two assembler files. This is the default action if no option is specified.

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6. ANSI C Standard Issues

This compiler is a freestanding implementation that conforms to the ISO/IEC 9899:1990 Standard (referred to as the C90 standard) as well the ISO/IEC 9899:1999 Standard (C99) for programming languages, unless otherwise stated.

6.1. Divergence Fom the ANSI C Standard

There are no divergences from the ANSI C standard.

6.2. Extensions to the ANSI C Standard

C/C++ code for the MPLAB XC32 C/C++ Compiler differs from the ANSI C standard in these areas: keywords, statements and expressions.

6.2.1. Keyword Differences

The new keywords are part of the base GCC implementation and the discussions in the referenced sections are based on the standard GCC documentation, tailored for the specific syntax and semantics of the 32-bit compiler port of GCC.

- Specifying Attributes of Variables – Variable Attributes
- Specifying Attributes of Functions – Function Attributes and Specifiers
- Inline Functions – Inline Functions
- Variables in Specified Registers – Variable Attributes
- Complex Numbers – Complex Data Types
- Double-Word Integers – Integer Data Types
- Referring to a Type with `typeof` – Standard Type Qualifiers

6.2.2. Statement Differences

The statement differences are part of the base GCC implementation, and the discussions in the referenced sections are based on the standard GCC documentation, tailored for the specific syntax and semantics of the 32-bit compiler port of GCC.

- Labels as Values – Labels as Values
- Conditionals with Omitted Operands – Conditional Operator Operands
- Case Ranges – Case Ranges

6.2.3. Expression Differences

Expression differences are:

Binary constants – Constant Types and Formats.

6.3. Implementation-Defined Behavior

Certain features of the ANSI C standard have implementation-defined behavior. This means that the exact behavior of some C code can vary from compiler to compiler. The exact behavior of the MPLAB XC32 C/C++ Compiler is detailed throughout this documentation, and is fully summarized in C Implementation-Defined Behavior.

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7. Device-Related Features

The MPLAB XC32 C/C++ Compiler supports a number of special features and extensions to the C/C++ language which are designed to ease the task of producing ROM-based applications. This chapter documents the special language features which are specific to these devices.

7.1. Device Support

MPLAB XC32 C/C++ Compiler aims to support all PIC32 devices. However, new devices in these families are frequently released.

7.2. Device Header Files

There is one header file that is recommended be included into each source file you write. The file is `<xc.h>` and is a generic file that will include other device-specific header files when you build your project.

Inclusion of this file will allow access to SFRs via special variables, as well as `#defineS` which allow the use of conventional register names from within assembly language files.

7.2.1. CP0 Register Definitions Header File

The CP0 register definitions header file (`cp0defs.h`) is a file that contains definitions for the CP0 registers and their fields. In addition, it contains macros for accessing the CP0 registers. These macros are defined in `cp0defs.h` so the application code should `#include <cp0defs.h>`.

The CP0 register definitions header file is located in the `pic32m/include` directory of your compiler installation directory.

Some compiler-specific header files are located in the `./lib/gcc/pic32m/<version>/include-fixed/limits.h` directory rather than in `/pic32m/include`.

The CP0 register definitions header file is automatically included when you include the generic device header file, `xc.h`.

The CP0 register definitions header file was designed to work with either Assembly or C/C++ files. The CP0 register definitions header file is dependent on macros defined within the processor generic header file.

7.3. Configuration Bit Access

The `#pragma config` directive specifies the Configuration Words to be programmed into the device running the application. This pragma can be used with either C or C++ programs.

All 32-bit target devices have several Configuration Words. The bits within these words control fundamental device operation, such as the oscillator mode, watchdog timer, programming mode and code protection. Failure to correctly set these bits may result in code failure, or a non-running device.

The `config` pragma has the following general form:

```
#pragma config setting = value
```

where *`setting`* is a configuration word bit-field name (e.g., `WDT_ENABLE`) and *`value`* can be either a textual description of the desired state (e.g., `CLEAR`) or a numerical value, as required by the setting. Multiple pragmas may be used to incrementally specify the complete device state; however, more than one comma-separated setting-value pair may be specified with each pragma.

Refer to the `PIC32ConfigSet.html` file, located in `Program Files/ Microchip/ <install-dir>/<version>/docs/PIC32ConfigSet.html` for the setting/value pairs relevant for your target device.

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Configuration settings may be specified with multiple `#pragma config` directives. The compiler verifies that the configuration settings specified are valid for the processor for which it is compiling. If a given setting in the Configuration word has not been specified in any `#pragma config` directive, the bits associated with that setting default to the unprogrammed value. Configuration settings should be specified in only a single translation unit (a C/C++ file with all of its include files after preprocessing).

For each Configuration word for which a setting is specified with the `#pragma config` directive, the compiler generates a read-only data section named `.config_address`, where *address* is the hexadecimal representation of the address of the Configuration word. For example, if a configuration setting was specified for the Configuration word located at address `0xBFC02FFC`, a read-only data section named `.config_BFC02FFC` would be created.

7.3.1. Syntax

The following shows the meta syntax notation for the different forms the pragma may take.

```
pragma-config-directive:
     # pragma config setting-list
setting-list:
     setting
   | setting-list, setting
setting:
     setting-name = value-name
```

The setting-name and value-name are device specific and can be determined by using the PIC32ConfigSet.html document located in the installation directory, docs folder.

All `#pragma config` directives should be placed outside of a function definition as they do not define executable code.

PIC32MZ config pragmas include `config_alt`, `config_bf1`, `config_abf1`, `config_bf2`, and `config_abf2` pragmas to support placing configuration bit values in the alternate, boot flash 1, alternate boot flash 1, boot flash 2, and alternate boot flash 2 PIC32MZ memory regions, respectively. (Example: `#pragma config_bf2 FWDTEN=off`)

Integer values for config pragmas can be set using the `config` and `config_region` pragmas. (Examples: `#pragma config_bf2 TSEQ = 1` and `#pragma config USERID = 0x1234u`)

7.3.2. Example

The following example shows how the `#pragma config` directive might be utilized. The example does the following:

- Enables the Watchdog Timer
- Sets the Watchdog Postscaler to 1:128
- Selects the HS Oscillator for the Primary Oscillator

```
#pragma config FWDTEN = ON, WDTPS = PS128
#pragma config POSCMOD = HS
...
int main (void)
{
...
}
```

7.4. ID Locations

User-defined ID locations are implemented in one Configuration Word. These locations should be programmed using the #pragma config directive. See Configuration Bit Access.

Example: `#pragma config USERID=0x1234`.

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7.5. Using SFRs From C Code

The Special Function Registers (SFRs) are registers which control aspects of the MCU operation or that of peripheral modules on the device. These registers are memory mapped, which means that they appear at specific addresses in the device memory map. With some registers, the bits within the register control independent features.

Memory-mapped SFRs are accessed by special C variables that are placed at the addresses of the registers and use special attributes. These variables can be accessed like any ordinary C variable so that no special syntax is required to access SFRs.

The SFR variables are predefined in header files and will be accessible once the `<xc.h>` header file (see Device Header Files) has been included into your source code. Structures are also defined by these header files to allow access to bits within the SFR.

The names given to the C variables, which map over the registers and bit variables, or bit fields, within the registers are based on the names specified in the device data sheet. The names of the structures that hold the bit fields will typically be those of the corresponding register followed by `bits`. For example, the following shows code that includes the generic header file, clears PORTB as a whole and sets bit 2 of PORTB using the structure/bit field definitions

Note: The symbols `PORTB` and `PORTBbits` refer to the same register and resolve to the same address. Writing to one register will change the values held by both.

```
#include <xc.h>
int main(void)
{
  PORTBCLR = 0xFFFFu;
  PORTBbits.RB2 = 1;
  PORTBSET= _PORTB_RB2_MASK;
}
```

For use with assembly, the `PORTB` register is declared as: `.extern PORTB`.

To confirm the names that are relevant for the device you are using, check the device specific header file that `<xc.h>` will include for the definitions of each variable. These device-specific headers are contained in the Device Family Packs (DFPs) downloaded separately (see Dfp Option); however, they should not be explicitly included into your code, as this will reduce portability. There is a one-to-one correlation between device and header file names that will be included by `<xc.h>`, for example, when compiling for a PIC32MX360F512L device, the `<xc.h>` header file will include `<proc/p32mx360f512l.h>`. Remember that you do not need to include this chip-specific file into your source code; it is automatically included by `<xc.h>`.

Some of the PIC32 SFRs have associated registers that allow the bits within the SFR to be set, cleared or toggled atomically. For example, the `PORTB` SFR has the write-only registers `PORTBSET`, `PORTBCLR` and `PORTBINV` associated with it. Writing a `'1'` to a bit location in these registers sets, clears or toggles, respectively, the corresponding bit in the `PORTB` SFR. So to set bit 1 in `PORTB`, you can use the following code:

```
PORTBSET = 0x2;
```

or alternatively, using macros provided in the device header files:

```
PORTBSET = _PORTB_RB1_MASK;
```

7.5.1. CP0 Register Definitions

When the CP0 register definitions header file is included from an Assembly file, the CP0 registers are defined as:

```
    #define _CP0_register_name $register_number, select_number
```


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For example, the `IntCtl` register is defined as:

```
#define _CP0_INTCTL $12, 1
```

When the CP0 register definitions header file is included from a C file, the CP0 registers and selects are defined as:

```
#define _CP0_register_name register_number
#define _CP0_register_name_SELECT select_number
```

For example, the `IntCtl` register is defined as:

```
#define _CP0_INTCTL 12
#define _CP0_INTCTL_SELECT 1
```

7.5.2. CP0 Register Field Definitions

When the CP0 register definitions header file is included from either an Assembly or a C/C++ file, three `#defines` exist for each of the CP0 register fields.

`_CP0_register_name_field_name_POSITION` – the starting bit location

`_CP0_register_name_field_name_MASK` – the bits that are part of this field are set

`_CP0_register_name_field_name_LENGTH` – the number of bits that this field occupies

For example, the vector spacing field of the `IntCtl` register has the following defines:

```
#define _CP0_INTCTL_VS_POSITION 0x00000005
#define _CP0_INTCTL_VS_MASK     0x000003E0
#define _CP0_INTCTL_VS_LENGTH   0x00000005
```

7.5.3. CP0 Access Macros

When the CP0 register definitions header file is included from a C file, CP0 access macros are defined. Each CP0 register may have up to six different access macros defined:

`_CP0_GET_register_name ()`	Returns the value for register, `register_name`.
`_CP0_SET_register_name (val)`	Sets the register, `register_name`, to `val`, and returns `void`. Only defined for registers that contain a writable field.
`_CP0_XCH_register_name (val)`	Sets the register, `register_name`, to `val`, and returns the previous register value. Only defined for registers that contain a writable field.
`_CP0_BIS_register_name (set)`	Sets the register, `register_name`, to (`reg |= set`), and returns the previous register value. Only defined for registers that contain writable bit fields.
`_CP0_BIC_register_name (clr)`	Sets the register, `register_name`, to (`reg &= ~clr`), and returns the previous register value. Only defined for registers that contain writable bit fields.
`_CP0_BCS_register_name (clr, set)`	Sets the register, `register_name`, to (`reg = (reg & ~clr) | set`), and returns the previous register value. Only defined for registers that contain writable bit fields.

7.5.4. Address Translation Macros

System code may need to translate between virtual and physical addresses, as well as between kernel segment addresses. The macros are defined in `sys/kmem.h` so the application code should `#include <sys/kmem.h>`. Macros are provided to make these translations easier and to determine the segment an address is in.

`KVA_TO_PA(v)`	Translate a kernel virtual address to a physical address.

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`PA_TO_KVA0(pa)`	Translate a physical address to a KSEG0 virtual address.
`PA_TO_KVA1(pa)`	Translate a physical address to a KSEG1 virtual address.
`KVA0_TO_KVA1(v)`	Translate a KSEG0 virtual address to a KSEG1 virtual address.
`KVA1_TO_KVA0(v)`	Translate a KSEG1 virtual address to a KSEG0 virtual address.
`IS_KVA(v)`	Evaluates to 1 if the address is a kernel segment virtual address, zero otherwise.
`IS_KVA0(v)`	Evaluate to 1 if the address is a KSEG0 virtual address, zero otherwise.
`IS_KVA1(v)`	Evaluate to 1 if the address is a KSEG1 virtual address, zero otherwise.
`IS_KVA01(v)`	Evaluate to 1 if the address is either a KSEG0 or a KSEG1 virtual address, zero otherwise.

7.6. Code Coverage

After purchase of the Analysis Tool Suite License (SW006027-2), the compiler's code coverage feature can be used to facilitate analysis of the extent to which a project's source code has been executed.

When enabled, this feature instruments the project's program image with small assembly sequences. When the program image is executed, these sequences record the execution of the code that they represent in reserved areas of device RAM. The records stored in the device can be later analyzed to determine which parts of a project's source code have been executed. Compiler-supplied library code is not instrumented.

When code coverage is enabled, the compiler will execute an external tool called `xc-ccov` to determine the most efficient way to instrument the project. The tool considers the program's basic blocks, which can be considered as sequences of one or more instructions with only one entry point, located at the start of the sequence and only one exit located at the end. Not all of these blocks need to be instrumented, with the tool determining the minimum set of blocks that will allow the program to be fully analyzed.

Use the `-mcodecov` option to enable code coverage in the compiler. The preprocessor macro `__CODECOV` will be defined once the feature is enabled.

All compiler options you use to build the project, when using code coverage, are significant, as these will affect the program image that is ultimately instrumented. To ensure that the analysis accurately reflects the shipped product, the build options should be the same as those that will be used for the final release build.

If code coverage is enabled, there will be 1 bit of RAM allocated per instrumented basic block, which will increase the data memory requirement of the project.

There is a small sequence of assembly instructions inserted into each instrumented basic block to set the corresponding coverage bit.

The instrumented project code must be executed for code coverage data to be generated and this execution will be fractionally slower due to the added assembly sequences. Provide the running program with input and stimulus that should exercise all parts of the program code, so that execution of all parts of the program source can be recorded.

Code coverage data can be analyzed in the MPLAB X IDE. Information in the ELF file produced by the compiler will allow the plugin to locate and read the device memory containing the code coverage results and display this in a usable format. See Microchip's Analysis Tool Suite License webpage for further information on the code coverage feature and other analysis tools.

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8. Supported Data Types and Variables

The MPLAB XC32 C/C++ Compiler supports a variety of data types and attributes. These data types and variables are discussed here. For information on where variables are stored in memory, see Memory Allocation and Access.

8.1. Identifiers

A C/C++ variable identifier (the following is also true for function identifiers) is a sequence of letters and digits, where the underscore character "_" counts as a letter. Identifiers cannot start with a digit. Although they may start with an underscore, such identifiers are reserved for the compiler's use and should not be defined by your programs. Such is not the case for assembly domain identifiers, which often begin with an underscore

Identifiers are case sensitive, so `main` is different than `Main`.

All characters are significant in an identifier, although identifiers longer than 31 characters in length are less portable.

8.2. Data Representation

The compiler stores multibyte values in little-endian format. That is, the Least Significant Byte is stored at the lowest address.

For example, the 32-bit value `0x12345678` would be stored at address `0x100` as:

Address	`0x100`	`0x101`	`0x102`	`0x103`
Data	`0x78`	`0x56`	`0x34`	`0x12`

8.3. Integer Data Types

Integer values in the compiler are represented in 2's complement and vary in size from 8 to 64 bits. These values are available in compiled code via limits.h.

Type	Bits	Min	Max
`char, signed char`	8	-128	127
`unsigned char`	8	0	255
`short, signed short`	16	-32768	32767
`unsigned short`	16	0	65535
`int, signed int, long, signed long`	32	-2^{31}	$2^{31}-1$
`unsigned int, unsigned long`	32	0	$2^{32}-1$
`long long, signed long long`	64	-2^{63}	$2^{63}-1$
`unsigned long long`	64	0	$2^{64}-1$

8.3.1. Signed and Unsigned Character Types

By default, values of type plain `char` are signed values. This behavior is implementation-defined by the C standard, and some environments (notably, PowerPC) define a plain C/C++ `char` value to be unsigned. The command line option `-funsigned-char` can be used to set the default type to unsigned for a given translation unit.

8.3.2. `limits.h`

The `limits.h` header file defines the ranges of values which can be represented by the integer types.

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Macro Name	Value	Description
CHAR_BIT	8	The size, in bits, of the smallest non-bit field object.
SCHAR_MIN	-128	The minimum value possible for an object of type `signed char`.
SCHAR_MAX	127	The maximum value possible for an object of type `signed char`.
UCHAR_MAX	255	The maximum value possible for an object of type `unsigned char`.
CHAR_MIN	-128 (or 0, see Signed and Unsigned Character Types)	The minimum value possible for an object of type `char`.
CHAR_MAX	127 (or 255, see Signed and Unsigned Character Types)	The maximum value possible for an object of type `char`.
MB_LEN_MAX	16	The maximum length of multibyte character in any locale.
SHRT__MIN	-32768	The minimum value possible for an object of type `short int`.
SHRT_MAX	32767	The maximum value possible for an object of type `short int`.
USHRT_MAX	65535	The maximum value possible for an object of type `unsigned short int`.
INT_MIN	-2^{31}	The minimum value possible for an object of type `int`.
INT_MAX	$2^{31}-1$	The maximum value possible for an object of type `int`.
UINT_MAX	$2^{32}-1$	The maximum value possible for an object of type `unsigned int`.
LONG_MIN	-2^{31}	The minimum value possible for an object of type `long`.
LONG_MAX	$2^{31}-1$	The maximum value possible for an object of type `long`.
ULONG_MAX	$2^{32}-1$	The maximum value possible for an object of type `unsigned long`.
LLONG_MIN	-2^{63}	The minimum value possible for an object of type `long long`.
LLONG_MAX	$2^{63}-1$	The maximum value possible for an object of type `long long`.
ULLONG_MAX	$2^{64}-1$	The maximum value possible for an object of type unsigned `long long`.

8.4. Floating-Point Data Types

The compiler uses 32- and 64-bit forms of the IEEE-754 floating-point format to store floating-point values. The implementation limits applicable to a translation unit are contained in the `float.h` header.

Important: Some target PIC32M devices implement a Floating-point Unit (FPU). The compiler implements certain features, described in this guide, to support this hardware.

The table below shows the data types and their corresponding size and arithmetic type.

Type	Bits
float	32

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Floating-Point Data Types (continued)	
Type	**Bits**
`double`	64
`long double`	64

Variables may be declared using the `float`, `double` and `long double` keywords, respectively, to hold values of these types. Floating-point types are always signed and the `unsigned` keyword is illegal when specifying a floating-point type. All floating-point values are represented in little endian format with the Least Significant Byte (LSB) at the lower address.

This format is described in the table below, where:

- Sign is the sign bit which indicates if the number is positive or negative.
- For 32-bit floating-point values, the exponent is 8 bits which is stored as excess 127 (i.e., an exponent of 0 is stored as 127).
- For 64-bit floating-point values, the exponent is 11 bits which is stored as excess 1023 (i.e., an exponent of 0 is stored as 1023).
- Mantissa is the mantissa, which is to the right of the radix point. There is an implied bit to the left of the radix point which is always 1 except for a zero value, where the implied bit is zero. A zero value is indicated by a zero exponent.

The value of this number for 32-bit floating-point values is:

$(-1)^{sign} \times 2^{(exponent-127)} \times 1.$ mantissa

and for 64-bit values

$(-1)^{sign} \times 2^{(exponent-1023)} \times 1.$ mantissa.

In the following table, examples of the 32- and 64-bit IEEE 754 formats are shown. Note that the Most Significant bit of the mantissa column (that is, the bit to the left of the radix point) is the implied bit, which is assumed to be 1 unless the exponent is zero (in which case the float number is zero).

Table 8-1. Floating-Point Format Example IEEE 754

Format	Number	Biased Exponent	1.mantissa	Decimal
32-bit	0x7DA6B69C	11111011b (251)	1.01001101011011010011100b (1.3024477959)	2.770000117e+37 —
64-bit	0x47B4D6D37131A DE	10001111011b (1147)	1.0100110101101101001101110001001100011010011011011110b (1.3024477407110946)	2.77e+37 —

The example in the table can be calculated manually as follows.

The sign bit is zero; the biased exponent is 251, so the exponent is 251-127=124. Take the binary number to the right of the decimal point in the mantissa. Convert this to decimal and divide it by 2^{23} where 23 is the number of bits taken up by the mantissa, to give 0.302447676659. Add 1 to this fraction. The floating-point number is then given by:

$-1^{0} \times 2^{124} \times 1.302447676659$

which becomes:

$1 \times 2.126764793256e+37 \times 1.302447676659$

which is approximately equal to:

2.77000*e*+37

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Binary floating-point values are sometimes misunderstood. It is important to remember that not every floating-point value can be represented by a finite-sized floating-point number. The size of the exponent in the number dictates the range of values that the number can hold, and the size of the mantissa relates to the spacing of each value that can be represented exactly. Thus the 64-bit floating-point format allows for values with a larger range of values and that can be more accurately represented.

So, for example, if you are using a 32-bit wide floating-point type, it can exactly store the value 95000.0. However, the next highest number it can represent is (approximately) 95000.00781 and it is impossible to represent any value in between these two in such a type as it will be rounded. This implies that C/C++ code which compares floating-point type may not behave as expected. For example:

```
volatile float myFloat;
myFloat = 95000.006;
if(myFloat == 95000.007) // value will be rounded
   LATA++;               // this line will be executed!
```

in which the result of the `if()` expression will be true, even though it appears the two values being compared are different.

The characteristics of the floating-point formats are described by macros defined in `<float.h>` and which are described in the *Microchip Unified Standard Library Reference Guide*.

8.5. Structures and Unions

MPLAB XC32 C/C++ Compiler supports `struct` and `union` types. Structures and unions only differ in the memory offset applied to each member.

These types will be at least 1 byte wide. Bit fields are fully supported.

Structures and unions may be passed freely as function arguments and function return values. Pointers to structures and unions are fully supported.

8.5.1. Structure and Union Qualifiers

The MPLAB XC32 C/C++ Compiler supports the use of type qualifiers on structures. When a qualifier is applied to a structure, all of its members will inherit this qualification. In the following example the structure is qualified `const`.

```
const struct {
        int number;
        int *ptr;
} record = { 0x55, &i };
```

In this case, the entire structure will be placed into the program memory and each member will be read-only. Remember that all members are usually initialized if a structure is `const` as they cannot be initialized at runtime.

If the members of the structure were individually qualified `const`, but the structure was not, then the structure would be positioned into RAM, but each member would be read-only. Compare the following structure with the above.

```
struct {
        const int number;
        int * const ptr;
} record = { 0x55, &i};
```

8.5.2. Bit Fields in Structures

MPLAB XC32 C/C++ Compiler fully supports bit fields in structures.

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Bit fields are always allocated within 8-bit storage units, even though it is usual to use the type `unsigned int` in the definition. Storage units are aligned on a 32-bit boundary, although this can be changed using the `packed` attribute.

The first bit defined will be the Least Significant bit of the word in which it will be stored. When a bit field is declared, it is allocated within the current 8-bit unit if it will fit; otherwise, a new byte is allocated within the structure. Bit fields can never cross the boundary between 8-bit allocation units. For example, the declaration:

```
struct {
        unsigned        lo : 1;
        unsigned        dummy : 6;
        unsigned        hi : 1;
} foo;
```

will produce a structure occupying 1 byte.

Unnamed bit fields may be declared to pad out unused space between active bits in control registers. For example, if `dummy` is never referenced, the structure above could have been declared as:

```
struct {
        unsigned        lo : 1;
        unsigned           : 6;
        unsigned        hi : 1;
} foo;
```

A structure with bit fields may be initialized by supplying a *comma*-separated list of initial values for each field. For example:

```
struct {
        unsigned        lo  : 1;
        unsigned        mid : 6;
        unsigned        hi  : 1;
} foo = {1, 8, 0};
```

Structures with unnamed bit fields may be initialized. No initial value should be supplied for the unnamed members, for example:

```
struct {
        unsigned        lo  : 1;
        unsigned            : 6;
        unsigned        hi  : 1;
} foo = {1, 0};
```

will initialize the members `lo` and `hi` correctly.

The MPLAB XC compiler supports anonymous unions. These are unions with no identifier and whose members can be accessed without referencing the enclosing union. These unions can be used when placing inside structures. For example:

```
struct {
        union {
        int x;
        double y;
    };
} aaa;

int main(void)
{
    aaa.x = 99;
    // ...}
```

Here, the union is not named and its members accessed as if they are part of the structure. Anonymous unions are not part of any C Standard and so their use limits the portability of any code.

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8.6. Pointer Types

There are two basic pointer types supported by the MPLAB XC32 C/C++ Compiler: data pointers and function pointers. Data pointers hold the addresses of variables which can be indirectly read, and possible indirectly written, by the program. Function pointers hold the address of an executable function which can be called indirectly via the pointer.

8.6.1. Combining Type Qualifiers and Pointers

It is helpful to first review the ANSI C/C++ standard conventions for definitions of pointer types.

Pointers can be qualified like any other C/C++ object, but care must be taken when doing so as there are two quantities associated with pointers. The first is the actual pointer itself, which is treated like any ordinary C/C++ variable and has memory reserved for it. The second is the target, or targets, that the pointer references, or to which the pointer points. The general form of a pointer definition looks like the following:

*target_type_&_qualifiers * pointer's_qualifiers pointer's_name;*

Any qualifiers to the right of the `*` (that is, next to the pointer's name) relate to the pointer variable itself. The type and any qualifiers to the left of the `*` relate to the pointer's targets. This makes sense since it is also the `*` operator that dereferences a pointer, which allows you to get from the pointer variable to its current target.

Here are three examples of pointer definitions using the `volatile` qualifier. The fields in the definitions have been highlighted with spacing:

```
volatile int *          vip ;
int          * volatile  ivp ;
volatile int * volatile  vivp ;
```

The first example is a pointer called `vip`. It contains the address of `int` objects that are qualified `volatile`. The pointer itself — the variable that holds the address — is *not* `volatile`; however, the objects that are accessed when the pointer is dereferenced are treated as being `volatile`. In other words, the target objects accessible via the pointer may be externally modified.

The second example is a pointer called `ivp` which also contains the address of `int` objects. In this example, the pointer itself is `volatile`, that is, the address the pointer contains may be externally modified; however, the objects that can be accessed when dereferencing the pointer are not `volatile`.

The last example is of a pointer called `vivp` which is itself qualified `volatile`, and which also holds the address of `volatile` objects.

Bear in mind that one pointer can be assigned the addresses of many objects; for example, a pointer that is a parameter to a function is assigned a new object address every time the function is called. The definition of the pointer must be valid for every target address assigned.

Note: Care must be taken when describing pointers. Is a "const pointer" a pointer that points to `const` objects, or a pointer that is `const` itself? You can talk about "pointers to const" and "const pointers" to help clarify the definition, but such terms may not be universally understood.

8.6.2. Data Pointers

Pointers in the compiler are all 32 bits in size. These can hold an address which can reach all memory locations.

8.6.3. Function Pointers

The MPLAB XC compiler fully supports pointers to functions, which allows functions to be called indirectly. These are often used to call one of several function addresses stored in a user-defined C/C++ array, which acts like a lookup table.

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Function pointers are always 32 bits in size and hold the address of the function to be called.

Any attempt to call a function with a function pointer containing NULL will result in an ifetch Bus Error.

8.6.4. Special Pointer Targets

Pointers and integers are not interchangeable. Assigning an integer constant to a pointer will generate a warning to this effect. For example:

```
const char * cp = 0x123; // the compiler will flag this as bad code
```

There is no information in the integer constant, 0x123, relating to the type or size of the destination. This code is also not portable and there is a very good chance of code failure if pointers are assigned integer addresses and dereferenced, particularly for PIC® devices that have more than one memory space.

Always take the address of a C/C++ object when assigning an address to a pointer. If there is no C/C++ object defined at the destination address, then define or declare an object at this address which can be used for this purpose. Make sure the size of the object matches the range of the memory locations that can be accessed.

For example, a checksum for 1000 memory locations starting at address `0xA0001000` is to be generated. A pointer is used to read this data. You may be tempted to write code such as:

```
int * cp;
cp = 0xA0001000;  // what resides at 0xA0001000???
```

and increment the pointer over the data. A much better solution is this:

```
int * cp;
int __attribute__((address(0xA0001000))) inputData [1000];
cp = &inputData;
// cp is incremented over inputData and used to read values there
```

In this case, the compiler can determine the size of the target and the memory space. The array size and type indicates the size of the pointer target.

Take care when comparing (subtracting) pointers. For example:

```
if(cp1 == cp2)
  ; take appropriate action
```

The ANSI C standard only allows pointer comparisons when the two pointer targets are the same object. The address may extend to one element past the end of an array.

Comparisons of pointers to integer constants are even more risky, for example:

```
if(cp1 == 0xA0000100)
  ; take appropriate action
```

A NULL pointer is the one instance where a constant value can be assigned to a pointer and this is handled correctly by the compiler. A NULL pointer is numerically equal to 0 (zero), but this is a special case imposed by the ANSI C standard. Comparisons with the macro `NULL` are also allowed.

8.7. Complex Data Types

Complex data types are currently not implemented in MPLAB XC32 C/C++ Compiler.

8.8. Constant Types and Formats

A constant is used to represent a numerical value in the source code, for example 123 is a constant. Like any value, a constant must have a C/C++ type. In addition to a constant's type, the actual value can be specified in one of several formats. The format of integral constants specifies their radix.

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MPLAB XC32 C/C++ supports the ANSI standard radix specifiers as well as ones which enables binary constants to be specified in C code.

The formats used to specify the radices are given in the table below. The letters used to specify binary or hexadecimal radices are case insensitive, as are the letters used to specify the hexadecimal digits.

Table 8-2. Radix Formats

Radix	Format	Example
binary	`0b` *number* or `0B` *number*	0b10011010
octal	`0` *number*	0763
decimal	*number*	129
hexadecimal	`0x` *number* or `0X` *number*	0x2F

Any integral constant will have a type of `int`, `long int` or `long long int`, so that the type can hold the value without overflow. Constants specified in octal or hexadecimal may also be assigned a type of `unsigned int`, `unsigned long int` or `unsigned long long int` if the signed counterparts are too small to hold the value.

The default types of constants may be changed by the addition of a suffix after the digits, for example, `23U`, where `U` is the suffix. The table below shows the possible combination of suffixes and the types that are considered when assigning a type. For example, if the suffix `l` is specified and the value is a decimal constant, the compiler will assign the type `long int`, if that type will hold the constant; otherwise, it will assigned `long long int`. If the constant was specified as an octal or hexadecimal constant, then unsigned types are also considered.

Table 8-3. Suffixed and Assigned Types

Suffix	Decimal	Octal or Hexadecimal

`u` or `U`	`unsigned int`
	`unsigned long int`
	`unsigned long long int`
		`unsigned int`
		`unsigned long int`
		`unsigned long long int`

`l` or `L`	`long int`
	`long long int`
		`long int`
		`unsigned long int`
		`long long int`
		`unsigned long long int`

`u` or `U`, and `l` or `L`	`unsigned long int` `unsigned long long int`	`unsigned long int` `unsigned long long int`
`ll` or `LL`	`long long int`	`long long int` `unsigned long long int`
`u` or `U`, and `ll` or `LL`	`unsigned long long int`	`unsigned long long int`

Here is an example of code that may fail because the default type assigned to a constant is not appropriate:

```
unsigned long int result;
unsigned char shifter;

int main(void)
{
    shifter = 40;
    result = 1 << shifter;
    // code that uses result
}
```

The constant `1` will be assigned an `int` type hence the result of the shift operation will be an `int` and the upper bits of the `long` variable, `result`, can never be set, regardless of how much

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the constant is shifted. In this case, the value 1 shifted left 40 bits will yield the result 0, not 0x10000000000.

The following uses a suffix to change the type of the constant, hence ensure the shift result has an `unsigned long` type.

```
result = 1UL << shifter;
```

Floating-point constants have `double` type unless suffixed by `f` or `F`, in which case it is a `float` constant. The suffixes `l` or `L` specify a `long double` type.

Character constants are enclosed by single quote characters, `'`, for example `'a'`. A character constant has `int` type, although this may be optimized to a `char` type later in the compilation.

Multi-byte character constants are accepted by the compiler but are not supported by the standard libraries.

String constants, or string literals, are enclosed by double quote characters `" "`, for example `"hello world"`. The type of string constants is `const char *` and the character that make up the string are stored in the program memory, as are all objects qualified `const`.

To comply with the ANSI C standard, the compiler does not support the extended character set in characters or character arrays. Instead, they need to be escaped using the backslash character, as in the following example:

```
const char name[] = "Bj\370rk";
printf("%s's Resum\351", name); \\ prints "Bjørk's Resumé"
```

Assigning a string literal to a pointer to a non-`const char` will generate a warning from the compiler. This code is legal, but the behavior if the pointer attempts to write to the string will fail. For example:

```
char * cp= "one";          // "one" in ROM, produces warning
const char * ccp= "two";   // "two"  in ROM, correct
```

Defining and initializing a non-const array (i.e., not a pointer definition) with a string,

```
char ca[]= "two"; // "two" different to the above
```

is a special case and produces an array in data space which is initialized at start-up with the string `"two"` (copied from program space), whereas a string constant used in other contexts represents an unnamed `const` -qualified array, accessed directly in program space.

The MPLAB XC32 C/C++ Compiler will use the same storage location and label for strings that have identical character sequences. For example, in the code snippet

```
if(strncmp(scp, "hello world", 6) == 0)
    fred = 0;
if(strcmp(scp, "hello world") == 0)
    fred++;
```

the two identical character string greetings will share the same memory locations. The link-time optimization must be enabled to allow this optimization when the strings may be located in different modules.

Two adjacent string constants (that is, two strings separated *only* by white space) are concatenated by the compiler. Thus:

```
const char * cp = "hello"  "world";
```

will assign the pointer with the address of the string `"hello world"`.

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8.9. Standard Type Qualifiers

Type qualifiers provide additional information regarding how an object may be used. The MPLAB XC32 C/C++ Compiler supports both standard C qualifiers and additional, special qualifiers that are useful for embedded applications and that take advantage of the PIC32M architecture.

8.9.1. Const Type Qualifier

The `const` type qualifier is used to tell the compiler that an object is read only and must not be modified. The compiler will issue a warning or error if you attempt to modify an object declared `const` in source code.

A `const` object is usually defined with initial values, as the program cannot write to these objects at runtime. However this is not a requirement. An uninitialized `const` object is allocated space in one of the bss sections, along with other uninitialized RAM variables, but is still treated as read-only by the compiler.

```
const char IOtype = 'A';  // initialized const object
const char buffer[10];    // I just reserve memory in RAM
```

Objects qualified only with `const` are not guaranteed to be located in program memory. The use of some options can affect where `const`-qualified object are located. Objects qualified `const` might be placed in data memory when the `-fzero-initialized-in-bss`, `-fdata-sections`, or `-mno-embedded-data` options are used. To explicitly request that the object be placed in program memory regardless of the usage of the options listed, use the `space(prog)` attribute along with the `const` qualifier (see Variables in Program Memory).

8.9.2. Volatile Type Qualifier

The `volatile` type qualifier is used to tell the compiler that an object cannot be guaranteed to retain its value between successive accesses. This prevents the optimizer from eliminating apparently redundant references to objects declared `volatile` because it may alter the behavior of the program to do so.

Any SFR which can be modified by hardware or which drives hardware is qualified as `volatile` and any variables which may be modified by interrupt routines should use this qualifier as well. For example:

```
extern volatile unsigned int WDTCON __attribute__((section("sfrs")));
```

The `volatile` qualifier does not guarantee that any access will be atomic, but the compiler will try to implement this.

The code produced by the compiler to access `volatile` objects may be different than that to access ordinary variables and typically the code will be longer and slower for `volatile` objects, so only use this qualifier if it is necessary. However, failure to use this qualifier when it is required may lead to code failure.

Another use of the `volatile` keyword is to prevent variables from being removed if they are not used in the C/C++ source. If a non-`volatile` variable is never used, or used in a way that has no effect on the program's function, then it may be removed before code is generated by the compiler.

A C/C++ statement that consists only of a `volatile` variable's name will produce code that reads the variable's memory location and discards the result. For example the entire statement:

```
PORTB;
```

will produce assembly code that reads `PORTB`, but does nothing with this value. This is useful for some peripheral registers that require reading to reset the state of interrupt flags. Normally such a statement is not encoded as it has no effect.

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8.10. Variable Attributes

The compiler keyword `__attribute__` allows you to specify special attributes of variables or structure fields. This keyword is followed by an attribute specification inside double parentheses.

To specify multiple attributes, separate them by commas within the double parentheses, for example:

```
__attribute__ ((aligned (16), packed)).
```

Note: It is important to use variable attributes consistently throughout a project. For example, if a variable is defined in file A with the `aligned` attribute, and declared `extern` in file B without `aligned`, then a link error may result.

8.10.1. Address Variable Attribute

The `address(addr)` attribute specifies an absolute virtual address for the variable. This attribute can be used in conjunction with a section attribute.

Note: For a data variable on a target device without an L1 cache, the address is typically in the range [0xA0000000,0xA00FFFFC], as defined in the linker script as the `kseg1_data_mem` region. For data variables on a target feature an L1 data cache, the address is typically in the range [0x80000000,0x800FFFFC] as defined in the linker script as the `kseg0_data_mem` region. Take special care to use the correct kseg region for your device or more than one variable might be allocated to the same physical address.

The `address` attribute can be used to start a group of variables at a specific address:

```
int foo __attribute__((section("mysection"),address(0xA0001000)));
int bar __attribute__((section("mysection")));
int baz __attribute__((section("mysection")));
```

Keep in mind that the compiler performs no error checking on the specified address. The section will be located at the specified address regardless of the memory-region ranges listed in the linker script or the actual ranges on the target device. This application code is responsible for ensuring that the address is valid for the target device and application.

Also, be aware that variables attributed with an absolute address are not accessed via GP-relative addressing. This means that they may be more expensive to access than non-address attributed variables.

Sections used to hold objects placed at an absolute address will use a name `.address.`*`N`*`.`*`decl`*, where *`N`* is the address and *`decl`* is the name of the declaration.

In addition, to make effective use of absolute sections and the best-fit allocator, standard program-memory and data-memory sections should not be mapped in the linker script. The built-in linker script does not map most standard sections such as the `.text`, `.data`, `.bss`, or `.ramfunc` section. By not mapping these sections in the linker script, we allow these sections to be allocated using the best-fit allocator rather than the sequential allocator. Sections that are unmapped in the linker script can flow around absolute sections whereas sections that are linker-script mapped are grouped together and allocated sequentially, potentially causing conflicts with absolute sections.

Finally, note that “small” data and bss (`.sdata`, `.sbss`, etc.) sections are still mapped in the built-in default linker script. This is because “small” data variables must be grouped together so that they are within range of the more efficient GP-relative addressing mode. *To avoid conflict with these linker-script mapped sections, choose high addresses for your absolute-address variables.*

Note: In almost all cases, you will want to combine the address attribute with the space attribute to indicate code or data with `space(prog)` or `space(data)`, respectively. Also, see the description for the attribute `space`.

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8.10.2. Alias Variable Attribute

The `alias ("symbol")` attribute indicates that the variable is an alias for another symbol. For example:

```
int var_target;
extern int __attribute__ ((alias ("var_target"))) var_alias;
```

defines `var_alias` to be an alias for the `var_target` variable.

It is an error if the alias target is not defined in the same translation unit as the alias.

8.10.3. Aligned Variable Attribute

The `aligned (n)` attribute instructs the compiler to align the variable on the next `n` byte boundary.

The `aligned` attribute can also be used on a structure member. Such a member will be aligned to the indicated boundary within the structure.

If the alignment value *n* is omitted, the alignment of the variable is set 8 (the largest alignment value for a basic data type).

Note that the `aligned` attribute is used to increase the alignment of a variable, not reduce it. To decrease the alignment value of a variable, use the `packed` attribute.

8.10.4. Cleanup Variable Attribute

The `cleanup (function)` attribute indicates the name of a function that the compiler must call when the attributed object goes out of scope. This would be useful to ensure that allocated memory is freed or that an object's contents has been scrubbed before the program proceeds or terminates.

The attribute must be applied only to automatic objects. It must not be used with function parameters or with any objects that have static storage duration. The *function* argument must be the name of a function; it cannot be a function pointer. The function indicated in the attribute must take one parameter, that being a pointer to a type compatible with the object. The return value of the function (if one is specified) will be ignored.

Where multiple objects in the same scope specify `cleanup` attributes, their associated cleanup functions are run in the reverse order to that in which the objects were defined (that is, the object defined last in the source will have its cleanup function executed first).

For example, the following shows two automatic objects using the attribute. The functions `cleanUp_string()` will be called when `main()` exits and `str` goes out of scope, then the `cleanUp_int()` function will be called to process the value held by `myVar`.

```
void cleanUp_int(int * dirty) {
  *dirty = 0x55;
}
void cleanUp_string(char ** dirty) {
  free(* dirty);
}

int main(void) {
  int myVar __attribute__ ((cleanup(cleanUp_int))) = 1;
  char * str __attribute__ ((cleanup(cleanUp_string))) = NULL;

  str = (char *)malloc((sizeof(char)) * 100);
  fillCmd(str);
  while (*str++) {
    process(myVar);
  }

  return 0;
}
```

If the `-fexceptions` option is in effect, the nominated cleanup function is guaranteed to execute and do soif variables go out of scope during the stack unwinding that happens when processing the

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exception. Note that the `cleanup` attribute does not allow the exception to be caught; it only allows an action to be performed. It is undefined what occurs if the *`function`* does not return normally.

8.10.5. Coherent Variable Attribute

The `coherent` variable attribute causes the compiler/linker to place the variable into a unique section that is allocated to the kseg1 region, rather than the kseg0 region (which is the default on L1 cached devices). This means that the variable is accessed through an uncached address.

For devices featuring an L1 data cache, data variables are allocated to the kseg0 data-memory region (`kseg0_data_mem`), making it accessible through the L1 cache. Likewise, the linker-allocated heap and stack are allocated to the kseg0 region.

The `coherent` variable attribute that allows you to create a DMA buffer allocated to the kseg1_data_mem region:

```
unsigned int __attribute__((coherent)) buffer [1024];
```

When combining the `coherent` attribute with the `address` attribute, be sure to use the default data-memory region address for the device. On devices featuring an L1 data cache, the default data-memory region is kseg0_data_mem:

```
unsigned int __attribute__((coherent,address(0x80001000))) buffer[1024]
```

The `__pic32_alloc_coherent(size_t)` and `__pic32_free_coherent(void *)` functions allocate and free memory from the uncached kseg1_data_mem region. The default stack is allocated to the cached kseg0_data_mem region, but you may want to create an uncached DMA buffer, so you can use these functions to allocate an uncached buffer. These functions call the standard `malloc()/free()` functions, but the pointers that they use are translated from kseg0 to kseg1. For example:

```
#include<xc.h>
void jak(void) {
   char * buffer = __pic32_alloc_coherent(1024);
   if (buffer) {
     /* do somehing */
   } else {
     /* handle error */
   }
   if (buffer) {
     __pic32_free_coherent(buffer);
   }
}
```

Important: When allocating uncached storage in this way, it is the user's responsibility to ensure that the storage obtained will not share a cache line with other data items that may be cached. Failing to do so can cause data corruption.

To avoid having cached and uncached data on the same cache line, you can, for example, allocate 16 bytes (one cache line) more than required, then create a new pointer and assign it this address rounded up to the next 16 byte boundary. Use the new pointer to read/write data, and use the original pointer when you want to free the space. For example:

```
mytype *p1, *p2;

 p1 = __pic32_calloc_coherent (sizeof(mytype) + 16);
 uintptr_t addr = (uintptr_t)p1;
 uintptr_t aligned_addr = (addr + 15) & ~((uintptr_t)15);
 p2 = (mytype *)aligned_addr;
```


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8.10.6. Copy Variable Attribute

The `copy` attribute is used to apply a set of attributes to a variable. This set is derived from the attributes applied to the variable specified as the argument to the `copy` attribute. This is particularly useful in libraries that define aliases, ensuring that the aliases have the same attributes as the original symbols. It's important to note that the `copy` attribute only duplicates syntactic and semantic attributes. It does not copy attributes that influence a symbol's linkage or visibility, such as `alias` or `weak`. Additionally, the `deprecated` attribute is not copied. For example:

```
int __attribute__((persistent))input;
int __attribute__((copy(input)))output;
```

8.10.7. Deprecated Variable Attribute

The `deprecated (msg)` attribute instructs the compiler to issue a warning if the variable is used. The optional `msg` argument, which must be a string, will be printed in the warning, if present.

8.10.8. Externally_visible Variable Attribute

The `externally_visible` attribute when used with a global object nullifies the effect of the `-fwhole-program` command-line option, so the object remains visible outside the current compilation unit. This might prevent certain optimizations from being performed on the object.

8.10.9. Noload Variable Attribute

The `noload` attribute causes the variable or function to be placed in a section that has the `noload` attribute set. This attribute tells consumers of the ELF file not to load the contents of the section. This attribute can be useful when you just want to reserve memory for something, but you don't want to clear or initialize memory.

8.10.10. Packed Variable Attribute

The `packed` attribute instructs the compiler to use the smallest possible alignment with the variable or structure member. That is, no alignment padding storage will be allocated for the declaration. Used in combination with the `aligned` attribute, `packed` can be used to set an arbitrary alignment restriction greater or lesser than the default alignment for the type of the variable or structure member.

8.10.11. Persistent Variable Attribute

The `persistent` attribute specifies that the variable should not be initialized or cleared at startup. Use a variable with the `persistent` attribute to store state information that will remain valid after a device Reset. For example:

```
int last_mode __attribute__((persistent));
```

The `persistent` attribute typically causes the compiler to place the variable in the `.pbss` section, which does not get cleared by the default runtime startup code; however, that might not be the case if the object is defined using other attributes. For example, use of either the `address` or `section` attributes in addition to `persistent` will place the object in sections with different names. Because the section used for `persistent` objects must be placed in data space, this attribute is not compatible with the `space` attribute. The `persistent` attribute implies the `coherent` attribute. That is, `persistent` attributed variables are accessed via the uncached address. The `const` qualifier can be used with the `persistent` attribute provided the object is not initialized. Any attempt to initialize such an object will result in a warning and the initial value ignored.

8.10.12. Section Variable Attribute

The `section ("section-name")` attribute places the variable into the named section.

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For example,

```
unsigned int dan __attribute__ ((section (".quixote")))
```

will place the variable `dan` will be placed in section `.quixote`.

The `-fdata-sections` command line option has no effect on variables defined with a `section` attribute unless `unique_section` is also specified.

8.10.13. Space Variable Attribute

The `space(`*`memory-space`*`)` attribute can be used to direct the compiler to allocate a variable in a specific memory space. Valid memory spaces are `prog` for program memory, `data` for data memory, and `serial_mem` for serial memory such as SPI Flash. The `data` space is the default space for non-const variables.

The `prog`, `data`, and `serial_mem` spaces normally correspond to the `kseg0_prog_mem`, `ksegN_data_mem`, and `serial_mem` memory regions, respectively, as specified in the default device-specific linker scripts.

This attribute also controls how initialized data is handled. The linker generates an entry in the data-initialization template for the default `space(data)`. But, it does not generate an entry for `space(prog)` or `space(serial_mem)`, since the variable is located in non-volatile memory. Typically, this means that `space(data)` applies to variables that will be initialized at runtime startup; while `space(prog)` and `space(serial_mem)` apply to variables that will be programmed by an in-circuit programmer or a bootloader.

For example:

```
const unsigned int __attribute__((space(prog))) jack = 10;
const unsigned int __attribute__((space(serial_mem))) zori = 1;
signed int __attribute__((space(data))) oz = 5;
```

8.10.14. Uninitialized Variable Attribute

The `uninitialized` attribute is used with objects having automatic storage duration and indicates to the compiler that the object should not be automatically initialized when the option `-ftrivial-auto-var-init` is in effect.

The `-ftrivial-auto-var-init` option forces all automatic variables that do not have explicit initializers to be assigned a value by the compiler. These additional compiler initializations can incur a significant run-time overhead. Use this attribute to exclude selected objects from this initialization, in order to reduce runtime overhead. This attribute has no effect when the `-ftrivial-auto-var-init` option has not been specified.

8.10.15. Unique_section Variable Attribute

The `unique_section` attribute places the variable in a uniquely named section, just as if `-fdata-sections` had been specified. If the variable also has a `section` attribute, use that section name as the prefix for generating the unique section name.

For example,

```
int tin __attribute__ ((section (".ofcatfood"), unique_section)
```

will place the variable `tin` in section `.ofcatfood`.

8.10.16. Unused Variable Attribute

The `unused` attribute indicates to the compiler that the variable might not be used. The compiler will not issue a warning for this variable if it is not used.

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8.10.17. Used Variable Attribute

The `used` attribute indicates to the compiler that the object is always used and storage must be allocated for the object, even if the compiler cannot see a reference to it. For example, if inline assembly is the only reference to an object.

8.10.18. Weak Variable Attribute

The `weak` attribute causes the declaration to be emitted as a weak symbol. A weak symbol indicates that if a global version of the same symbol is available, that version should be used instead.

When `weak` is applied to a reference to an external symbol, the symbol is not required for linking. For example:

```
extern int __attribute__((weak)) s;
int foo() {
  if (&s) return s;
  return 0; /* possibly some other value */
}
```

In the above program, if `s` is not defined by some other module, the program will still link but `s` will not be given an address. The conditional verifies that `s` has been defined (and returns its value if it has). Otherwise `'0'` is returned. There are many uses for this feature, mostly to provide generic code that can link with an optional library.

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9. Memory Allocation and Access

There are two broad groups of RAM-based variables: auto/parameter variables, which are allocated to some form of stack, and global/static variables, which are positioned freely throughout the data memory space. The memory allocation of these two groups is discussed separately in the following sections.

9.1. Address Spaces

Unlike the 8- and 16-bit PIC devices, the PIC32 has a unified programming model. PIC32 devices provide a single 32-bit wide address space for all code, data, peripherals and Configuration bits.

Memory regions within this single address space are designated for different purposes; for example, as memory for instruction code or memory for data. Internally the device uses separate buses* to access the instructions and data in these regions, thus allowing for parallel access. The terms program memory and data memory, which are used on the 8- and 16-bit PIC devices, are still relevant on PIC32 devices, but the smaller parts implement these in different address spaces.

All addresses used by the CPU within the device are virtual addresses. These are mapped to physical addresses by the system control processor (CP0).

* The device can be considered a Harvard architecture in terms of its internal bus arrangement.

9.2. Variables in Data Memory

Most variables are ultimately positioned into the data memory. The exceptions are non-`auto` variables which are qualified as `const`, which are placed in the program memory space, see Const Type Qualifier.

Due to the fundamentally different way in which auto variables and non-`auto` variables are allocated memory, they are discussed separately. To use the C/C++ language terminology, these two groups of variables are those with automatic storage duration and those with permanent storage duration, respectively.

Note: The terms “local” and “global” are commonly used to describe variables, but are not ones defined by the language standard. The term “local variable” is often taken to mean a variable which has scope inside a function, and “global variable” is one which has scope throughout the entire program. However, the C/C++ language has three common scopes: block, file (that is, internal linkage) and program (that is, external linkage), so using only two terms to describe these can be confusing. For example, a `static` variable defined outside a function has scope only in that file, so it is not globally accessible, but it can be accessed by more than one function inside that file, so it is not local to any one function either. In terms of memory allocation, variables are allocated space based on whether it is an `auto` or not, hence the grouping in the following sections.

9.2.1. Non-Auto Variable Allocation

Non-`auto` variables (those with permanent storage duration) are located by the compiler into any of the available data banks. This is done in a two-stage process: placing each variable into an appropriate section and later linking that section into data memory.

The compiler considers three categories of non-`auto` variable which all relate to the value the variable should contain by the time the program begins. The following sections are used for the categories described.

- `.pbss` - These sections are used to store variables which use the `persistent` attribute, whose values should not be altered by the runtime start-up code. They are not cleared or otherwise modified at start-up.
- `.bss` - These sections (also `.sbss`) contain any uninitialized variables, which are not assigned a value when they are defined, or variables which should be cleared by the runtime start-up code.

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- `.data` - These sections (also `.sdata`) contain the RAM image of any initialized variables, which are assigned a non-zero initial value when they are defined and which must have a value copied to them by the runtime start-up code.

Note that the data section used to hold initialized variables is the section that holds the RAM variables themselves. There is a corresponding section (called `.dinit`) that is placed into program memory (so it is non-volatile) and which is used to hold the initial values that are copied to the RAM variables by the runtime start-up code.

9.2.2. Static Variables

All `static` variables have permanent storage duration, even those defined inside a function which are "local static" variables. Local `static` variables only have scope in the function or block in which they are defined, but unlike `auto` variables, their memory is reserved for the entire duration of the program. Thus, they are allocated memory like other non-`auto` variables. Static variables may be accessed by other functions via pointers, since they have permanent duration.

Variables which are `static` are guaranteed to retain their value between calls to a function, unless explicitly modified via a pointer.

Variables which are `static` and initialized have their initial value assigned only once during the program's execution. Thus, they may be preferable over initialized `auto` objects which are assigned a value every time the block they are defined in begins execution. Any initialized static variables are initialized in the same way as other non-`auto` initialized objects by the runtime start-up code, see Peripheral Library Functions. Static variables are located in the same sections as their non-`static` counterparts.

9.2.3. Non-Auto Variable Size Limits

Arrays of any type (including arrays of aggregate types) are fully supported by the compiler. So too are the structure and union aggregate types, see Structures and Unions. There are no theoretical limits as to how large these objects can be made.

9.2.4. Changing the Default Non-Auto Variable Allocation

There are several ways in which non-`auto` variables can be located in locations other than the default.

Variables can be placed in other device memory spaces by the use of qualifiers. For example if you wish to place variables in the program memory space, then the `const` specifier should be used (see Const Type Qualifier).

If you wish to prevent all variables from using one or more data memory locations so that these locations can be used for some other purpose, it is best to define a variable (or array) using the `address` attribute so that it consumes the memory space, see Variable Attributes .

If only a few non-`auto` variables are to be located at specific addresses in data space memory, then the variables can be located using the `address` attribute. This attribute is described in Variable Attributes.

9.2.5. Data Memory Allocation Macros

The `sys/attribs.h` header file provides many macros for commonly used attributes in order to enhance code readability.

`__section__(s)`	Apply the `section` attribute with section name `s`.
`__unique_section__`	Apply the `unique_section` attribute.
`__ramfunc__`	Locate the attributed function in the RAM function code section.
`__longramfunc__`	Locate the attributed function in the RAM function code section and apply the `longcall` attribute.

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`__longcall__`	Apply the `longcall` attribute.
`__ISR(v,ipl)`	Apply the `interrupt` attribute with priority level `ipl` and the `vector` attribute with vector number `v`.
`__ISR_AT_VECTOR(v,ipl)`	Apply the interrupt attribute with priority level `ipl` and the `at_vector` attribute with vector number `v`. This macro is especially useful on PIC32 devices that feature variable vector offsets.
`__ISR_SINGLE__`	Specifies a function as an Interrupt Service Routine in single-vector mode. This places a jump at the single-vector location to the interrupt handler.
`__ISR_SINGLE_AT_VECTOR__`	Places the entire single-vector interrupt handler at the vector 0 location. When used, ensure that the vector spacing is set to accommodate the size of the handler.

9.3. Auto Variable Allocation and Access

This section discusses allocation of `auto` variables (those with automatic storage duration). This also includes function parameter variables, which behave like `auto` variables, as well as temporary variables defined by the compiler.

The `auto` (short for *automatic*) variables are the default type of local variable. Unless explicitly declared to be `static`, a local variable will be made `auto`. The `auto` keyword may be used if desired.

The `auto` variables, as their name suggests, automatically come into existence when a function is executed, then disappear once the function returns. Since they are not in existence for the entire duration of the program, there is the possibility to reclaim memory they use when the variables are not in existence and allocate it to other variables in the program.

The software stack of the PIC32 is used to store all `auto` variables. Functions are reentrant and each instance of the function has its own area of memory on the stack for its auto and parameter variables, as described below. See Software Stack andInitialize Stack Pointer and Heap for more information on the stack.

The compiler dedicates General Purpose Register 29 as the software Stack Pointer. All processor stack operations, including function call, interrupts and exceptions use the software stack. The stack grows downward from high addresses to low addresses.

By default, the size of the stack is 1024 bytes. The size of the stack may be changed by specifying the size on the linker command line using the `--defsym_min_stack_size` linker command line option. An example of allocating a stack of 2048 bytes using the command line is:

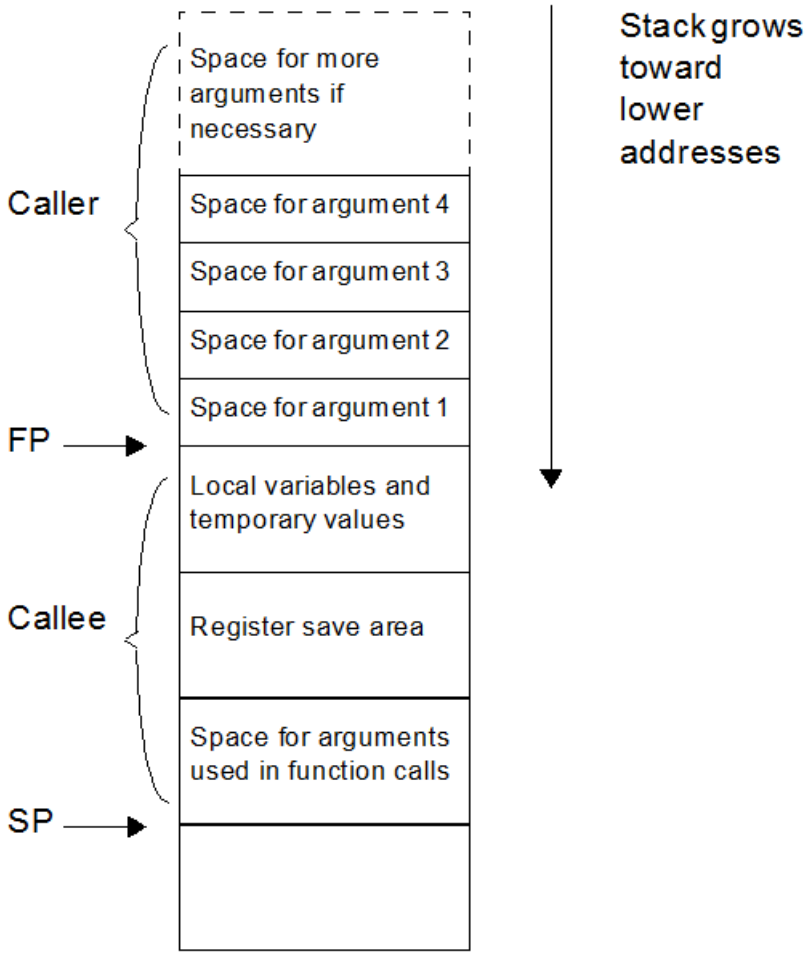
```
xc32-gcc foo.c -Wl,--defsym,_min_stack_size=2048
```

The run-time stack grows downward from higher addresses to lower addresses (see the figure below). The compiler uses two working registers to manage the stack:

- Register 29 (`sp`) – This is the Stack Pointer. It points to the next free location on the stack.
- Register 30 (`fp`) – This is the Frame Pointer. It points to the current function's frame. Each function, if required, creates a new frame from which automatic and temporary variables are allocated. Compiler optimization may eliminate Stack Pointer references via the Frame Pointer to equivalent references via the Stack Pointer. This optimization allows the Frame Pointer to be used as a General Purpose Register.

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Figure 9-1. Stack Frame



The the standard qualifiers const and volatile may both be used with auto variables and these do not affect how they are positioned in memory. This implies that a local const-qualified object is still an auto object and, as such, will be allocated memory on the stack in the data memory, not in the program memory like with non-auto const objects.p

Local Variable Size Limits

There is no theoretical maximum size for auto variables.

9.4. Variables in Program Memory

To have objects placed into program memory, which is Flash memory on most target devices, they should be qualified `const` and additionally use the `space(prog)` attribute, for example:

```
const int __attribute__((space(prog))) const_symbol;
```

This combination places the object *`const_symbol`* into a `.text` section rather than a `.rodata` section. You still need to use the `space(prog)` attribute even if you are also using a `section()` attribute. Failure to use the `const` specifier with the `space(prog)` attribute will result in a compilation error: `space("prog") object 'symbol' should be const qualified`.

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Without the `space(prog)` attribute, some options can affect where objects only qualified with `const` are located, so both the attribute and qualifier should be used to ensure the objects are located in program memory. (See also Const Type Qualifier.)

9.4.1. Size Limitations of `const` Variables

There is no theoretical maximum size for const variables.

9.4.2. Changing the Default Allocation

If you only intend to prevent all variables from using one or more program memory locations so that you can use those locations for some other purpose, you are best reserving the memory using the memory adjust options.

If only a few non-auto `const` variables are to be located at specific addresses in program space memory, then the variables should use the `address` attribute to locate them at the desired location. This attribute is described in Address Variable Attribute.

9.5. Variable in Registers

Allocating variables to registers, rather than to a memory location, can make code more efficient. With MPLAB XC32 C/C++ Compiler, variables may be allocated to registers as part of code optimizations. For optimization levels 1 and higher, the values assigned to variables may cached in a register. During this time, the memory location associated with the variable may not hold a valid value.

The `register` keyword may be used to indicate your preference for the variable to be allocated a register, but this is just a recommendation and may not be honored. The specific register may be indicated as well, but this is not recommended as your register choice may conflict with the needs of the compiler. Using a specific register in your code may cause the compiler to generate less efficient code.

As indicated in Function Parameters, parameters may be passed to a function via a register.

Example 9-1. Variables in Registers

```
volatile unsigned int special;
unsigned int example (void)
{
  register unsigned int my_reg __asm__("$4");
  my_reg += special;
  return my_reg;
}
```

9.6. Application-Defined Memory Regions

On occasion, an application may require a new memory region that was not defined in the default device-specific linker scripts. One such case may be when using external memory connected to the External Bus Interface (EBI) on a PIC32MZ target device.

One way to handle adding a new memory region would be to create a custom linker script, add the new memory region, and explicitly map your sections to the new region. Another way to add a new memory region would be to add an application-defined memory region to your C/C++ source code. Some applications may even choose to combine a custom linker script and an application-defined memory region.

9.6.1. Advantages of an Application-Defined Memory Region

Using an application-defined memory region in source code can provide a few advantages over adding a memory region to a custom linker script.

- Portability: An application-defined memory region can help reduce the need for a custom linker script. This can be beneficial because you can use the device's default linker script and thereby

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avoid potential migration issues between XC32 versions, as well as between different PIC32 variants.

- Best-Fit Allocation: Region-attributed variables and functions are handled by the linker's best-fit allocator, as described in the *MPLAB XC32 Assembler, Linker, and Utilities User's Guide* (DS50002186). Sections mapped to a new region in a custom linker script must be explicitly mapped using the `SECTIONS` command and are allocated sequentially.

9.6.2. Advantages of a Linker Script-Defined Memory Region

Using a custom linker script with a new memory region can also provide advantages over an application-defined memory region.

- Update memory mapping at link time: A custom linker script allows you to easily switch between different memory mappings without rebuilding your C/C++ code.
- Standard GNU Binutils: A user migrating from another toolchain based on GNU Binutils may already be familiar and comfortable with creating new memory regions in a custom linker script. XC32 supports this standard mechanism.

9.6.3. Using an Application-Defined Memory Region

To use this feature, work through the following sections.

Define a New Memory Space

The XC32 tool suite requires information about each memory region. In order for the XC32 linker to be able to properly assign memory, you must specify information about the size of the memory region available and the origin of the memory region.

Define an application-defined memory region, with the origin and the size, using the '**region**' pragma as shown below.

```
#pragma region name=name origin=address size=bytes
```

where *name* is a quoted string containing the name of the region, *address* is the starting address of the region, and *bytes* is the size in bytes of the region.

Example 9-2. Defining a New Memory Space

```
#pragma region name="ext_mem" origin=0xC0000000 size=0x1000
```

In this example, we define an application-defined memory region to be used for external memory. We name the region `"ext_mem"` and specify that the starting address is `0xC0000000` and that it has a size of `0x1000` bytes. Consult your PIC32 device data sheet for information about the external-memory interface options and the memory mappings available on your device.

Define Variables within a Region

When you have defined a new memory region, you can then assign a variable to that region. Use the region attribute on a variable to specify that it should be allocated to the specified region. This requires the memory region definition to be present. Given the definition in the previous subsection, you can make the following variable definition:

```
int ext_array[256] __attribute__((region("ext_mem")));
```

ext_array will be allocated in the previously declared region **"ext_mem"**.

Once the variable has been defined with the region attribute, it may be accessed using normal C syntax.

When called with the `--report-mem` linker command-line option, the linker prints a summary of memory usage to `stdout`. If the `-Map` linker command-line option was specified, the memory summary will also be printed in the map file. When the application-defined memory region is used,

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the length of each section allocated to a region and the total memory used for each region is displayed.

Define Functions within a Region

You can also use the region attribute to assign individual functions to the region. This requires the memory region definition to be present. Given the definition in the previous subsection, you can make the following function definition:

```
int  __attribute__((far, region("ext_mem"))) foo()
{
   ext_array[2] = ext_array[0] + ext_array[1] ;
   return 0;
}
```

Use the region attribute with the far attribute to allocate the function in our example `"ext_mem"` region. In this case, we need the `far` attribute because the address of our `"ext_mem"` region is located outside of the 256 MB segment of our default program-memory region, `kseg0_program_mem`, as defined in our default linker script. Using the `far` attribute tells the compiler to generate a long call.

Initializing Memory Interfaces

When your application-defined memory region corresponds to an external-memory interface such as the Serial Quad Interface (SQI) or External Bus Interface (EBI), you will likely need to configure the interface module. For instance, the EBI module must be configured to understand such things as the type, size, and bus width of each attached device. See the device data sheet and the family reference manual for your target device.

The default XC32 runtime start-up code uses a linker-generated data-initialization template placed in a section named .dinit (see Initialize Objects and RAM Functions). For variables or functions placed in an application-defined memory region, the application must execute any memory-interface configuration code before the runtime start-up code attempts to initialize these variables or functions.

The default runtime start-up code provides an `_on_reset()` weak hook. This routine is called after initializing a minimum 'C' context, but before data initialization. You can provide your memory-interface configuration code in this hook. See The "On Reset" Routine for more information on this important hook.

Example 9-3. Hardware Init Before Data Init

```
/* The _on_reset() function will be called by the default
   runtime start-up code prior to data initialization. */
void _on_reset (void)
{
  /*  Call a function that configures the EBI control
      registers for the target board. */
  configure_ebi_sram();
}
```

On some target devices, your application may also need to enable the Memory Management Unit (MMU) and initialize the Translation Lookaside Buffer (TLB). On many devices, the XC32 toolchain provides a default mapping suitable for the SQI and EBI interfaces. See your target device data sheet for information on default memory mapping that is specific to your target device. For devices where a default SQI and EBI mapping is provided, you can override the default mapping by providing your own `__pic32_tlb_init_ebi_sqi()` function.

The source code for this is found in the pic32m-libs.zip file located at:

`<install-directory>/pic32-libs/`

Once the file is unzipped, the source code can be found at:

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`pic32m-libs/libpic32/stubs/pic32_init_tlb_ebi.S`.

The following sections provide example cases using the application-defined memory region feature.

Example 9-4. Case 1

Variables can be placed in external memory by using the region attribute.

```
#pragma region name="ext_mem" origin=0x0xC0000000 size=0x1000

signed int   ea1  __attribute__((region("ext_mem")));
unsigned int ea2  __attribute__((region("ext_mem")));

signed int   eb1[10]  __attribute__((region("ext_mem"))) = {10,20};
signed long  eb2[10]  __attribute__((region("ext_mem"))) =
                                        {0x987654321, 0x12345678};
```

Example 9-5. Case 2

Functions can be placed in external memory by using the region attribute. Since functions default to `space(prog)`, the function is assumed to be programmed into the region and will not be initialized by the runtime start-up code.

```
#pragma region name="ext_flash" origin=0xC0000000 size=0x1000

int ea1 __attribute__((region("ext_flash"))) ;
int eb1 __attribute__((region("ext_flash"))) = 0x1000 ;
int ec1 __attribute__((region("ext_flash"))) = 0x2000 ;

void __attribute__((region("ext_flash"))) foo()
{
    ea1 = eb1 + ec1 ;
}

void main()
{
    foo();
}
```

Apply the `far` attribute to `foo()`, since it is out of range of the default `kseg0_program_mem` region. Alternatively, use `-mlong-calls` option to compile the above example.

Example 9-6. Case 3

Combine the region attribute with the space (data) attribute to indicate that the function code should be initialized by the runtime start-up code's data initialization template. In this case, the code for the function is contained in the data-initialization template and copied to the memory region at startup.

```
#pragma region name="myebi_sram"  origin=0xC0004000  size=0x100
void __attribute__((far,space(data),region("myebi_sram"))) fn_in_sram()
{ /* Code here */ }
```

Example 9-7. Case 4

Combine the region attribute with the address() attribute to place a variable at an absolute address within the region.

```
#pragma region name="myebi_2"  origin=0xC0001000  size=0x10
```


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```
unsigned long __attribute__((region("myebi_2"),address(0xC0001000))) paws =
0xAAAABBBB;
```

9.7. Dynamic Memory Allocation

Dynamic memory allocation is the runtime allocation of uninitialized memory for arbitrary-sized data objects by various standard C library dynamic memory management functions that are explicitly called by the programmer (such as `calloc`, `malloc` and `realloc`) along with the C++ `new` operator. The memory for the objects is allocated from a region of reserved memory, usually called the heap. Memory allocated in this way can be freed for reuse by calling additional library routines (such as `free`) or the C++ `delete` operator, although indiscriminate use of this feature can lead to memory fragmentation.

There are two `libc` implementations of dynamic memory allocation available, allowing the programmer to select between a reduced code footprint or better memory management. These implementations can be selected using the `-mmalloc-variant=`*`scheme`* option.

Lite allocation uses a simple algorithm for allocating and freeing chunks of memory from the heap, resulting in a smaller code footprint and almost no runtime overhead. However, memory can easily fragment when allocating and subsequently freeing memory chunks in this way. This dynamic memory allocation implementation is selected when using the `-mmalloc-variant=lite` option or when this option has not been specified.

Binned allocation maintains free (unallocated) chunks of memory in bins, grouped by size. Algorithms are used to search for suitable memory chunks within the bins when requested. This algorithm adds some runtime overhead but overcomes many of the memory fragmentation problems associated with other schemes. The binned form of dynamic memory allocation will be utilized when using the `-mmalloc-variant=binned` option has been specified.

By default, no heap is used. If your program uses dynamic memory allocation, you must set aside memory to use as the heap. Most C++ applications will require a heap. In MPLAB X, you can specify a heap size in the **xc32-ld (32-Bit Linker)** category in the **Project Properties** dialog. MPLAB X will automatically pass the option to the linker when building your project. Alternatively, a heap can be created by specifying its size using the `--defsym=_min_heap_size` linker command line option. An example of allocating a heap of 512 bytes using the command line is:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" foo.c
-Wl,--defsym=_min_heap_size=512
```

An example of allocating a heap of `0xF000` bytes using the xc32-g++ driver is:

```
xc32-g++ -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150"
vector.cpp -Wl,--defsym=_min_heap_size=0xF000
```

The linker allocates the heap immediately before the stack.

9.8. Memory Models

MPLAB XC32 C/C++ Compiler does not use fixed memory models to alter allocation of variables to memory.

The `-G` option (see Options Specific to PIC32M Devices), which controls the gp-relative addressing threshold, is similar to the small-data/large-data/scalar-data memory models offered by the Microchip compilers for the 8- and 16-bit architectures. The value specified with this option indicates the maximum size of objects that will be allocated to the small data sections, for example, `sbss`, `sdata`, etc. Variables allocated to the small-data sections require fewer instructions to access than variables allocated to the other data sections. For example:

```
xc32-gcc -G128 -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150"
main.c
```


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In this example, data objects up to 128 bytes in size will be located in the efficient small-data or small-bss section.

In general larger `-G` values result in more efficient code. However, gp-relative addressing is limited to 64-KB of small data.

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10. Floating-point Support

Some PIC32M devices implement a 1985 IEEE-754 compliant Floating-point Unit (FPU) that supports single and double precision data types.

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11. Fixed-Point Arithmetic Support

The MPLAB XC32 C/C++ Compiler supports fixed-point arithmetic. This, according to ISO/IEC TR 18037:2008//the N1169 draft of ISO/IEC TR 18037, the ISO C99 technical report on Embedded C. It is available at [via]: http://www.open-std.org/JTC1/SC22/WG14/www/projects#18037. or standards.iso.org/ittf/PubliclyAvailableStandards/c051126_ISO_IEC_TR_18037_2008.zip

This chapter describes the implementation-specific details of the types and operations supported by the compiler under this draft standard.

Because of the sensitivity of DSP applications to performance, application developers have historically tended to write functions in assembly. However, the XC32 compiler reduces, and may even eliminate, the need to write assembly code. This chapter describes coding styles and usage tips that can help you to obtain the best optimizations for your DSP application.

Several Microchip PIC32 MCUs feature a DSP-enhanced core with four 64-bit accumulators. The DSP-enhanced core also provides a set of new instructions and a new architectural state, with computational support for fractional data types, SIMD (Single Instruction, Multiple Data), saturation, and other operations commonly used in DSP applications.

Note: Consult the data sheet for your specific target device to determine whether your target device supports the DSP-enhanced core.

11.1. Enabling Fixed-Point Arithmetic Support

Fixed-point arithmetic support is enabled by default by the MPLAB XC32 C/C++ compiler, allowing use of built-in fixed-point types, literals and operators. The `<stdfix.h>` header may be included to provide convenient definitions as described in Data Types.

The compiler automatically enables support for the DSP-enhanced core when you are compiling for an appropriate PIC32 target device as selected by the `-mprocessor` option.

11.2. Data Types

All 12 of the primary fixed-point types and their aliases, described in Section 4.1 “Overview and principles of the fixed-point data types” of ISO/IEC TR 18037:2008, are supported. Fixed-point data values contain fractional and optional integral parts. The format of fixed-point data in XC32 are as specified in the table below.

In the formats shown, `s` is the sign bit for a signed type (there is no sign bit for an unsigned type). The period character (`.`) is the specifier that separates the integral part and the fractional part. The numeric digits represent the number of bits in the integral part or in the fractional part.

Table 11-1. Fixed Point Formats

Type	Format	Description
`short _Fract`	s0.7	1 sign bit, no integer bits, 7 fractional bits
`unsigned short _Fract`	0.8	8 fractional bits only
`_Fract`	s0.15	1 sign bit, 15 fractional bits
`unsigned _Fract`	0.16	16 fractional bits only
`long _Fract`	s0.31	1 sign bit, no integer bits, 31 fractional bits
`unsigned long _Fract`	0.32	32 fractional bits only
`long long _Fract`	s0.63	1 sign bit, no integer bits, 63 fractional bits
`unsigned long long _Fract`	0.64	64 fractional bits only
`short _Accum`	s8.7	1 sign bit, 8 integer bits, 7 fractional bits

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Table 11-1. Fixed Point Formats (continued)

Type	Format	Description
`unsigned short _Accum`	8.8	8 integer bits, 8 fractional bits
`_Accum`	s16.15	1 sign bit, 16 integer bits, 15 fractional bits
`unsigned _Accum`	16.16	16 integer bits, 16 fractional bits
`long _Accum`	s32.31	1 sign bit, 32 integer bits, 31 fractional bits
`unsigned long _Accum`	32.32	32 integer bits, 32 fractional bits
`long long _Accum`	s32.31	1 sign bit, 32 integer bits, 31 fractional bits
`unsigned long long _Accum`	32.32	32 integer bits, 32 fractional bits

The `_Sat` type modifier may be used with any type in the above table to indicate that values are saturated, as described in ISO/IEC TR 18037:2008. For example, `_Sat short _Fract` is the saturating form of `short _Fract`. Signed types saturate at the most negative and positive numbers representable in the corresponding format. Unsigned types saturate at zero and the most positive number representable in the format.

The MPLAB XC32 C compiler provides an include file, `stdfix.h`, which provides various pre-processor macros related to fixed-point support. These include those show in the following table.

<stdfix.h> alias	Type
`fract`	`_Fract`
`accum`	`_Accum`
`sat`	`_Sat`

Usage example:

```
#include <stdfix.h>
void main () {
  int i;
  fract a[5] = {0.5,0.4,0.2,0.0,-0.1};
  fract b[5] = {0.1,0.8,0.6,0.5,-0.1};
  accum dp = 0;
  /* Calculate dot product of a[] and b[] */
  for (i=0; i<5; i++) {
      dp += a[i] * b[i];
  }
}
```

The default behavior of overflow on signed or unsigned types is saturation. The pragmas described in Section 4.1.3 "Rounding and Overflow" of ISO/IEC TR 18037:2008 to control the rounding and overflow behavior are not supported.

The following table describes the fixed-point literal suffixes supported to form fixed-point literals of each type.

Table 11-2. Fixed-Point Literal Suffixes

Type	Suffixes
`short _Fract`	`hr, HR`
`unsigned short _Fract`	`uhr, UHR`
`_Fract`	`r, R`
`unsigned _Fract`	`ur, UR`
`long _Fract`	`lr, LR`
`unsigned long _Fract`	`ulr, ULR`
`long long _Fract`	`llr, LLR`

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Table 11-2. Fixed-Point Literal Suffixes (continued)

Type	Suffixes
unsigned long long _Fract	ullr, ULLR
short _Accum	hk, HK
unsigned short _Accum	uhk, UHK
_Accum	k, K
unsigned _Accum	uk, UK
long _Accum	lk, LK
unsigned long _Accum	ulk, ULK
long long _Accum	llk, LLK
unsigned long long _Accum	ullk, ULLK

11.3. Fixed-point Library Functions

The fixed-point functions described in Section 4.1.7 in ISO/IEC TR 18037:2008 (rounding, conversion functions, etc.) are not provided in the current MPLAB XC32 standard C libraries.

11.4. Integer Representations

The Q15 data type can be represented by the 16-bit integer data type (`short`) and the Q31 data type can be represented by the 32-bit integer data type (`int`). These types are necessary when using the compiler's DSP built-in functions (see Built-in Functions). Typedefs are useful for Q15 and Q31 as follows:

```
typedef short q15;
typedef int q31;
```

The four 64-bit accumulators in the DSP-enhanced core can be represented by the `long long int` data type.

```
typedef long long int a64;
```

To initialize Q15 variables, multiply the fractional value (for example, 0.1234) by `0x1.0p15`. To initialize Q31 variables, programmers can multiply the fractional value by `0x1.0p31`.

```
Ex: /* Q15 Example  */
typedef short q15;
q15 a = 0.1234 * 0x1.0p15;

/* ------------------------------------------------------- */
Ex: /* Q31 Example  */
typedef int q31;
q31 b = 0.2468 * 0x1.0p31;
```

11.5. SIMD Variables

The 8-bit unsigned integer data and Q15 fractional data are packed in a single 32-bit register, and the new instructions operate simultaneously on the multiple data in the register in Single Instruction, Multiple Data (SIMD) fashion. This feature provides computation parallelism for increased application performance.

You can directly take advantage of SIMD parallelism by declaring SIMD data types as described here. In addition, the compiler may automatically take advantage of SIMD parallelism using auto-vectorization as described in the Auto-vectorization section below.

To declare SIMD data types, typedefs with special `vector_size` attributes are required. For example,

```
typedef signed char v4i8 __attribute__ ((vector_size(4)));
typedef signed char v4q7 __attribute__ ((vector_size(4)));
```


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```
typedef short v2i16 __attribute__ ((vector_size(4)));
typedef short v2q15 __attribute__ ((vector_size(4)));
```

`v4i8`, `v4q7`, `v2i16`, and `v2q15` are SIMD data types that consist of 4, 4, 2, and 2 elements of 8 bits, 8 bits, 16 bits, and 16 bits respectively in a single variable/register.

SIMD data types are powerful and can be applied to fixed-point data types as well. For example:

```
typedef _Sat unsigned short _Fract
  sat_v4uqq __attribute__ ((vector_size(4)));
typedef _Sat unsigned _Fract
  sat_v2uhq __attribute__ ((vector_size(4)));
typedef _Sat unsigned short _Accum
  sat_v2uha __attribute__ ((vector_size(4)));
typedef _Sat _Fract
  sat_v2hq __attribute__ ((vector_size(4)));
typedef _Sat short _Accum
  sat_v2ha __attribute__ ((vector_size(4)));
```

To initialize SIMD variables is similar to initializing aggregate data. The following examples show how to initialize SIMD variables.

Example:

```
/* v4i8 Example */
v4i8 a = {1, 2, 3, 4};
v4i8 b;
b = (v4i8) {5, 6, 7, 8};
/* ------------------------------------------------------ */
Ex: /* v2q15 Example */
v2q15 a = {0x0fcb, 0x3a75};
v2q15 b;
b = (v2q15) {0.1234 * 32768.0, 0.4567 * 32768.0};
```

Data is stored from the right-to-left location of a register. For the example of v4i8 a = {1, 2, 3, 4}, the register stores 1, 2, 3, and 4 from the right-to-left location as shown below.

a[3]=4	a[2]=3	a[1]=2	a[0]=1

Bit 31 Bit 0

Most arithmetic operations will simply work on the SIMD operands in the register irrespective of their right-to-left location within the register. However, you must be aware of such instructions that directly refer to the left or right portions of a register. For example, `MAQ_SA.W.PHL`.

11.6. Accessing Elements in SIMD Variables

The use of SIMD variables enables operations on multiple data in parallel. However, in certain situations, programmers need to access elements inside a SIMD variable. This can be done by using a union type that unites a SIMD type and an array of a basic type as follows.

```
typedef union
{
  v4i8 a;
  unsigned char b[4];
} v4i8_union;
typedef short q15;
typedef union
{
  v2q15 a;
  q15 b[2];
} v2q15_union;
```

As shown in the figure above for a `v4i8` variable, `b[0]` is used to access the first element in the variable. The element `b[0]` is right-most position. The following examples show how to extract or assign elements.

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Example:

```
/* v4i8 Example */
 v4i8 i;
 unsigned char j, k, l, m;
 v4i8_union temp;
 /* Assume we want to extract from i.  */
 temp.a = i;
 j = temp.b[0];
 k = temp.b[1];
 l = temp.b[2];
 m = temp.b[3];
/* Assume we want to assign j, k, l, m to i.  */
 temp.b[0] = j;
 temp.b[1] = k;
 temp.b[2] = l;
 temp.b[3] = m;
 i = temp.a;
 /* ------------------------------------------------------- */
```

Example:

```
/* v2q15 Example  */
 v2q15 i;
 q15 j, k;
 v2q15_union temp;
 /* Assume we want to extract from i.  */
 temp.a = i;
 j = temp.b[0];
 k = temp.b[1];
 /* Assume we want to assign j, k to i.  */
 temp.b[0] = j;
 temp.b[1] = k;
 i = temp.a;
```

Using SIMD data types is a very powerful technique. Programmers can enjoy the performance improvement from SIMD data types by calling the DSP built-in functions (see Built-in Functions) and/or using generic C operators. For SIMD data types, the compiler can map C operators (e.g., +, -, *, /) to hardware instructions directly, so long as the selected target PIC32 MCU features the DSP-enhanced core.

Note: In many cases, optimization level -O1 or greater may be required to optimize the code to use the SIMD instruction.

Here are some examples:

```
 typedef signed char v4i8 __attribute__ ((vector_size(4)));
 v4i8 a, b, c;
 c = a + b; // compiler generates addu.qb
 c = a - b; // compiler generates subu.qb
 /* ------------------------------------------------------- */
 typedef short v2q15 __attribute__ ((vector_size(4)));
 v2q15 d, e, f;
 f = d + e; // compiler generates addq.ph
 f = d - e; // compiler generates subq.ph
 /* ------------------------------------------------------- */
 typedef short v2i16 __attribute__ ((vector_size(4)));
 v2i16 x, y, z;
 z = x * y; // compiler generates mul.ph
 /* ------------------------------------------------------- */
 typedef _Sat _Fract sat_v2hq __attribute__ ((vector_size(4)));
 sat_v2hq a, b, c;
 c = a + b; // compiler generates addq_s.ph
 c = a - b; // compiler generates subq_s.ph
 c = a * b; // compiler generates mulq_rs.ph
```

Note: When char or short data elements are packed into SIMD data types, the first data must be aligned to 32 bits; otherwise, the unaligned memory accesses may generate general exceptions or decrease performance.

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11.7. Array Alignment and Data Layout

The compiler provides a mechanism to specify the alignment of variables by using `__attribute__ ((aligned (bytes)))`. The alignment is important to loading or storing SIMD variables: "`v4i8`" and "`v2q15`". If an array is aligned to a 4-byte boundary, that is, word-aligned, the compiler can load or store four 8-bit data for `v4i8` variables (or two 16-bit data for `v2q15` variables) at a time using the load word class of instructions. The following example shows that when a char array A is aligned to a 4-byte boundary, we can cast this array to a `v4i8` array and load four items to a `v4i8` variable at a time by using the `lwx` instruction. However, if this char array A is not aligned to a 4-byte boundary, executing the following code will result in an address exception due to a mis-aligned load.

Example:

```
/* v4i8 Example */
   char A[128] __attribute__ ((aligned (4)));
   v4i8 test (int i)
   {
     v4i8 a;
     v4i8 *myA = (v4i8 *)A;
     a = myA[i];
     return a;
   }
 # Illustrative generated assembly with optimizations
 test:
   lui     $2,%hi(A)
   sll     $4,$4,2
   addiu   $2,$2,%lo(A)
   lwx      $2,$2($4)
   j       $31
```

After SIMD data is loaded from memory into a register, ensure that the SIMD variables in the register are ready for use without requiring any rearrangement of the data. To avoid such data rearrangement which can reduce the benefit of parallelism, design your array with an efficient data layout that is favorable for SIMD calculations.

11.8. Operations on Fixed-Point Variables

Support for fixed-point types includes:

- Prefix and postfix increment and decrement operators (++, −−)
- Unary arithmetic operators (+, −, !)
- Binary arithmetic operators (+, −, *, /)
- Binary shift operators (<<, >>)
- Relational operators (<, <=, >=, >)
- Assignment operators (+=, −=, *=, /=, <<=, >>=)
- Conversions to and from integer, floating-point, or fixed-point types

The following example shows how fixed-point multiplication might be implemented for a PIC32M device.

```
#include <stdfix.h>
sat fract test (sat fract a, sat fract b)
{
    return (a * b);
}
# Illustrative generated assembly with optimizations
test:
    mulq_rs.ph   $2,$4,$5
    j            $31
```

11.9. Operations on SIMD Variables

Some specific C operators can be applied to SIMD variables. They are +, -, *, /, unary minus, ^, |, &, ~. The DSP-enhanced core provides SIMD addition and subtraction instructions for v4i8 and

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v2q15, allowing the XC32 to generate appropriate instructions for addition and subtraction of v4i8 and v2q15 variables. For other operators, the compiler synthesizes a sequence of instructions. The examples here show compiler-generated SIMD instructions when the appropriate operator is applied to SIMD variables.

Example:

```
/* v4i8 Addition */
  v4i8 test (v4i8 a, v4i8 b)
  {
    return a + b;
  }
  # Illustrative generated assembly with optimizations
  test:
    addu.qb $2, $4, $5
    j       $31
  # ------------------------------------------------------------
```

Example:

```
/* v4i8 Subtraction */
  v4i8 test (v4i8 a, v4i8 b)
  {
    return a - b;
  }
  # Illustrative generated assembly with optimizations
  test:
    subu.qb $2, $4, $5
    j $31
  # ------------------------------------------------------------
```

Example:

```
/* v2q15 Addition */
  v2q15 test (v2q15 a, v2q15 b)
  {
    return a + b;
  }
  # Illustrative generated assembly with optimizations
  test:
    addq.ph $2, $4, $5
    j $31
  # ------------------------------------------------------------
```

Example:

```
/* v2q15 Subtraction */
  v2q15 test (v2q15 a, v2q15 b)
  {
    return a - b;
  }
  # Illustrative generated assembly with optimizations
  test:
    subq.ph $2, $4, $5
    j       $31
```

In situations where your application requires special integer and fractional calculations and the compiler cannot generate them automatically, you can use the DSP built-in functions (see Built-in Functions).

11.10. DSP Built-In Functions

Built-in functions are very similar to standard function calls in syntax. Your application passes parameters to a built-in function, and the built-in function returns the result to variables. The difference between a built-in function and a standard function is that the compiler directly can map the built-in function to a specific instruction sequence for better performance. The DSP built-in functions are listed in (see Built-in Functions).

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11.11. DSP Control Register

The DSP-enhanced core includes a DSP control register that has six fields: CCOND (condition code bits), OUFLAG (overflow/underflow bits), EFI (extract fail indicator bit), C (carry bit), SCOUNT (size count bits) and POS (position bits). The compiler treats the SCOUNT and POS fields as global variables, such that instructions that modify SCOUNT or POS are never optimized away. These instructions include WRDSP, EXTPDP, EXTPDPV, and MTHLIP. A function call that jumps to a function containing WRDSP, EXTPDP, EXTPDPV, or MTHLIP is also never deleted by the compiler.

For correctness, you must assume that a function call clobbers all fields of the DSP control register. That is, do not depend on the values in CCOND, OUFLAG, EFI or C across a function-call boundary. Re-initialize the values of CCOND, OUFLAG, EFI or C before using them. Note that because SCOUNT and POS fields are treated as global variables, the values of SCOUNT and POS are always valid across function-call boundaries and can be used without re-initialization.

The following example shows possibly incorrect code. The first built-in function "`__builtin_mips_addsc`" sets the carry bit (C) in the DSP control register, and the second built-in function "`__builtin_mips_addwc`" reads the carry bit (C) from the DSP control register. However, a function call "func" inserted between "`__builtin_mips_addsc`" and "`__builtin_mips_addwc`" may change the carry bit to affect the correct result of "`__builtin_mips_addwc`".

```
Incorrect Ex:
int test (int a, int b, int c, int d)
{
  __builtin_mips_addsc (a, b);
  func();   // may clobber the carry bit
  return __builtin_mips_addwc (c, d);
}
```

The previous example may be corrected by moving "func" before the first built-in function or after the second built-in function as follows. p

```
Corrected Ex:
int test (int a, int b, int c, int d)
{
  func();    // may affect the carry bit
  __builtin_mips_addsc (a, b);
  return __builtin_mips_addwc (c, d);
}
/* ------------------------------------------------------- */
int test (int a, int b, int c, int d)
{
  int i;
  __builtin_mips_addsc (a, b);
  i = __builtin_mips_addwc (c, d);
  func();    // may affect the carry bit
  return i;
}
```

11.12. Using Accumulators

To access only HI or LO of an accumulator, use a union type as follows.

```
typedef union
{
  long long a;   // One 64-bit accumulator
  int b[2];      // 32-bit HI and LO
} a64_union;
```

To access HI, use b[1]. To access LO, use b[0].

Example:

```
int test (long long a, v2q15 b, v2q15 c)
{
  a64_union temp;
  temp.a = __builtin_mips_dpaq_s_w_ph (a, b, c);
```


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```
  return temp.b[0];  // access LO.
}
```

11.13. Mixed-Mode Operations

11.13.1. Multiply "32-bit int * 32-bit int = 64-bit long long int"

Multiply "32-bit int * 32-bit int = 64-bit long long int"

To multiply 32 bits by 32 bits to obtain a 64-bit result, cast the 32-bit integer to a 64-bit integer (long long) and then perform the multiplication operation as follows.

Example:

```
long long test (int a, int b)
{
  return (long long) a * b;
  // Same as (long long) a * (long long) b
  // NOT the same as (long long) (a * b)
}
```

We can then access the highest 32-bit result from HI as follows.

Example:

```
typedef union
{
  long long a;   // One 64-bit accumulator
  int b[2];      // 32-bit HI and LO
} a64_union;
int test (int a, int b)
{
  a64_union temp;
  temp.a = (long long) a * b;
  return temp.b[1];  // Access the HI 32 bits
}
# Illustrative generated assembly with optimizations
test:
  mult    $4,$5
  mfhi    $2
  j       $31
```

11.13.2. Multiply and Add "32-bit int * 32-bit int + 64-bit long long = 64-bit long long int"

To perform multiplication and addition, cast the 32-bit integer to 64-bit (long long) and then perform multiplication and addition as follows.

Example:

```
long long test (int a, int b, long long c)
{
  return c + (long long) a * b;
}
# Illustrative generated assembly with optimizations
test:
  mtlo $6
  mthi $7
  madd $4, $5
  mflo $2
  mfhi $3
  j $31
```

11.14. Auto-Vectorization to SIMD

The compiler supports auto-vectorization for loops at optimization level -O3. The advantage of auto-vectorization is that the compiler can recognize scalar variables (which can be integer, fixed-point, or floating-point types) in order to utilize SIMD (Single Instruction, Multiple Data) instructions automatically. In the ideal case, when auto-vectorization is used, there is no need to use SIMD variables explicitly.

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Example:

```
  /* add8.c */
  unsigned char a[32], b[32], c[32];
  void add8() {
    int i;
    for (i = 0; i < 32; i++)
    {
      c[i] = a[i] + b[i];
    }
  }
# Illustrative generated assembly code
add8:
  lui     v0,0x0
  addiu   v0,v0,0
  lui     a0,0x0
  addiu   a0,a0,0
  lui     v1,0x0
  addiu   v1,v1,0
  addiu   a3,v0,32
  lw      a2,0(a0)
  lw      a1,0(v0)
  addiu   v0,v0,4
  addiu   a0,a0,4
  addu.qb a1,a2,a1
  addiu   v1,v1,4
  bne     v0,a3,1c <add8+0x1c>
  sw      a1,-4(v1)
  jr      ra
```

In `add8.c`, elements in two arrays of `unsigned char` are added together. The compiler automatically generates the code for `addu.qb` to add four elements at a time.

For existing C code, try auto-vectorization at the -O3 optimization level without any modifications to see if the compiler can auto vectorize the loops. In some cases, if the loop body is too complex, the compiler will not be able to auto-vectorize the loop; in this case, you may choose to restructure and simplify the loop.

11.15. FIR Filter Example Project

The DSP_Intrinsics example project shows the advantages of a FIR filter implementation based on DSP Built-in Functions compared to traditional C code, without any DSP optimizations. First, the filter is implemented for Q15 input data represented as arrays of short variables:

```
short coeff[BUFSIZE] __attribute__ ((aligned(4)));
short delay[BUFSIZE] __attribute__ ((aligned(4)));
```

The traditional C code version for Q15 inputs doesn't use SIMD variables or DSP Built-in Functions. Instead, it implements the Q15 x Q15 multiplication by checking the saturation condition (both operands are 0x8000 or -1) and then left shifting the integer multiplication result by 1 bit before adding it to the accumulator.

```
long long FIR_Filter_Traditional_16(short *delay, short *coeff, int buflen)
{
    int i;
    short x, y;

    // 64-bit accumulator for result
    long long ac0 = 0;

    for (i = 0; i < buflen; i++) {
        x = coeff[i];
        y = delay[i];

        // check saturation condition
        if ((unsigned short)x == 0x8000 && (unsigned short)y == 0x8000) {
            ac0 += 0x7fffffff;
        } else {
            // multiply (Q15 x Q15) needs left shift
            // result is added to accumulator variable
            ac0 += ((x * y) << 1);
```


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```
        }
    }
    return ac0;
}
```

For this C implementation the compiler generates inefficient assembly code. It does not have enough information to auto-vectorize the loop.

```
# Illustrative generated assembly code
FIR_Filter_Traditional_16:
    …
    mul    $24,$13,$15
    sll    $25,$24,1
    addu    $12,$2,$25
    sra    $9,$25,31
    sltu    $11,$12,$2
    addu    $3,$3,$9
    move    $2,$12
    addu    $3,$11,$3
```

In the DSP Intrinsics approach of the filter the input buffers are casted to the v2q15 SIMD vector type defined above in section SIMD Variables. Inside the loop, the "__builtin_mips_dpaq_s_w_ph" DSP built-in function is called. The result of the call is stored in the accumulator variable, of type Q32.31 (64-bit), represented as integer type a64 (see definition in section Integer representation of Q15 and Q31).

```
a64 FIR_Filter_Intrinsics_16(short *delay, short *coeff, int buflen)
{
    int i;
    v2q15 *my_delay = (v2q15 *)delay;
    v2q15 *my_coeffs = (v2q15 *)coeff;
    // 64-bit accumulator for result
    a64 ac0 = 0;
    for (i = 0; i < buflen/2; i++) {
        ac0 = __builtin_mips_dpaq_s_w_ph (ac0,
my_delay[i],
my_coeffs[i]);
    }
    return ac0;
}
```

This function generates "dpaq_s.w.ph" assembly DSP instructions that apply the "Dot Product with Accumulate" operation on two sets of Q15 values. The result is stored in one of the four 64-bit accumulators in the DSP-enhanced core.

```
# Illustrative generated assembly code
FIR_Filter_Intrinsics_16:
    …
    mtlo    $0
    mthi    $0
    addiu    $8,$7,-1
    li    $6,1
    andi    $10,$8,0x7
    dpaq_s.w.ph   $ac0,$2,$3
    addiu    $3,$4,4
    beq    $6,$7,.L60
    addiu    $2,$5,4
```

The project targets the PIC32MZ2048EFM144 device. The tools used are MPLAB X IDE v3.10, MPLAB XC32 v1.40 compiler and PIC32 MZ EF Starter Kit/Simulator. Optimization level is set at "-O3" with "-funroll-loops" option enabled. Using an internal timer to count the ticks during calls to the 2 functions operating on the same Q15 data buffers reveals that the Intrinsics version is approximately **4.52 times faster** than the traditional C version.

Example timing output for input data buffers of size 2048:

```
16-bit without DSP Intrinsics: timer ticks 1180
16-bit with DSP Intrinsics: timer ticks: 261
```


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The project includes filter implementations for buffers of 32-bit integer data types using similar approaches as for the previous 16-bit versions.

First implementation uses multiply and add operators. The 32-bit is casted to 64-bit before multiply as it was described previously in Multiply and Add "32-bit int * 32-bit int + 64-bit long long = 64-bit long long int":

```
for (i = 0; i < buflen; i++) {
    acc += (long long)data[i] * coeff[i];
}

# Illustrative generated assembly code
FIR_Filter_32:
    …
    lwx    $24,$2($4)
    lwx    $25,$2($5)
    addiu    $2,$2,4
    madd   $ac0,$24,$25
```

The Intrinsics variant uses the "__builtin_mips_madd" to operate the multiply add.

```
for (i = 0; i < buflen; i++) {
    acc = __builtin_mips_madd (acc, data[i], coeff[i]);
}

# Illustrative generated assembly code
FIR_Filter_Intrinsics_32:
    …
    lw    $17,0($3)
    lw    $24,0($2)
    addiu     $7,$7,1
    addiu     $3,$3,4
    addiu     $2,$2,4
    madd   $ac0,$17,$24
```

The tick counts for the 32-bit implementations are very similar. In both cases the compiler is now generating the "MADD" DSP instructions.

Example timing output for input data buffers of size 2048:

```
32-bit without DSP Intrinsics: timer ticks 520
32-bit with DSP Intrinsics: timer ticks 484
```

11.16. Unsupported Features

The fixed-point conversion specifiers for formatted I/O, as described in Section 4.1.9 “Formatted I/O functions for fixed-point arguments” of ISO/IEC TR 18037:2008, are not supported by the current MPLAB XC32 standard C libraries. Fixed-point arguments must be used in formatted I/O routines by conversion to or from an appropriate floating-point representation. For example:

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

int main(void)
{
  fract a = 0.5;
  accum b;
  double d;

  scanf ("%lf", &d);           /* read into floating-point type */
  b = (accum) d;               /* convert to fixed-point type */
  printf ("%1.4f", (float) a); /* cast to floating-point type for output */
  return 0;
}
```

The fixed-point functions described in Section 4.1.7 of ISO/IEC TR 18037:2008 are not provided by the current MPLAB XC32 standard C libraries.

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12. Operators and Statements

The MPLAB XC32 C/C++ Compiler supports all ANSI operators. The exact results of some of these are implementation-defined. Implementation-defined behavior is fully documented in C Implementation-Defined Behavior. The following sections illustrate code operations that are often misunderstood, as well as additional operations that the compiler is capable of performing.

12.1. Integral Promotion

When there is more than one operand to an operator, they typically must be of exactly the same type. The compiler will automatically convert the operands, if necessary, so they do have the same type. The conversion is to a “larger” type so there is no loss of information; however, the change in type can cause different code behavior to what is sometimes expected. These form the standard type conversions.

Prior to these type conversions, some operands are unconditionally converted to a larger type, even if both operands to an operator have the same type. This conversion is called *integral promotion* and is part of Standard C behavior. The MPLAB XC32 C/C++ Compiler performs these integral promotions where required, and there are no options that can control or disable this operation. If you are not aware that the type has changed, the results of some expressions are not what would normally be expected.

Integral promotion is the implicit conversion of enumerated types, `signed` or `unsigned` varieties of `char`, `short int` or bit field types to either `signed int` or `unsigned int`. If the result of the conversion can be represented by an `signed int`, then that is the destination type, otherwise the conversion is to `unsigned int`.

Consider the following example:

```
unsigned char count, a=0, b=50;
if(a - b < 10)
  count++;
```

The `unsigned char` result of `a - b` is 206 (which is not less than 10), but both `a` and `b` are converted to `signed int` via integral promotion before the subtraction takes place. The result of the subtraction with these data types is -50 (which *is* less than 10) and hence the body of the `if()` statement is executed.

If the result of the subtraction is to be an `unsigned` quantity, then apply a cast. For example:

```
if((unsigned int)(a - b) < 10)
  count++;
```

The comparison is then done using `unsigned int`, in this case, and the body of the `if()` would not be executed.

Another problem that frequently occurs is with the bitwise compliment operator, `~`. This operator toggles each bit within a value. Consider the following code:

```
unsigned char count, c;
c = 0x55;
if( ~c == 0xAA)
  count++;
```

If `c` contains the value 0x55, it often assumed that `~c` will produce 0xAA, however the result is 0xFFFFFFAA and so the comparison in the above example would fail. The compiler may be able to issue a mismatched comparison error to this effect in some circumstances. Again, a cast could be used to change this behavior.

The consequence of integral promotion as illustrated above is that operations are not performed with `char` -type operands, but with `int` -type operands. However there are circumstances when

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the result of an operation is identical regardless of whether the operands are of type `char` or `int`. In these cases, the MPLAB XC32 C/C++ Compiler will not perform the integral promotion so as to increase the code efficiency. Consider the following example:

```
unsigned char a, b, c;
a = b + c;
```

Strictly speaking, this statement requires that the values of `b` and `c` should be promoted to `unsigned int`, the addition performed, the result of the addition cast to the type of `a`, and then the assignment can take place. Even if the result of the `unsigned int` addition of the promoted values of `b` and `c` was different to the result of the `unsigned char` addition of these values without promotion, after the `unsigned int` result was converted back to `unsigned char`, the final result would be the same. If an 8-bit addition is more efficient than a 32-bit addition, the compiler will encode the former.

If, in the above example, the type of `a` was `unsigned int`, then integral promotion would have to be performed to comply with the ANSI C standard.

12.2. Type References

Another way to refer to the type of an expression is with the `typeof` keyword. This is a non-standard extension to the language. Using this feature reduces your code portability.

The syntax for using this keyword looks like `sizeof`, but the construct acts semantically like a type name defined with `typedef`.

There are two ways of writing the argument to `typeof`: with an expression or with a type. Here is an example with an expression:

```
typeof (x[0](1))
```

This assumes that `x` is an array of functions; the type described is that of the values of the functions.

Here is an example with a `typename` as the argument:

```
typeof (int *)
```

Here the type described is a pointer to `int`.

If you are writing a header file that must work when included in ANSI C programs, write `__typeof__` instead of `typeof`.

A `typeof` construct can be used anywhere a `typedef` name could be used. For example, you can use it in a declaration, in a cast, or inside of `sizeof` or `typeof`.

- This declares `y` with the type of what `x` points to:
  ```
  typeof (*x) y;
  ```
- This declares `y` as an array of such values:
  ```
  typeof (*x) y[4];
  ```
- This declares `y` as an array of pointers to characters:
  ```
  typeof (typeof (char *)[4]) y;
  ```
  It is equivalent to the following traditional C declaration:
  ```
  char *y[4];
  ```

To see the meaning of the declaration using `typeof`, and why it might be a useful way to write, let's rewrite it with these macros:

```
#define pointer(T) typeof(T *)
#define array(T, N) typeof(T [N])
```

Now the declaration can be rewritten this way:

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```
array (pointer (char), 4) y;
```

Thus, `array (pointer (char), 4)` is the type of arrays of four pointers to `char`.

12.3. Labels as Values

You can get the address of a label defined in the current function (or a containing function) with the unary operator '`&&`'. This is a non-standard extension to the language. Using this feature reduces your code portability.

The value returned has type `void *`. This value is a constant and can be used wherever a constant of that type is valid. For example:

```
void *ptr;
...
ptr = &&foo;
```

To use these values, you need to be able to jump to one. This is done with the computed goto statement, `goto *exp;`. For example:

```
goto *ptr;
```

Any expression of type `void *` is allowed.

One way of using these constants is in initializing a static array that will serve as a jump table:

```
static void *array[] = { &&foo, &&bar, &&hack };
```

Then you can select a label with indexing, like this:

```
goto *array[i];
```

Note: This does not check whether the subscript is in bounds. (Array indexing in C never does.)

Such an array of label values serves a purpose much like that of the `switch` statement. The `switch` statement is cleaner and therefore preferable to an array.

Another use of label values is in an interpreter for threaded code. The labels within the interpreter function can be stored in the threaded code for fast dispatching.

This mechanism can be misused to jump to code in a different function. The compiler cannot prevent this from happening, so care must be taken to ensure that target addresses are valid for the current function.

12.4. Conditional Operator Operands

The middle operand in a conditional expression may be omitted. Then if the first operand is nonzero, its value is the value of the conditional expression. This is a non-standard extension to the language. Using this feature reduces your code portability.

Therefore, the expression:

```
x ? : y
```

has the value of `x` if that is nonzero; otherwise, the value of `y`.

This example is perfectly equivalent to:

```
x ? x : y
```

In this simple case, the ability to omit the middle operand is not especially useful. When it becomes useful is when the first operand does, or may (if it is a macro argument), contain a side effect. Then repeating the operand in the middle would perform the side effect twice. Omitting the middle operand uses the value already computed without the undesirable effects of recomputing it.

12.5. Case Ranges

You can specify a range of consecutive values in a single case label, like this:

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`case` *low* `...` *high*`:`

This has the same effect as the proper number of individual case labels, one for each integer value from `low` to `high`, inclusive. This is a non-standard extension to the language. Using this feature reduces your code portability.

This feature is especially useful for ranges of ASCII character codes:

```
case 'A' ... 'Z':
```

Be careful: Write spaces around the..., otherwise it may be parsed incorrectly when you use it with integer values. For example, write this:

```
case 1 ... 5:
```

rather than this:

```
case 1...5:
```

12.6. Has_builtin Operator

The `__has_builtin` operator evaluates to a constant integer that can be used in integer contexts, such as the conditional expressions to the `#if` and `#elif` preprocessor directives, to test whether the compiler recognizes the operator's argument as the name of a built-in function in the current language and conformance mode. A nonzero value is yielded if the argument is a recognized built-in function; zero otherwise.

The `__has_builtin` operator by itself, without any operand or parentheses, acts like a predefined macro, so that code can test for its validity in a portable way. For example:

```
#if defined __has_builtin
#  if __has_builtin (__builtin_object_size)
#    define builtin_object_size(ptr) __builtin_object_size (ptr, 2)
#  endif
#endif
#ifndef builtin_object_size
#  define builtin_object_size(ptr)   ((size_t)-1)
#endif
```


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13. Register Usage

This chapter examines registers used by the compiler to generate assembly from C/C++ source code.

13.1. Register Usage

When generating assembly from C/C++ source code, the compiler assumes that register contents will not be modified by external functions according to the calling conventions, or by inline assembly statements. The extended inline assembly syntax may be used to indicate the hardware registers used and/or modified by inline assembly so that the compiler may generate correct code in the presence of these statements.

13.2. Register Conventions

The 32 general purpose registers contained in the PIC32 are shown in the table below. Some of these registers are assigned a dedicated task by the compiler. The name used in assembly code and the usage is indicated.

Table 13-1. Register Conventions

Register Number	Software Name	Use
$0	`zero`	Always 0 when read.
$1	`at`	Assembler temporary variable. Do not use the $at register from source code unless you fully understand the implications.
$2-$3	`v0-v1`	Return value from functions.
$4-$7	`a0-a3`	Used for passing arguments to functions.
$8-$15	`t0-t7`	Temporary registers used by compiler for expression evaluation. Values not saved across function calls.
$16-$23	`s0-s7`	Temporary registers whose values are saved across function calls.
$24-$25	`t8-t9`	Temporary registers used by compiler for expression evaluation. Values not saved across function calls.
$26-$27	`k0-k1`	Reserved for interrupt/trap handler.
$28	`gp`	Global Pointer.
$29	`sp`	Stack Pointer.
$30	`fp` or `s8`	Frame Pointer if needed. Additional temporary saved register if not.
$31	`ra`	Return address for functions.

The PIC32MZ family uses the microMIPS compressed instruction-set architecture. You can use the `micromips` function attribute to compile the function for the microMIPS compressed mode. This compressed ISA generally results in a ~30% reduction in overall application code size at the expense of ~2% in performance. The microcontroller can switch between the MIPS32 and microMIPS modes on a function call. Consult your device data sheet to determine if your target device supports the microMIPS ISA.

Example function:

```
#include <xc.h>
void
__attribute__((micromips))
peanut (void)
{
```


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```
  // function code here
}
```

Important: Standard function calls can switch between MIPS32 and microMIPS modes. However, when calling a MIPS32 library function from a microMIPS function, the compiler may generate a compressed `jals` instruction to call the library function. A `jals` instruction cannot change modes to MIPS32 and upon linking, you may receive an error, “Unsupported jump between ISA modes; consider recompiling with interlinking enabled.” In that case, add the `-mno-jals` option to the Alternative Options field in your project properties for xc32-gcc, so it is passed to the compiler.

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14. Stack

The software stack used with the PIC32M devices is discussed in this chapter.

14.1. Software Stack

The PIC32 devices use what is referred to in this user's guide as a "software stack." This is the typical stack arrangement employed by most computers and is ordinary data memory accessed by a push-and-pop type instruction and a stack pointer register. The term "hardware stack" is used to describe the stack employed by Microchip 8-bit devices, which is only used for storing function return addresses.

The PIC32 devices use a dedicated stack pointer register `sp` (register 29) for use as a software Stack Pointer. All processor stack operations, including function calls, interrupts and exceptions, use the software stack. It points to the next free location on the stack. The stack grows downward, towards lower memory addresses.

The size of the stack can be changed by specifying the size on the linker command line using the `--defsym _min_stack_size` linker command line option. An example of allocating a stack of 2048 bytes using the command line is:

```
xc32-gcc foo.c -Wl,--defsym,_min_stack_size=2048
```

The run-time stack grows downward from higher addresses to lower addresses. Two working registers are used to manage the stack:

- Register 29 (`sp`) – This is the Stack Pointer. It points to the next free location on the stack.
- Register 30 (`fp`) – This is the Frame Pointer. It points to the current function's frame.

No stack overflow detection is supplied.

The C/C++ run-time start-up module initializes the stack pointer during the start-up and initialization sequence, see Initialize Stack Pointer and Heap.

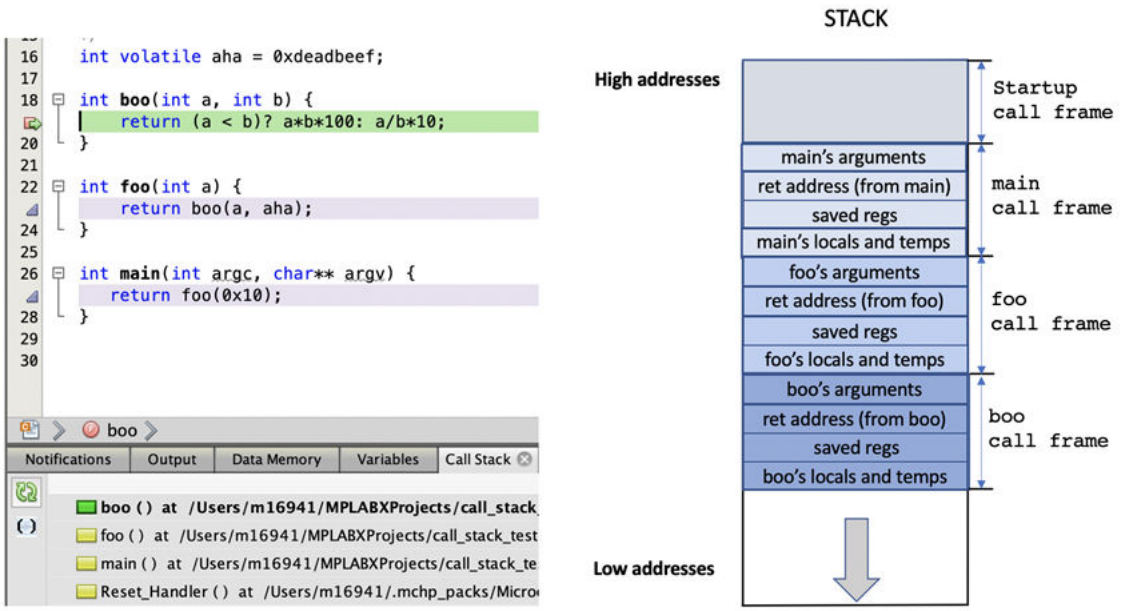
14.2. Call Frame

The stack is a memory region that grows dynamically at runtime. It starts at high address and grows to lower address (stack grows downward).

The stack has call frames, each one containing data corresponding to an active function call.

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Figure 14-1. Call Frame Diagram



A call frame contains:

- callee saved registers
- parameters passed through stack
- local variables
- temporary variables (inserted by compiler)
- interrupt context

14.3. Stack Guidance

Available with a PRO compiler license, the compiler's stack guidance feature can be used to estimate the maximum depth of any stack used by a program.

Runtime stack overflows cause program failure and can be difficult to track down, especially when the program is complex and interrupts are being used. The compiler's stack guidance feature constructs and analyzes the call graph of a program, determines the stack usage of each function, and produces a report, from which the depth of stacks used by the program can be inferred. Monitoring a program's stack usage during its development will mitigate the possibility of stack overflow situations.

This feature is enabled by the `-mchp-stack-usage` command-line option.

Once enabled, the operation of the stack guidance feature is fully automatic. For command-line execution of the compiler, a report will be displayed directly to the console after a successful build. When building in the MPLAB X IDE, this same report will be displayed in the build view in the **Output** window.

A more detailed and permanent record of the stack usage information will be available in the map file, should one be requested using the `-Wl,-Map=`*`mapfile`* command-line option or the equivalent control in the MPLAB X IDE project properties.

14.3.1. What is a Stack Overflow?

A stack overflow can occur if the stack pointer exceeds the RAM address range reserved for the call stack. When the application uses more space than is reserved for the stack, it can overwrite and corrupt other data such as statically allocated variables and the heap. In addition, when those other

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variables are accessed, they can corrupt values on the stack. This data corruption can be challenging to debug and leads to unpredictable runtime behavior of the application.

14.3.2. Estimating Stack Usage

In a bare-metal embedded application, the application developer must determine an appropriate minimum amount of data RAM to reserve for the stack and pass that value to the XC32 linker. The linker then uses this value to ensure that sufficient RAM is reserved for the stack.

However, due to reasons described later, the exact stack requirements of an application can be determined only at runtime. At link time, XC32 can use static analysis to ***estimate*** the maximum stack size required by the application and provide guidance in a human-readable report. It does this by computing the stack usage of each function and then using application's call graph to find the largest stack usage.

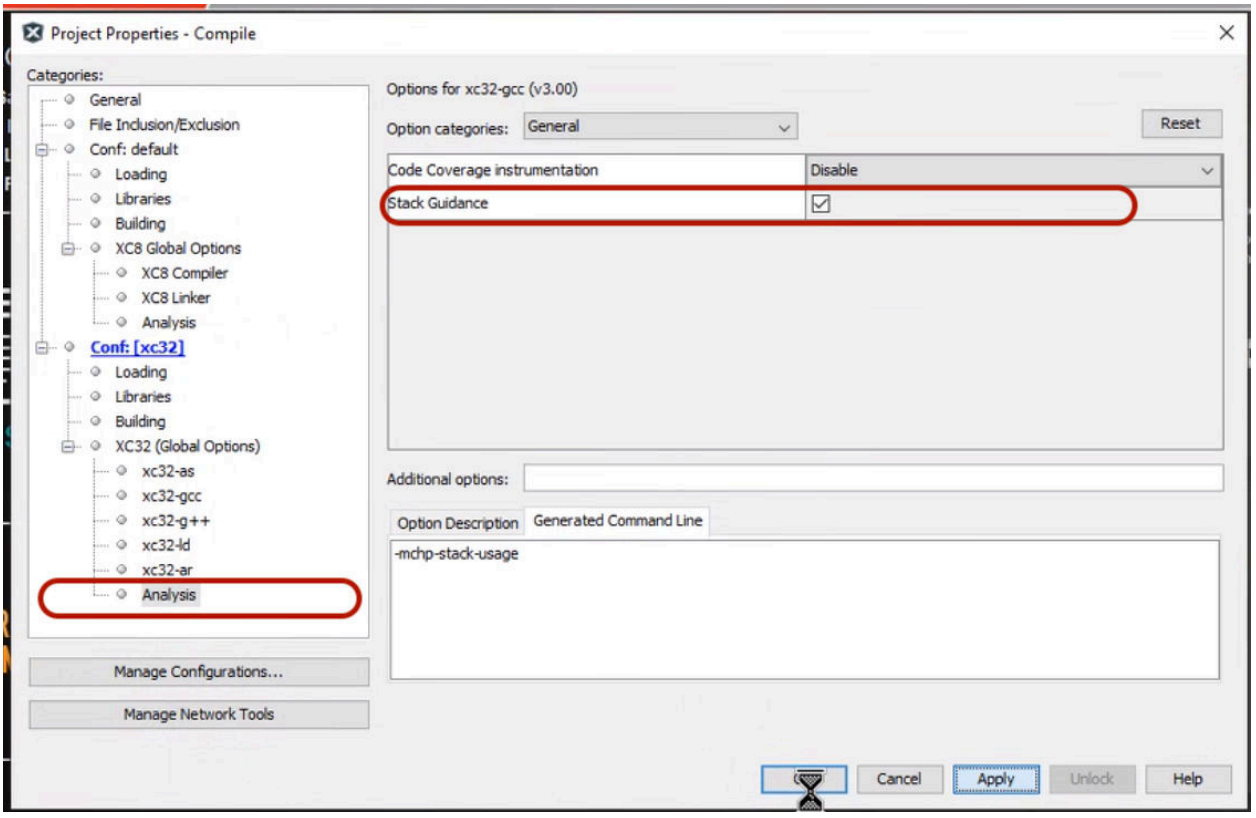
Generally speaking, this report cannot provide you with an exact value, but it provides you with information that you can use to determine an appropriate size for your stack reservation. *Only you understand the precise system-level, runtime behavior of your application.*

14.3.3. Enabling the Stack Usage Report

The feature can be used only when a PRO XC32 license is present. The stack-usage report is enabled through the `-mchp-stack-usage` command-line option, which is passed to XC32 when the **Stack Guidance** checkbox is enabled in the MPLAB X Project Properties.

To enable Stack Usage Analysis from MPLAB X, set Stack Guidance in **Project Properties** > **XC32** > **Analysis**.

Figure 14-2. Project Properties for Stack Guidance



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or pass `-mchp-stack-usage` in command line.

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -mchp-stack-usage -O0 test.c
```

14.3.4. Interpreting the Report

The stack-usage report is written:

- Directly to standard error (either on terminal for command-line execution or in the MPLAB X output window).
- To the map file.

The same information is available in both places, but the map file can serve as a record for later review.

The report contains:

- The largest stack usage that could be determined by static analysis.
- A list of reasons that the maximum stack usage couldn't be determined, such as recursion or variable adjustment of the stack.
- A list of disjoint and/or interrupt handler functions, which are not called directly by the main flow of the program.

To determine the appropriate stack size for your application:
First, start with the initial value from the reset-handler call graph. In this example, the report shows 72 bytes required for the reset-handler call graph.

Stack Usage Report

```
============= STACK USAGE GUIDANCE =============
In the call graph beginning at Reset_Handler,
72 bytes of stack are required.
```

Second, add the listed stack allowances based on the system-level, runtime behavior of your application.

Stack Usage Report

```
However, the following cautions exists:
1. The following functions cannot be connected to the main call graph.
This is usually caused by some indirection:
frame_dummy uses 8 bytes
Dummy_Handler uses 0 bytes
__libc_init_array uses 40 bytes
You must add stack allowances for those functions.
================================================
```

Third, add stack allowances for your Interrupt handlers (interrupt service routines) as described in the following section.

14.3.4.1. MIPs Interrupts

The use of interrupts increases a program's stack usage, but an estimate of the additional memory used is properly reported through the stack guidance feature.

The PIC32M devices allow nesting of interrupts based on a priority level; however, nesting can be disabled as required by specifying the `keep_interrupts_masked` attribute with those interrupt functions that should not be interruptable. The stack guidance feature is aware of the use of this attribute and the function's interrupt priority level, and will report the maximum possible stack usage of the configuration of interrupt functions. A worst case scenario is computed if required and will be the stack usage of the interrupt functions that have the highest stack usage per priority level, summed over each level.

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14.3.5. Stack Usage Limitations

Static estimation of the maximum stack usage is inaccurate if the application contains functions falling in at least one of the following categories:

- Functions for which the stack usage information is not available (not compiled/assembled with `-mchp-stack-usage`).
- Functions containing indirect calls to other functions (the callees can not be identified).
- Functions containing variable stack adjustments, inline assembly, or stack-usage information generated by the assembler (which might be inaccurate).
- Recursive functions (direct or indirect) - only if at least one of the functions in the cycle has non-zero stack consumption.

For each of these cases, a list of the involved functions is provided.

Be aware that the stack-usage estimation for assembly files may be inaccurate if your assembly code adjusts the stack. Be sure to take these adjustments into account when estimating your stack usage.

14.3.6. Example Stack Report

For this simple example, assumed to be stored in a file named `test.c`,

```
int max(int a, int b) {
        if (a < b)
                return b;
        return a;
}

int main(void) {
        int a[10], i, j;

        for (i =0; i < 10; i++)
                a[i] = i;
        for (i = 0; i < 10; i++)
                a[i] = max(a[i], a[10-i/2]);
        return a[0];
}
```

when built with:

```
xc32-gcc -mprocessor=32MZ2048ECH100 -mdfp="Microchip/Microchip.PIC32MZ-EC_DFP.1.4.150" -mchp-
stack-usage -O0 mips_stack_guidance.c
```

the compiler will print the following stack-usage report.

```
============= STACK USAGE GUIDANCE =============
In the call graph beginning at _reset,
    104 bytes of stack are required.

However, the following cautions exists:

1. Indeterminate stack adjustment has been detected:
    _main_entry uses 104 bytes
    __pic32_software_reset uses 24 bytes
No stack usage predictions can be made.

2. The following functions cannot be connected to the main call graph.
This is usually caused by some indirection:
    __DbgExecReturn uses 24 bytes
    _bev_exception uses 48 bytes
    _gen_exception uses 136 bytes
    simple_tlb_refill_vector uses 136 bytes
    _cache_err_vector uses 136 bytes
    __pic32_size_cache uses 0 bytes
    _DefaultInterrupt uses 24 bytes
You must add stack allowances for those functions.
================================================
```


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15. Functions

The following sections describe how function definitions are written, and specifically how they can be customized to suit your application. The conventions used for parameters and return values, as well as the assembly call sequences are also discussed.

15.1. Writing Functions

Functions may be written in the usual way in accordance with the C/C++ language.

The only specifier that has any effect on function is `static`. Interrupt functions are defined with the use of the `interrupt` attribute, see Function Attributes and Specifiers.

A function defined using the `static` specifier only affects the scope of the function, that is, limits the places in the source code where the function may be called. Functions that are `static` may only be directly called from code in the file in which the function is defined. The equivalent symbol used in assembly code to represent the function may change if the function is `static`, see Static Variables. This specifier does not change the way the function is encoded.

15.2. Function Attributes and Specifiers

The compiler keyword `__attribute__` allows you to specify special attributes of functions. This keyword is followed by an attribute specification inside double parentheses.

You may also specify attributes with __ (double underscore) preceding and following each keyword (e.g., `__noreturn__` instead of `noreturn`). This allows you to use them in header files without being concerned about a possible macro of the same name.

To specify multiple attributes, separate them by commas within the double parentheses, for example:

```
__attribute__ ((address(0x100), keep))
```

The attribute specifier can be placed either before or after the function's return type.

Note: It is important to use function attributes consistently throughout a project. For example, if a function is defined in file A with the an attribute, and declared `extern` in file B without the same attribute, then a link error might result.

15.2.1. Access Function Attribute

The `access(`*`access-mode`*`, `*`ref-index`*`[, `*`size-index`*`])` attribute provides additional information about how a function accesses memory. It can assist in diagnosing potential bugs related to memory access via compiler warnings and help the compiler perform better optimizations.

The *`ref_index`* argument is the index (starting from the left with index 1) of the function pointer argument that points to the target object being accessed. A function pointer argument can be referenced by at most one distinct `access` attribute.

The *`access_mode`* argument specifies the type of memory access made by the pointer referenced by the *`ref_index`* and can be one of:

`read_only`	The pointer only reads from the target object. Unless the indexed size argument is zero, the target object must be initialized. This check is more robust than just using the `const` qualifier with the target as it cannot be cast away.
`write_only`	The pointer (which cannot be to a `const`-qualified type) only writes to the target object. The object referenced by the pointer need not be initialized.
`read_write`	The pointer (which cannot be to a `const`-qualified type) both reads from and writes to the target object. Unless the indexed size argument is zero, the target object must be initialized.

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none The pointer does not access the target object at all. Unless the pointer is `NULL`, the target object must exist and have at least the size held by the size-index argument. If the size-index argument is omitted for a pointer of `void *` type, the actual pointer argument is ignored. The referenced object need not be initialized. The mode is intended to be used as a means to help validate the expected object size, for example in functions that call `__builtin_object_size`.

The optional *`size_index`* argument is the index of the function argument that specifies the number of elements of the pointer type referenced by *`ref-index`*, or the number of bytes when the pointer type is `void *`. When this argument is not specified, the pointer argument must be either `NULL` or point to a space that is suitably aligned and sized for at least one object of the referenced type (this implies that a past-the-end pointer is not a valid argument). The actual size of the access may be less but it must not be more.

For example, the following code uses the `access` attribute to declare that the pointer argument to `puts()` will only read its target of unspecified size. The attribute is used again to indicate that the second argument to `memcpy()` only reads its target and that this target has a size indicated by the value of the third function argument.

```
__attribute__ ((access (read_only, 1))) int puts(const char *);

__attribute__ ((access (read_only, 2, 3))) void * memcpy(void *, const void *, size_t);
```

15.2.2. Address Function Attribute

The `address(`*`addr`*`)` attribute specifies an absolute physical address at which the attributed routine will be placed in memory. It can be used with C and C++ functions.

The `address` attribute specifies an absolute virtual address for the function. Be sure to specify the `address` attribute using an appropriate virtual address for the target device. The address is typically in the range [0x9D000000,0x9D0FFFFC], as defined in the linker script as the `kseg0_program_mem` memory region. For example:

```
__attribute__((address(0x9D008000))) void bar (void);
```

The compiler performs no error checking on the address. The section containing the function will be located at the specified address regardless of the memory-regions specified in the linker script or the actual memory ranges on the target device. The application code must ensure that the address is valid for the target device.

Sections used to hold functions placed at an absolute address will use a name `.address.`*`N`*`.`*`decl`*, where *`N`* is the address and *`decl`* is the name of the declaration.

To make effective use of absolute sections and the new best-fit allocator, standard program-memory and data-memory sections should not be mapped in the linker script. The built-in linker script does not map most standard sections such as the `.text`, `.data`, `.bss`, or `.ramfunc` sections. By not mapping these sections in the linker script, we allow these sections to be allocated using the best-fit allocator rather than the sequential allocator. Sections that are unmapped in the linker script can flow around absolute sections, whereas sections that are linker-script mapped are grouped together and allocated sequentially, potentially causing conflicts with absolute sections.

15.2.3. Alias Function Attribute

The `alias ("`*`symbol`*`")` attribute indicates that the function is an alias for another symbol. For example:

```
void foo (void) { /* stuff */ }
__attribute__ ((alias("foo"))) void bar (void);
```

The symbol `bar` is considered to be an alias for the symbol `foo`.

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15.2.4. Always_inline Function Attribute

The `always_inline` attribute will force a function declared `inline` to be inlined, even if an optimization level required to enable inlining is not specified, for example:

```
void __attribute__ ((always_inline))  foo (void);
```

15.2.5. At_vector Function Attribute

The `at_vector(`*`address`*`)` attribute places the body of the function at the indicated exception vector address, for example:

```
void __attribute__ ((interrupt(IPL4SOFT))) __attribute__ ((at_vector(54)))
foo void);
```

See also Interrupts and Exception Handlers.

15.2.6. Const Function Attribute

The `const` attribute instructs the compiler to more aggressively optimize calls to the function. The compiler enforces that such functions declared with the attribute do not read objects that affect its return value between successive invocations, such as global objects. However, such functions can safely read objects that do not change their return value, such as non-volatile constants. Note that a function which de-references a pointer argument should not be attributed with `const`, since the pointer de-reference uses a value which is not a parameter, even though the pointer itself is a parameter. For example:

```
int __attribute((const)) rv(int a);
```

15.2.7. Copy Function Attribute

The `copy(`*`func`*`)` attribute is used to apply a set of attributes to a function. This set is derived from the attributes applied to the argument *`func`*. This is particularly useful in libraries that define aliases, ensuring that the aliases have the same attributes as the original symbols. It's important to note that the `copy` attribute only duplicates syntactic and semantic attributes. It does not copy attributes that influence a symbol's linkage or visibility, such as `alias` or `weak`. Additionally, the `deprecated` attribute is not copied. For example:

```
#define StrongAlias(TargetFunc, AliasDecl)  \
  extern __typeof__ (TargetFunc) AliasDecl  \
    __attribute__ ((alias (#TargetFunc), copy (TargetFunc)));

extern __attribute__ (malloc, pure)) void* allocate (size_t);
StrongAlias (allocate, alloc);
```

15.2.8. Deprecated Function Attribute

The `deprecated (`*`msg`*`)` attribute will trigger a compiler warning should the attributed function be called in a program. If the optional *`msg`* argument string is present, that string will be printed in the warning instead of a default message, for example:

```
void __attribute__ ((deprecated ("The bar function is no longer used"))) bar (void);
```

15.2.9. Externally_visible Function Attribute

The `externally_visible` attribute nullifies the effect of the `-fwhole-program` command-line option, so the function remains visible outside the current compilation unit. This might prevent certain optimizations from being performed on the function. For example:

```
void __attribute__((externally_visible)) foo (void);
```


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15.2.10. Far Function Attribute

The `far` attribute instructs the compiler to invoke the function by first loading its address into a register and executing a call based on the address in that register. This allows a function located beyond the 28-bit addressing range of the direct `JAL` instruction to be called. For example:

```
void __attribute__((far)) foo (void);
```

15.2.11. Format Function Attribute

The `format (type, format_index, first_to_check)` attribute indicates that the function takes a `printf`, `scanf`, `strftime`, or `strfmon` style format string and arguments and that the compiler should type check those arguments against the format string, just as it does for the standard library functions, for example:

```
extern int __attribute__ ((format (printf, 2, 3))) my_printf (void *my_object, const char
*my_format, ...);
```

The *`type`* parameter is one of `printf`, `scanf`, `strftime` or `strfmon` (optionally with surrounding double underscores, for example, `__printf__`) and determines how the format string will be interpreted.

The *`format_index`* parameter specifies which function parameter is the format string. Function parameters are numbered from the left-most parameter, starting from 1.

The *`first_to_check`* parameter specifies which parameter is the first to check against the format string. If *`first_to_check`* is zero, type checking is not performed and the compiler only checks the format string for consistency (for example, `vfprintf`).

15.2.12. Format_arg Function Attribute

The `format_arg` attribute specifies that a function manipulates a `printf` style format string and that the compiler should check the format string for consistency. The *`index`* parameter gives the position of the format string in the parameter list of the function, numbered from the left beginning at index 1. For example:

```
extern char * __attribute__ ((format_arg (2))) my_foo (char *my_str, const char *my_format);
```

15.2.13. Function_replacement_prologue Function Attribute

The `function_replacement_prologue` attribute allows the application to redirect one function to another implementation at runtime without replacing the existing function. This is achieved by changing the method of invoking functions through a function replacement table instead of from a linker-resolved address. Initially the function address in the table points to the location of the entry point of the original function's prologue. The application can then replace the table entry with the new function address. Now, during the program execution, the control will pass to the new function address and returns to the caller function. This feature adds a new `function_replacement_prologue` function attribute. To redirect the function, modify the corresponding Function Replacement Table entry at runtime.

Example C code:

```
int a, b, c, d;
int __attribute__((function_replacement_prologue)) foo (void)
{
   a = b + c;
   return (a);
}
int main()
{
   d = foo();
   return 0;
}
```


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Example generated assembly code:

```
# Function Replacement Table entries, located in data memory
  .section .fixtable, data
fixtable.foo:
    .word       cont.foo       # By default, populate the table with the address
                               # of the original implementation. Redirect to
                               # another implementation by overwriting this
                               # location with the address of the new implementation.

  .section .text, code
    .globl foo
    .ent foo
    .type foo, @function
foo:
    # Begin Function Replacement Table Prologue
    lui $25,%hi(fixtable.foo)          # Load address from .fixtable above
    lw $25,%lo(fixtable.foo)($25)
    j $25                                 # Jump to address loaded from table
    nop
cont.foo:
    # End Function Replacement Table Prologue
    addiu $sp,$sp,-8
    sw $fp,4($sp)
    move $fp,$sp
    lw $3,%gp_rel(b)($28)
    ...........
    j $31
    nop
```

15.2.14. Interrupt Function Attribute

The `interrupt (priority)` attribute instructs the compiler to generate prologue and epilogue code for the function as an interrupt handler function. The argument specified the interrupt priority level using the symbols `IPLnSOFT`, `IPLnSRS`, or `IPLnAUTO` where *n* represents the 7 levels of priority and `SOFT|SRS|AUTO` specifies the context saving mode.

See Interrupts for more information on writing and handling interrupts.

15.2.15. Keep Function Attribute

The `keep` attribute will prevent the linker from removing the function when the `--gc-sections` option has been issued, even if that function is unused. For example:

```
void __attribute__((keep)) foo(void);
```

15.2.16. Longcall Function Attribute

The **longcall** attribute is an alias to the `far` attribute. For example:

```
void __attribute__((longcall)) foo (void);
```

15.2.17. Malloc Function Attribute

The **malloc** attribute indicates that the function is malloc-like, in that the pointer it returns will not alias any other pointer that is live at that time, and additionally that the storage addressed by the pointer will not contain any pointers to valid objects.

For example:

```
void __attribute__ ((malloc)) *custom_malloc (int size_t);
```

This attribute allows the compiler to improve optimization.

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15.2.18. Micromips Function Attribute

The `micromips` attribute instructs the compiler to generate code for the attributed function in the compressed microMIPS instruction set, for example:

```
void __attribute__ ((microcmips)) foo(void);
```

15.2.19. Micromips Function Attribute

The `mips16` attribute instructs the compiler to generate code for the attributed function using the MIPS16 instruction set, for example:

```
void __attribute__ ((mips16)) foo(void);
```

15.2.20. Naked Function Attribute

The `naked` attribute instructs the compiler to generate no prologue or epilogue code for the function. This attribute is intended for functions that exclusively contain extended inline assembly code. Using C code within such an attributed function might not work properly. Since the compiler will not generate prologue or epilogue code for functions using this attribute, the application code within is responsible for managing the stack and additionally handling formal parameters, return values, and the function return. For example:

```
void __attribute__ ((naked)) foo(void);
```

15.2.21. Near Function Attribute

The `near` attribute instructs the compiler to always invoke the function with an absolute `CALL` instruction, even when the `-mlong-calls` command line option is specified, for example:

```
void __attribute__ ((near)) foo(void);
```

15.2.22. No_fpu Function Attribute

The `no_fpu` attribute must be used in conjunction with the `interrupt (priority)` attribute and specifies that the interrupt service routine (ISR) should not preserve the Floating-Point Unit (FPU) context. In addition it causes the compiler to insert code into the ISR that will disable the FPU, by clearing the CU1 bit of the CP0 Status register. If your ISR attempts to perform floating-point operations while the FPU is disabled, the device will trigger a general exception. This also means that any higher-priority ISR interrupting an ISR using the `no_fpu` attribute must re-enable the FPU if floating-point operations are required. The ISR restores the original value of the status register before returning from the interrupt. For example:

```
void __attribute__((interrupt(IPL7SRS), vector(_CORE_TIMER_VECTOR), no_fpu)) isr(void);
```

15.2.23. Noinline Function Attribute

The `noinline` attribute instructs the compiler that the function should never be considered for inlining, for example:

```
void __attribute__ ((noinline)) foo(void);
```

15.2.24. Noload Function Attribute

The `noload` attribute instructs the compiler to place the function in a section that has the `noload` attribute set. It tells consumers of the ELF files not to load the contents of the section. This attribute can be useful when you just want to reserve memory for something, but you don't want to clear or initialize memory. For example:

```
void __attribute__ ((noload)) foo(void);
```


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15.2.25. Nomips16 Function Attribute

The **nomips16** attribute instructs the compiler to always generate code for the function in the MIPS32® instruction set, even when compiling the translation unit with the `-mips16` command line option, for example:

```
void __attribute__ ((nomips16)) foo(void);
```

15.2.26. Nonnull Function Attribute

The `nonnull (`*`index`*`, ...)` attribute indicates to the compiler that one or more pointer arguments to the function must be non-null. If the compiler determines that a Null Pointer is passed as a value to a non-null argument, and the `-Wnonnull` command line option was specified, a warning diagnostic is issued.

If no arguments are given to the `nonnull` attribute, all pointer arguments of the function are marked as non-null. For example:

```
void * __attribute__((nonnull)) my_memset (void * ptr, int x, size_t len);
```

15.2.27. Noreturn Function Attribute

The `noreturn` attribute indicates to the compiler that the function will never return. In some situations, this can allow the compiler to generate more efficient code in the calling function since optimizations can be performed without regard to behavior if the function ever did return. Functions declared as `noreturn` should always have a return type of void. For example:

```
void __attribute__ ((noreturn)) myExit(void);
```

15.2.28. Optimize Function Attribute

The `optimize(`*`optimization`*`)` attribute allows a function to be built with optimizations that differ from what has been specified on the command line and which will be applied to the rest of the program. The *`optimization`* argument can either be a number or a string. String arguments represent the command-line option used to control an optimization, for example, to enable peephole optimizations (`-fpeephole`), use `optimize("peephole")`. The `-f` option prefix does not need to be specified with the argument. If you want to specify more than one optimization, separate the arguments with commas but with no space characters. Arguments that begin with `O` are assumed to be an optimization level option, for example `optimize("O1,unroll-loops")` turns on level 1 optimizations and the unroll-loops optimizations (controlled by the `-funroll-loops` command-line option). A numerical argument is also assumed to be an optimization level, for example `optimize(3)` turns on level 3 optimizations and is equivalent to the full usage of the attribute in the following example.

```
int __attribute__((optimize("O3"))) pandora (void) {
  if (maya > axton)
    return 1;
  return 0;
}
```

This feature can be used, for instance, to have frequently executed functions compiled with more aggressive optimization options that produce faster and larger code, while other functions can be called with less aggressive options. Typically, however, it is not used for production builds.

15.2.29. Pure Function Attribute

The `pure` attribute instructs the compiler to perform more aggressive optimizations around invocations of a function when that function has no side effects other than its return value, and the return value is dependent only on parameters and/or (nonvolatile) global variables. Such functions can be indicated with the `pure` attribute, for example:

```
void __attribute__ ((pure)) foo(void);
```


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15.2.30. Ramfunc Function Attribute

The `ramfunc` attribute locates the attributed routine in RAM rather than in Flash memory on devices that normally execute code from Flash. This attribute can be used for both C functions and C++ class methods. The compiler's default runtime startup code uses the data-initialization template to copy the code associated with functions using this attribute from Flash to RAM at program startup.

When this attribute is used with C functions, the function is placed at the highest appropriately aligned address for executable code. Note that due to `ramfunc` alignment and placement requirements, the `address` attribute should not be used with the `ramfunc` attribute. The presence of the `ramfunc` section causes the linker to emit the symbols necessary for the `crt0.S` start-up code to initialize the bus matrix appropriately for executing code out of data memory.

Use this attribute along with the `far/longcall` attribute and the `section` attribute. For example:

```
__attribute__((ramfunc,section(".ramfunc"),far,unique_section))
unsigned int myramfunct (void)
  { /* code */ }
```

A macro in the <sys/attribs.h> header file makes the `ramfunc` attribute simple to use:

```
#include <sys/attribs.h>
__ramfunc__ unsigned int  myramfunct (void)
  { /* code */ }
```

In C++ code, the attribute can be used with class methods, as shown in the following example.

```
class printmyname {
    // Access specifier
public:
    // Data  Members
    string myname;
    int  dummy ;
    // Member Functions()
    printmyname (){
        myname = "microchip";
    }

    void  __attribute__((ramfunc, long_call)) set_name(string newname){
        myname = newname;
        dummy = 9;
    }
    void printname() { cout << "name is:" << myname; }
};
```

The MIPs `JAL` instruction only has an 28-bit addressing range. As a result, RAM might not be within range of calls made from code in Flash. To allow such calls, additionally use the `long_call` attribute with the definition of the function located in RAM when it must be called from functions in Flash. For example:

```
__attribute__((ramfunc, long_call))
unsigned int myramfunct(void)
{ /* code */ }
```

The <sys/attribs.h> header file provides a `__longramfunc__` macro that will specify both the `ramfunc` and `long_call` attributes. For example:

```
#include <sys/attribs.h>
__longramfunc__ unsigned int myramfunct(void)
{ /* code */ }
```

If a function in Flash is called by a function located in RAM, the Flash-based function definition must include the `long_call` attribute.

```
__attribute__ ((long_call))
unsigned int myflashfunct(void)
{ /* code */ }

__attribute__((ramfunc))
unsigned int myramfunct(void)
```


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```
{
        return myflashfunct();
}
```

Having functions located in RAM rather than Flash can increase code size as well as startup time, as the attributed functions must be copied from Flash to RAM at startup. It may also have an impact on runtime performance, depending on your target device. Verify that your application meets your startup timing constraints. Also verify that the increased runtime performance meets your application's timing requirements and that your application does not have hidden dependencies on timing that is negatively impacted by this design selection.

15.2.31. Section Function Attribute

The `section("name")` attribute places the function into the named section. For example:

```
void __attribute__ ((section (".wilma"))) baz () {return;}
```

will place the function `baz` will be placed in section `.wilma`.

The `-ffunction-sections` command line option has no effect on functions defined with a `section` attribute.

15.2.32. Uninitialized Function Attribute

The `uninitialized` attribute can be used with automatic objects to indicate that they should never be initialized, even if the `-ftrivial-auto-var-init` option (see Trivial-auto-var-init Option) has been specified.

15.2.33. Unique_section Function Attribute

The `unique_section` attribute places the function in a uniquely named section, as if `-ffunction-sections` had been specified. If the function also has a `section` attribute, use that section name as the prefix for generating the unique section name. For example:

```
void __attribute__ ((section (".fred"), unique_section) foo (void) {return;}
```

will place the function `foo`in section `.fred.foo`.

15.2.34. Unused Function Attribute

The `unused` attribute indicate to the compiler that the function may not be used. The compiler will not issue a warning for this function if it is not used, for example:

```
void __attribute__ ((unused)) opt_setting(void);
```

15.2.35. Used Function Attribute

The `used` attribute indicates to the compiler that the function is always used and code must be generated for the function even if the compiler cannot see a reference to the function. Such might be the case if inline assembly is the only reference to a `static` function. For example:

```
void __attribute__ ((used)) foo(void);
```

15.2.36. Vector Function Attribute

The `vector (num)` attribute instructs the compiler to generate a branch instruction at the indicated exception vector which targets the function. See Interrupts and Exception Handlers. For example:

```
void __attribute__((vector(0), interrupt(IPL7AUTO))) myisr(void);
```


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15.2.37. Warn_unused_result Function Attribute

The `warn_unused_result` attribute instructs the compiler to warn if the return value of the indicated function is unused by a caller, for example:

```
void __attribute__ ((warn_unused_result)) foo(void);
```

15.2.38. Weak Function Attribute

The `weak` attribute indicate that a symbol is weak, which means that if another version of the same symbol is available, that version should be used instead. This is useful when a library function is implemented such that it can be overridden by a user written function. For example:

```
void __attribute__ ((weak)) foo(void);
```

15.2.39. Zero_call_used_regs Function Attribute

The `zero_call_used_regs(`*`choice`*`)` attribute instructs the compiler to zero out a subset of the "call-used" registers associated with each function when those functions return. Call-used registers are those registers that can be altered by a function call. This action can enhance program security by reducing the risk of return-oriented programming (ROP) attacks or preventing information leakage through registers.

The *`choice`* argument to this attribute is identical to that for the `-fzero-call-used-regs` option (see Zero-call-used-regs Option), which sets the default behavior for functions that do not use this attribute.

15.3. Allocation of Function Code

Code associated with C/C++ functions is normally always placed in the program Flash memory of the target device.

Functions may be located in and executed from RAM rather than Flash by using the `__ramfunc__` and `__longramfunc__` macros.

Functions specified as a RAM function will be copied to RAM by the start-up code and all calls to those functions will reference the RAM location. Functions located in RAM will be in a different 512MB memory segment than functions located in program memory, so the `longcall` attribute should be applied to any RAM function, which will be called from a function not in RAM. The `__longramfunc__` macro will apply the `longcall` attribute as well as place the function in RAM.

```
#include <sys/attribs.h>
/* function 'foo' will be placed in RAM */
void __ramfunc__ foo (void)
{
}

/* function 'bar' will be placed in RAM and will be invoked
   using the full 32 bit address */
void __longramfunc__ bar (void)
{
}
```

Note: Specifying `__longramfunc__` is functionally equivalent to specifying both `__ramfunc__` and `__longcall__`.

15.4. Changing the Default Function Allocation

The assembly code associated with a C/C++ function can be placed at an absolute address. This can be accomplished by using the `address` attribute and specifying the virtual address of the function, see Address Function Attribute.

Functions can also be placed at specific positions by placing them in a user-defined section and then linking this section at an appropriate address, see Section Function Attribute.

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15.5. Function Size Limits

There are no theoretical limits as to how large functions can be made.

15.6. Function Parameters

MPLAB XC uses a fixed convention to pass arguments to a function. The method used to pass the arguments depends on the size and number of -arguments involved.

Note: The names “argument” and “parameter” are often used interchangeably, but typically an argument is the actual value that is passed to the function and a parameter is the variable defined by the function to store the argument.

The Stack Pointer is always aligned on an 8-byte boundary.

- All integer types smaller than a 32-bit integer are first converted to a 32-bit value. The first four 32 bits of arguments are passed via registers `a0-a3` (see the table below for how many registers are required for each data type).
- Although some arguments may be passed in registers, space is still allocated on the stack for all arguments to be passed to a function (see the figure below). Application code should not assume that the current argument value is on the stack, even when space is allocated.
- When calling a function:
  - Registers `a0-a3` are used for passing arguments to functions. Values in these registers are not preserved across function calls.
  - Registers `t0-t7` and `t8-t9` are caller saved registers. The calling function must push these values onto the stack for the registers’ values to be saved.
  - Registers `s0-s7` are called saved registers. The function being called must save any of these registers it modifies.
  - Register `s8` is a saved register if the optimizer eliminates its use as the Frame Pointer. `s8` is a reserved register otherwise.
  - Register `ra` contains the return address of a function call.

Table 15-1. Registers Required

Data Type	Number of Registers Required
`char`	1
`short`	1
`int`	1
`long`	1
`long long`	2
`float`	1
`double`	1
`long double`	2
`structure`	Up to 4, depending on the size of the struct.

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Figure 15-1. Passing Arguments

Example 1:

```
int add (int, int)
a= add (5, 10);
```



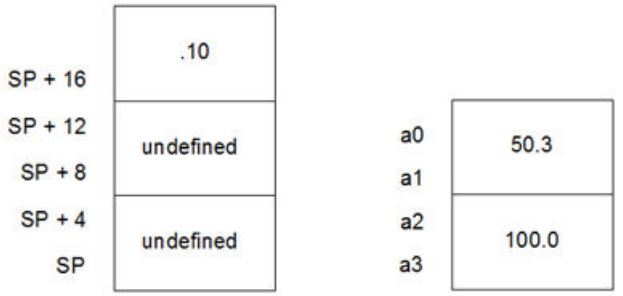
Example 2:

```
void foo (long double, long double)
call= foo (10.5, 20.1);
```



Example 3:

```
void calculate (long double, long double, int)
calculate (50.3, 100.0, .10);
```



15.7. Function Return Values

Function return values are returned in registers.

Integral or pointer value are placed in register `v0`. All floating-point values, regardless of precision, are returned in floating-point register `$f0`.

If a function needs to return an actual structure or union – not a pointer to such an object – the called function copies this object to an area of memory that is reserved by the caller. The caller passes the address of this memory area in register $4 when the function is called. The function also returns a pointer to the returned object in register `v0`. Having the caller supply the return object's space allows re-entrance.

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15.8. Calling Functions

By default, functions are called using the direct form of the call (`jal`) instruction. This allows calls to destinations within a 256 MB segment. This operation can be changed through the use of attributes applied to functions or command-line options so that a longer, but unrestricted, call is made.

The `-mlong-calls` option, see Options Specific to PIC32M Devices, forces a register form of the call to be employed by default. Generated code is longer, but calls are not limited in terms of the destination address.

The attributes `longcall` or `far` can be used with a function definition to always enforce the longer call sequence for that function. The `near` attribute can be used with a function so that calls to it use the shorter direct call, even if the `-mlong-calls` option is in force.

15.9. Inline Functions

By declaring a function `inline`, you can direct the compiler to integrate that function's code into the code for its callers. This usually makes execution faster by eliminating the function-call overhead. In addition, if any of the actual argument values are constant, their known values may permit simplifications at compile time, so that not all of the inline function's code needs to be included. The effect on code size is less predictable. Machine code may be larger or smaller with inline functions, depending on the particular case.

Note: Function inlining will only take place when the function's definition is visible (not just the prototype). In order to have a function inlined into more than one source file, the function definition may be placed into a header file that is included by each of the source files.

To declare a function inline, use the `inline` keyword in its declaration, like this:

```
inline int inc (int *a) {
  (*a)++;
}
```

If you are using the `-ansi` option, write `__inline__` instead of `inline`. You can also make all "simple enough" functions inline with the command-line option `-finline-functions`. The compiler heuristically decides which functions are simple enough to be worth integrating in this way, based on an -estimate of the function's size.

Note: The `inline` keyword will only be recognized with `-finline` or optimizations enabled.

Certain usages in a function definition can make it unsuitable for inline substitution. Among these usages are: use of `varargs`, use of `alloca`, use of variable-sized data, use of computed `goto` and use of nonlocal `goto`. Using the command-line option `-Winline` will warn when a function marked `inline` could not be substituted and will give the reason for the failure.

In compiler syntax, the `inline` keyword does not affect the linkage of the function.

When a function is both `inline` and `static`, and all direct calls to the function are integrated into the callers' code, and the function's address is never used, then the function's own assembler code is never referenced. In this case, the compiler does not actually output assembler code for the function itself, unless you specify the command-line option `-fkeep-inline-functions`. Some calls cannot be integrated for various reasons (in particular, calls that precede the function's definition cannot be integrated and neither can recursive calls within the definition). If there is a non-integrated call, then the function is compiled to assembler code as usual. The function must also be compiled as usual if the program refers to its address, because that can't be inlined. The compiler will only eliminate `inline` functions if they are declared to be `static` and if the function definition precedes all uses of the function.

When an `inline` function is not `static`, then the compiler must assume that there may be calls from other source files. Since a global symbol can be defined only once in any program, the function must not be defined in the other source files, so the calls therein cannot be integrated. Therefore, a non-`static` inline function is always compiled on its own in the usual fashion.

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If you specify both `inline` and `extern` in the function definition, then the definition is used only for inlining. In no case is the function compiled on its own, not even if you refer to its address explicitly. Such an address becomes an external reference, as if you had only declared the function and had not defined it.

This combination of `inline` and `extern` has a similar effect to a macro. Put a function definition in a header file with these keywords and put another copy of the definition (lacking `inline` and `extern`) in a library file. The definition in the header file will cause most calls to the function to be inlined. If any uses of the function remain, they will refer to the single copy in the library.

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16. Interrupts

Interrupt processing is an important aspect of most microcontroller applications. Interrupts may be used to synchronize software operations with events that occur in real time. When interrupts occur, the normal flow of software execution is suspended, and special functions are invoked to process the event. At the completion of interrupt processing, previous context information is restored and normal execution resumes.

PIC32M devices support multiple interrupts, from both internal and external sources. The devices allow high-priority interrupts to override any lower priority interrupts that may be in progress.

The compiler provides full support for interrupt processing in C/C++ or inline assembly code. This section presents an overview of interrupt processing.

16.1. Interrupt Operation

The compiler incorporates features allowing interrupts to be fully handled from C/C++ code. Interrupt functions are often called interrupt handlers or Interrupt Service Routines (ISRs).

Each interrupt source typically has a control bit in an SFR which can disable that interrupt source. Check your device data sheet for full information how your device handles interrupts.

Interrupt code is the name given to any code that executes as a result of an interrupt occurring. Interrupt code completes at the point where the corresponding return from interrupt instruction is executed. This contrasts with *main-line code*, which, for a freestanding application, is usually the main part of the program that executes after Reset.

16.2. Writing an Interrupt Service Routine

An interrupt handler function is different than an ordinary function in that it handles the context save and restore to ensure that upon return from interrupt, the program context is maintained. A different code sequence is used to return from these functions as well.

Several attributes can be used to ensure that the compiler generates the correct code for an ISR. Macros are provided so that this is easier to accomplish, see the following sections.

There are several actions that the compiler needs to take to generate an interrupt service routine. The compiler has to be told to use an alternate form of return code. The function also needs to be linked to the interrupt vector. All ISRs must use either the MIPS32® r2 or the microMIPS™ ISA modes. Apply the 'nomips16' function attribute to each interrupt function.

Note: For devices that support multiple Instruction Set Architecture (ISA) modes, there may be a configuration bit that determines which mode the device uses for an exception/interrupt. If your device is configured to use the microMIPS ISA on interrupt, be sure to apply the `micromips` function attribute to your interrupt function. Consult your the data sheet for your target device to determine if it supports handling exceptions and interrupts in an alternate ISA mode.

An interrupt function must be declared as type `void` and may not have parameters. This is the only function prototype that makes sense for an interrupt function since they are never directly called in the source code.

Interrupt functions must not be called directly from C/C++ code (due to the different return instruction that is used), but they themselves may call other functions, both user-defined and library functions, but be aware that this may use additional registers which will need to be saved and restored by the context switch code.

A function is marked as an interrupt handler function, or ISR, via either the `interrupt` attribute or the interrupt pragma*. While each method is functionally equivalent to the other, the `interrupt` attribute is more commonly used and therefore the recommended method. The interrupt is specified as handling interrupts of a specific priority level or for operating in single vector mode.

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For all interrupt vectors without specific handlers, a default interrupt handler will be installed. The default interrupt handler is supplied by the libpic32.a library and will cause a debug breakpoint and reset the device. An application may override the default handler and provide an application-specific default interrupt handler by declaring an interrupt function with the name `_DefaultInterrupt`.

Note: * Pre-processor macros are not expanded in pragma directives.

16.2.1. Interrupt Attribute

Use the `interrupt` attribute to indicate that the specified function is an interrupt handler. The compiler generates function entry and exit sequences suitable for use in an interrupt handler when this attribute is present. The generated code preserves context by either using a shadow register set (SRS) or using generated software instructions (SOFT) to push context onto the stack.

The attribute has the general form:

```
__attribute__((interrupt([IPLn[SRS|SOFT|AUTO]])))
```

where *n* is in the range of 0 through 7, inclusive.

Example 16-1. Interrupt Attribute

```
void __attribute__((interrupt(IPL7SRS))) bambam (void)
{
  // interrupt code goes here
}
```

When programming in C++, the interrupt handler symbol must be allocated to the C namespace, which can be accomplished using `extern "C"` with the definition, for example:

```
extern "C"
void __attribute__((interrupt(IPL7SRS))) bambam (void)
{
  // interrupt code goes here
}
```

Note: Some PIC32 target devices allow the exception/interrupt code to be in either the MIPS32® or microMIPS™ ISA mode via a device configuration bit (BOOTISA). On these devices, if your BOOTISA bit is set to microMIPS mode, add the 'micromips' attribute to your interrupt function. If your BOOTISA bit is set to MIPS32 mode, add the 'nomicromips' attribute to your interrupt function. See your device data sheet for more information on this configuration bit.

Many PIC32 devices allow us to specify, via configuration-bit settings, which interrupt priority level will use the shadow register set (for example, `#pragma config FSRSSEL=PRIORITY_7`). Refer to the device data sheet to determine if your PIC32 target device supports this feature. This means we must specify which context-saving mechanism to use for each interrupt handler. The compiler will generate interrupt function prologue and epilogue code utilizing shadow register context saving for the `IPLnSRS` Interrupt Priority Level (IPL) specifier. It will use software context saving for the `IPLnSOFT` IPL specifier.

Other PIC32 variants may have 8 register sets (1 standard set and 7 shadow register sets) meaning that there are enough shadow register sets for every interrupt priority level. Therefore, you should use the IPLnSRS IPL specifier for every interrupt service routine on these device variants.

Note: Application code is responsible for applying the correct IPL specifier value to each ISR. The interrupt source's priority level must match the ISR's IPL value (for example, IPLnSRS) or the interrupt will not be handled correctly. Mismatching priority levels may result in critical runtime problems such as a stack overflow that overwrites data memory. This can include corruption of memory reserved for use by the Debug Executive, causing the debug tool to behave erratically.

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The compiler also supports an `IPLnAUTO` IPL specifier that uses the run-time value in `SRSCTL` to determine whether it should use software or SRS context-saving code. The compiler defaults to using `IPLnAUTO` when the IPL specifier is omitted from the `interrupt()` attribute.

For devices that do not support a shadow register set for interrupt context saving, use IPLnSOFT for all interrupt handlers.

Note: `SRS` has the shortest latency and `SOFT` has a longer latency due to registers saved on the stack. `AUTO` adds a few cycles to test if `SRS` or `SOFT` should be used.

For `IPL7(SRS | SOFT | AUTO)`, the compiler assumes that nothing can interrupt priority 7. This means that there is no reason to save `EPC` or `SRSCtl` and that global disabling of interrupts is unnecessary.

The `IPLnSAVEALL` interrupt priority specifier can be used with the interrupt attribute. Use this specifier in place of `IPLnSOFT` to force software context saving of all software-saved general registers even if they are not used within the Interrupt Service Routine (ISR). This attribute can be useful for some RTOS implementations.

The `keep_interrupts_masked` attribute can be used to modify the behavior of an interrupt handler. The attribute keeps interrupts masked for the whole function. Without this attribute, the XC32 compiler re-enables interrupts for as much of the function as it can. By keeping interrupts masked, support for nested interrupts is disables. Users can re-enable them as necessary in their own code.

The attribute `keep_interrupts_masked` can be combined with the `interrupt` attribute. This attribute causes the Interrupt Service Routine (ISR) prologue code to not re-enable interrupts. Application code may then choose whether and when to re-enable interrupts in the ISR.

16.2.2. Interrupt Pragma

Note: The interrupt pragma is provided only for compatibility when porting code from other compilers. The `interrupt` function attribute is the preferred and more common way to write an interrupt service routine.

```
# pragma interrupt function-name IPLn[AUTO|SOFT|SRS] [vector [@]vector-number [, vector-number-list]]
# pragma interrupt function-name  single [vector [@] 0
```

Where *n* is in the range of 0..7, inclusive.

The `IPLn[AUTO|SOFT|SRS]` IPL specifier may be all uppercase or all lowercase.

The function definition for a handler function indicated by an interrupt pragma must follow in the same translation unit as the pragma itself.

The `interrupt` attribute will also indicate that a function definition is an interrupt handler. It is functionally equivalent to the interrupt pragma.

For example, the definitions of `foo` below both indicate that it is an interrupt handler function for an interrupt of priority 4 that uses software context saving.

```
#pragma interrupt foo IPL4SOFT
void foo (void)
```

is functionally equivalent to

```
void __attribute__ ((interrupt(IPL4SOFT))) foo (void)
```


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16.2.3. __ISR Macros

The <sys/attribs.h> header file provides macros intended to simplify the application of attributes to interrupt functions. There are also vector macros defined in the processor header files. See the appropriate header file in the Device Family Pack (DFP) downloaded for your device.

Note: Some PIC32 target devices allow the exception/interrupt code to be in either the MIPS32® or microMIPS™ ISA mode via a device configuration bit (BOOTISA). On these devices, if your BOOTISA bit is set to microMIPS mode, add the 'micromips' attribute to your interrupt function. If your BOOTISA bit is set to MIPS32 mode, add the 'nomicromips' attribute to your interrupt function. See your device data sheet for more information on this configuration bit.

__ISR(V, IPL)

Use the `__ISR(v, IPL)` macro to assign the vector-number location and associate it with the specified IPL. This will place a jump to the interrupt handler at the associated vector location. This macro also applies the `nomips16` attribute since PIC32 devices require that interrupt handlers must use the MIPS32 instruction set.

The following example creates an interrupt handler function for the core timer interrupt that has an interrupt priority level of two. The compiler places a dispatch function at the associated vector location. To reach this function, the core timer interrupt flag and enable bits must be set, and the interrupt priority should be set to a level of two. The compiler generates software context-saving code for this handler function.

Example 16-2. Core Timer Vector, IPL2SOFT

```
#include <xc.h>
#include <sys/attribs.h>
void __ISR(_CORE_TIMER_VECTOR, IPL2SOFT) CoreTimerHandler(void);
```

The example below creates an interrupt handler function for the core software interrupt 0 that has an interrupt priority level of three. The compiler places a dispatch function at the associated vector location. To reach this function, the core software interrupt flag and enable bits must be set, and the interrupt priority should be set to a level of three. The device configuration fuses must assign Shadow Register Set 1 to interrupt priority level three. The compiler generates code that assumes that register context will be saved in SRS1.

Example 16-3. Core Software 0 Vector, IPL3SRS

```
#include <xc.h>
#include <sys/attribs.h>
void __ISR(_CORE_SOFTWARE_0_VECTOR,IPL3SRS) CoreSoftwareInt0Handler(void);
```

The example below creates an interrupt handler function for the core software interrupt 1 that has an interrupt priority level of zero. The compiler places a dispatch function at the associated vector location. To reach this function, the core software interrupt 1 flag and enable bits must be set, and the interrupt priority should be set to a level of zero. The compiler generates code that determines at run time whether software context saving is required.

Example 16-4. Core Software 1 Vector, IPL0AUTO

```
#include <xc.h>
#include <sys/attribs.h>
void __ISR(_CORE_SOFTWARE_1_VECTOR, IPL0AUTO) CoreSoftwareInt1Handler(void);
```

The next example is functionally equivalent to Example 14-4. Because the IPL specifier is omitted, the compiler assumes `IPL0AUTO`.

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Example 16-5. Core Software 1 Vector, Default

```
#include <xc.h>
#include <sys/attribs.h>
void __ISR(_CORE_SOFTWARE_1_VECTOR) _CoreSoftwareInt1Handler(void);
```

__ISR_AT_VECTOR(v, IPL)

Use the `__ISR_AT_VECTOR(v, IPL)` to place the entire interrupt handler at the vector location and associate it with the software-assigned interrupt priority. Application code is responsible for making sure that the vector spacing is set to accommodate the size of the handler. This macro also applies the nomips16 attribute since ISR functions are required to be MIPS32.

The following example creates an interrupt handler function for the core timer interrupt that has an interrupt priority level of two. The compiler places the entire interrupt handler at the vector location. It does not use a dispatch function. To reach this function, the core timer interrupt flag and enable bits must be set, and the interrupt priority should be set to a level of two. The compiler generates software context-saving code for this handler function.

Example 16-6. Core Timer Vector, IPL2SOFT

```
#include <xc.h>
#include <sys/attribs.h>
void __ISR_AT_VECTOR(_CORE_TIMER_VECTOR, IPL2SOFT) CoreTimerHandler(void);
```

INTERRUPT-VECTOR MACROS

Each processor-support header file provides a macro for each interrupt-vector number (See the appropriate header file in the Device Family Pack (DFP) downloaded for your device.). When used in conjunction with the `__ISR()` macro provided by the `sys\attribs.h` header file, these macros help make an Interrupt Service Routine easier to write and maintain.

The example below creates an interrupt handler function for the Timer 1 interrupt that has an interrupt priority level of seven. The compiler places a dispatch function at the vector location associated with macro `_TIMER_1_VECTOR` as defined in the device-specific header file. To reach this function, the Timer 1 interrupt flag and enable bits must be set, and the interrupt priority should be set to a level of seven. For devices that allow assignment of shadow registers to specific IPL values, the device Configuration bit settings must assign Shadow Register Set 1 to interrupt priority level seven. The compiler generates code that assumes that register context will be saved in SRS1.

Example 16-7. Interrupt-Vector with Handler

```
#include <xc.h>
#include <sys/attribs.h>
void __ISR (_TIMER_1_VECTOR, IPL7SRS) Timer1Handler (void);
```

16.3. Associating a Handler Function with an Exception Vector

For PIC32 devices, each interrupt source is mapped to an exception vector, as specified in the device data sheet. For devices with a constant vector spacing, a default of four words of space are reserved at each vector address for a dispatch to the handler function for that exception source. For devices with a variable vector spacing, the default linker script adjusts each vector's spacing for the size of the designated interrupt function.

An interrupt handler function can be associated with an interrupt vector either as the target of a dispatch function located at the exception vector address, or as being located directly at the exception vector address. A single handler function can be the target of multiple dispatch functions.

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The association of a handler function to one or more exception vector addresses is specified via a vector attribute on the function declaration. For compatibility purposes, you may also associate a handler function to a vector address using a clause of the interrupt pragma, a separate vector pragma, or a vector attribute on the function declaration.

16.3.1. Vector Attribute

A handler function can be associated with one or more exception vector addresses via an attribute. The `at_vector` attribute indicates that the handler function should itself be placed at the exception vector address. The `vector` attribute indicates that a dispatch function should be created at the exception vector address(es) which will transfer control to the handler function.

For example, the following declaration specifies that function `foo` will be created as an interrupt handler function of priority four. `foo` will be located at the address of exception vector 54.

```
void __attribute__ ((interrupt(IPL4SOFT))) __attribute__ ((at_vector(54)))
foo void);
```

The following declaration specifies that function `foo` will be created as an interrupt handler function of priority four. Define dispatch functions targeting `foo` at exception vector addresses 52 and 53.

```
void __attribute__ ((interrupt(IPL4SOFT))) __attribute__ ((vector(53, 52)))
foo void)
```

Handler functions that are linked directly to the vector will be executed faster. Although the vector spacing can be adjusted, there is limited space between vectors and linking a substantial handler function directly at a vector may cause it to overlap the higher vector locations, preventing their use. In such situations, using a dispatch function is a safer option.

The newer devices family features variable offsets for vector spacing. The compiler and linker work together to treat the `OFFnnn` SFRs as initialized data so that they are initialized at startup. This means there is no need for application code to initialize the `OFFnnn` SFRs. This also means that it is often more efficient to place the ISR within the vector table rather than using a dispatch function.

Example 16-8. Example Interrupt Service Routine

```
#include <xc.h>
#include <sys/attribs.h>
void
__ISR_AT_VECTOR(_CORE_TIMER_VECTOR, IPL7SRS)
CoreTimerHandler(void)
{
   // ISR code here
}
```

16.3.2. Interrupt-Pragma Vector Clause

Note: The interrupt pragma and its vector clause are provided only for compatibility when porting code from other compilers. The vector function attribute is the preferred way to associate a handler function to an exception vector address.

The interrupt pragma has an optional `vector` clause following the priority specifier.

```
# pragma interrupt function-nameIPL-specifier [vector [@]vector-number [,
vector-number-list]]
```

A dispatch function targeting the specified handler function will be created at the exception vector address for the specified vector numbers. If the first vector number is specified with a preceding “@” symbol, the handler function itself will be located there directly.

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For example, the following pragma specifies that function `foo` will be created as an interrupt handler function of priority four. `foo` will be located at the address of exception vector 54. A dispatch function targeting `foo` will be created at exception vector address 34.

```
#pragma interrupt foo IPL4AUTO vector @54, 34
```

The following pragma specifies that function `bar` will be created as an interrupt handler function of priority five. `bar` will be located in general purpose program memory (.text section). A dispatch function targeting `bar` will be created at exception vector address 23.

```
#pragma interrupt bar IPL5SOFT vector 23
```

16.3.3. Vector Pragma

Note: The vector pragma is provided only for compatibility when porting code from other compilers. The vector function attribute is the preferred way to associate a handler function to an exception vector address.

The `vector` pragma creates one or more dispatch functions targeting the indicated function. For target functions specified with the `interrupt` pragma, this functions as if the vector clause had been used. The target function of a `vector` pragma can be any function, including external functions implemented in assembly or by other means.

 # pragma vector `function-name` **vector** `vector-number [, vector-number-list]`

The following pragma defines a dispatch function targeting `foo` at exception vector address 54.

```
#pragma vector foo 54
```

16.4. Exception Handlers

The PIC32 devices also have exception vectors for non-interrupt exceptions. These exceptions are grouped into bootstrap exceptions and general exceptions.

16.4.1. Bootstrap Exception

A Reset exception is any exception which occurs while bootstrap code is running ($Status_{BEV}$=1). All Reset exceptions are vectored to `0xBFC00380`.

At this location, the 32-bit toolchain places a branch instruction targeting a function named `_bootstrap_exception_handler()`. In the standard library, a default weak version of this function is provided, which merely causes a software Reset. When compiling for in-circuit debugging or emulation, the default implementation of `_bootstrap_exception_handler` will first cause a software breakpoint and then a software Reset. If the user application provides an implementation of `_bootstrap_exception_handler()`, that implementation will be used instead.

16.4.2. General Exception

A general exception is any non-interrupt exception which occurs during program execution outside of bootstrap code ($Status_{BEV}$=0). General exceptions are vectored to offset `0x180` from `EBase`.

At this location, the 32-bit toolchain places a branch instruction targeting a function named `_general_exception_context()`. The provided implementation of this function saves context, calls an application handler function, restores context and performs a return from the exception instruction. The context saved is the `hi` and `lo` registers, and all General Purpose Registers except `s0-s8`, which are defined to be preserved by all called functions and so are not necessary to actively save here again.

```
void _general_exception_handler (void);
```

A weak default implementation of `_general_exception_handler()` is provided in the standard library which merely causes a software Reset. When compiling for in-circuit debugging or emulation, the default implementation of `_general_exception_handler` will first cause a

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software breakpoint and then a software Reset. If the user application provides an implementation of `_general_exception_handler()`, that implementation will be used instead.

16.4.3. Simple TLB Refill Exception

During an instruction fetch or data access, a TLB refill exception occurs when no TLB entry matches a reference to a mapped address space and the EXL bit is 0 in the Status register. Note that this is distinct from the case in which an entry matches, but has the valid bit off. In that case, a TLB Invalid exception occurs.

```
void _simple_tlb_refill_exception_handler(void);
```

A weak default implementation of `_simple_tlb_refill_exception_handler()` is provided which merely causes a software Reset.

When compiling for in-circuit debugging or emulation, the default implementation of `_simple_tlb_refill_exception_handler` will first cause a software breakpoint and then a software Reset.

16.4.4. Cache Error Exception

A cache-error exception occurs when an instruction or data reference detects a cache tag or data error. This exception is not maskable. To avoid disturbing the error in the cache array the exception vector is to an unmapped, uncached address. This exception is precise.

```
void _cache_err_exception_handler(void);
```

A weak default implementation of `_cache_err_exception_handler()` is provided which merely causes a software Reset. When compiling for in-circuit debugging or emulation, the default implementation of `_cache_err_exception_handler` will first cause a software breakpoint and then a software Reset.

16.5. Context Switching

The compiler will automatically link code into your project which saves the current status when an interrupt occurs and then restores this status when the interrupt returns.

16.5.1. Context Save on Interrupt

The standard calling convention for C/C++ functions will already preserve `zero`, `s0-s7`, `gp`, `sp`, and `fp`. `k0` and `k1` are used by the compiler to access and preserve non-GPR context, but are always accessed atomically (that is, in sequences with global interrupts disabled), so they need not be preserved actively. A handler function will actively preserve the `a0-a3`, `t0-t9`, `v0`, `v1` and `ra` registers in addition to the standard registers.

An interrupt handler function will also actively save processor status registers that are utilized by the handler function. Specifically, the `EPC`, `SR`, `hi` and `lo` registers are preserved as context. All available DSP accumulators are preserved as necessary.

In addition, if a DSP accumulator register is preserved, the DSP Control register is also preserved.

Handler functions may use a shadow register set to preserve the General Purpose Registers, enabling lower latency entry into the application code of the handler function. On some devices, the shadow register set is assigned to an interrupt priority level (IPL) using the device Configuration bit settings (for example, `#pragma config FSRSSEL=PRIORITY_6`). While on other devices, the shadow register set may be hard wired to IPL7. Consult the target device's data sheet for more information on the shadow register set.

By default, the compiler saves the Floating-point Unit (FPU) general registers and the FCSR register on the stack as required for `interrupt()` attributed functions. This includes functions that use the `__ISR(vector,priority)` macro. As always, to minimize the required context saving for an ISR, avoid making calling functions from within the ISR so that the compiler generates code for only the registers used within the ISR.

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The `no_fpu` function attribute can be used to suppress context saving of the FPU register. For example:

```
void __attribute__((interrupt(IPL7SRS),vector(_CORE_TIMER_VECTOR),no_fpu)) ct_isr(void)
{
  foo();
}
```

It also causes the compiler to disable the FPU in the ISR prologue, such that any use of the FPU from within the ISR context would result in a general exception. This means that any higher-priority ISR interrupting an ISR using the `no_fpu` attribute must re-enable the FPU if floating-point operations are required.

16.5.2. Context Restoration

Any objects saved by software are automatically restored by software before the interrupt function returns. The order of restoration is the reverse to that used when context is saved.

If the `no_fpu` function attribute has been used with an interrupt function, the FPU-enable bit is restored to its original state in the function's epilogue code.

16.6. Latency

There are two elements that affect the number of cycles between the time the interrupt source occurs and the execution of the first instruction of your ISR code. These are:

- **Processor Servicing of Interrupt** – The amount of time it takes the processor to recognize the interrupt and branch to the first address of the interrupt vector. To determine this value, refer to the processor data sheet for the specific processor and interrupt source being used.
- **ISR Code** – The compiler saves the registers that were used by the ISR. Moreover, if the ISR calls an ordinary function, then the compiler will save all the working registers, even if they are not all used explicitly in the ISR itself. This must be done, because the compiler cannot know, in general, which resources are used by the called function.

16.7. Nesting Interrupts

Interrupts may be nested. The interrupt priority scheme implemented in the PIC32M architecture allows you to specify which interrupt sources may be interruptible by others. See your device data sheet for explicit details on interrupt operation.

The compiler Interrupt Service Routine prologue code automatically re-enables interrupts by default.

16.8. Enabling/Disabling Interrupts

The built-in functions `__builtin_get_isr_state` and `__builtin_set_isr_state` can be used to check and set the Interrupt Priority Level and Interrupt Enable bits. The `__builtin_disable_interrupts` and `__builtin_enable_interrupts` built-in functions can be used to disable and enable interrupts. See Built-in Functions for a description of these built-in functions.

16.9. ISR Considerations

There are a few things to consider when writing an interrupt service routine.

As with all compilers, limiting the number of registers used by the interrupt function, or any functions called by the interrupt function, may result in less context switch code being generated and executed by the compiler, see Latency. Keeping interrupt functions small and simple will help you achieve this.

When interrupt latency is a concern, avoid calling other functions from your ISR. You may be able to replace a function call with a `volatile` flag that is handled by your application's main control loop.

If you are building with link-time optimizations (the `-flto` option), you might need to take special steps to ensure that code associated with interrupts is not removed. These optimizations for the

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most part work on the whole program. When the whole program is analyzed, interrupt functions will be found to be not called by any other function, so the compiler believes it can remove them. To prevent this from occurring, interrupt functions must be marked with the `used` attribute to inform the compiler that they are not redundant. The same attribute should be used with data objects that are used by interrupt functions. As an alternative, consider building source files containing interrupt functions with link-time optimizations disabled.

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17. Main, Runtime Start-up and Reset

When creating C/C++ code, there are elements that are required to ensure proper program operation: a `main` function must be present; start-up code will be needed to initialize and clear variables and setup registers and the processor; and Reset conditions will need to be handled.

17.1. The Main Function

The identifier `main` is special. It must be used as the name of a function that will be the first function to execute in a program. You must always have one and only one function called `main` in your programs. Code associated with `main`, however, is not the first code to execute after Reset. Additional code provided by the compiler and known as the runtime start-up code is executed first and is responsible for transferring control to the `main()` function.

17.2. Runtime Start-Up Code

A C/C++ program requires certain objects to be initialized and the processor to be in a particular state before it can begin execution of its function `main()`. It is the job of the runtime start-up code to perform these tasks before the execution of `main()`.

If you require any additional initialization to be performed, you typically do not need to modify the default runtime startup code provided by the compiler. That would only be required if any of the existing actions taken by the startup code needed to be changed. The special On Reset and On Bootstrap hooks allow the startup code to be customized at various places in the startup sequence.

The PIC32 start-up code will perform the following tasks, which are discussed in the sections that follow.

1. Switch to the selected instruction set (ISA) mode.
2. Jump to NMI handler (`_nmi_handler`) if an NMI occurred.
3. Initialize stack pointer and heap.
4. Initialize global pointer in all register sets available on the selected target device.
5. Call the application-provided “on reset” routine (`_on_reset`).
6. Call the `__pic32_init_cache` routine to initialize the L1 cache on target devices that feature an L1 cache.
7. Call the `__pic32_tlb_init_ebi_sqi` routine to initialize the TLB on -target devices that use pre-mapped EBI and SQI external memory regions.
8. Clear uninitialized small bss sections.
9. Initialize data using the linker-generated data-initialization template.
10. If the target device that features a bus matrix and the application uses a RAM function, initialize the bus matrix for execution from data memory.
11. Initialize the CP0 registers, including the enabling of the DSPr2 engine and Floating-Point Unit (FPU) for devices on which these are implemented.
12. Call the “On Bootstrap” routine (`_on_bootstrap`).
13. Change the location of exception vectors.
14. For C++, call the C++ initialization code to invoke all constructors for file-scope static storage objects.
15. Call `main()`.
16. On return from main(), call `exit()` if the `CALL_EXIT` macro is defined; otherwise, enter an infinite loop.

The following provisions are made regarding the run-time model:

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- Kernel mode only
- KSEG1 only
- RAM functions are attributed with `__ramfunc__` or `__longramfunc__`, (defined in `sys/attribs.h`), meaning that all RAM functions end up in the `.ramfunc` section and the function is `ramfunc` attributed.

17.2.1. Switch to the Selected Instruction Set (ISA) Mode

Some PIC32 MCUs support both the MIPS32 and microMIPS Instruction Set Architecture (ISA) modes. The microMIPS instruction set delivers the same functionality as the MIPS32 ISA, with the added benefit of smaller code size.

Devices that support both the MIPS32 and microMIPS ISA modes use the BOOTISA configuration bit in a device Configuration Word to determine the ISA mode on boot. The device can be configured to boot to either the MIPS32 or the microMIPS ISA mode. See the target-device data sheet for more information on the BOOTISA bit.

The microMIPS ISA supplies assembler-source code compatibility with MIPS32 instead of binary compatibility. Because of this, the XC32 toolchain provides a copy of the runtime start-up code compiled for the MIPS32 ISA as well as a copy compiled for the microMIPS ISA. The toolchain determines which copy to link based on the presence of the `-mmicromips` command-line option. In the MPLAB X IDE project properties, select *xc32-ld >Option category: Libraries> "Link microMIPS compressed startup code and libraries"* to get the `-mmicromips` option.

For added flexibility, the default start-up code attempts to ensure that the linked Precompiled mode matches the current ISA mode at runtime. To enable this, a binary code sequence is required that can be run in either instruction set and change code paths, depending on the instruction set that is being used.

The following binary sequence achieves this goal:

```
0x1000wxyz  // where w,x,y,z represent hexadecimal digits
0x00000000
```

For the MIPS32 instruction set, this binary sequence is interpreted as:

```
// branch to location of more MIPS32 instructions
BEQ $0, $0, wxyz
NOP
```

For the microMIPS instruction set, this binary sequence is interpreted as:

```
ADDI32 $0, $0, wxyz // do nothing
NOP                 // fall through to more microMIPS instructions
```

In the default runtime startup-code, we place this binary sequence at the _reset symbol, which is then located at the reset vector by the default linker script. We follow this binary sequence with a `jal _startup` to jump to the remainder of the startup code.

This sequence is included only for devices that support both the MIPS32 and microMIPS ISA modes.

On PIC32M devices, bit 0 of the address indicates the ISA mode. When this bit is clear, the device is running in MIPS32 Mode. When this bit is set, the device is running in either MIPS16 or microMIPS mode, depending on the device core. This means that if you execute a hard-coded jump, bit 0 must be set to the appropriate value for your target function. Hard-coded jumps are most commonly seen when jumping from a bootloader to a bootloaded application.

17.2.2. Jump to NMI Handler (`_nmi_handler`) if an NMI Occurred

If a Non-Maskable Interrupt (NMI) caused entry to the Reset vector, which is located at 0xBFC00000 on PIC32M MIPS cores, the startup code's `_reset` function jumps to an NMI Handler procedure

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named `_nmi_handler`. A weak version of the NMI handler procedure is provided that performs an `ERET`.

To override the default NMI Handler with an application-specific handler, use an assembly-code .S file to create a routine named `__nmi_handler`. This routine *must* be written in assembly code because the startup code calls this routine before the C runtime environment is initialized. The `__nmi_handler` routine must either use only the k0, k1 CPU registers or it must save context before using other registers.

17.2.3. Initialize Stack Pointer and Heap

The Stack Pointer (`sp`) register must be initialized in the start-up code. To enable the start-up code to initialize the `sp` register, the linker must initialize a variable which points to the end of KSEG0/KSEG1 data memory.

Note: The end of data memory is different based on whether RAM functions exist. If RAM functions exist, then part of the DRM must be configured for the kernel program to contain the RAM functions, and the Stack Pointer is located one word prior to the beginning of the DRM kernel program boundary address. If RAM functions do not exist, then the Stack Pointer is located at the true end of DRM.

The linker allocates the stack to KSEG0 on devices featuring an L1 data cache. It allocates the stack to KSEG1 on devices that do not have an L1 cache.

This variable is named `_stack`. The user can change the minimum amount of stack space allocated by providing the command line option `--defsym _min_stack_size=`*`N`* to the linker. `_min_stack_size` is provided by the linker script with a default value of `1024`. On a similar note, the user may wish to utilize a heap with their application. While the start-up code does not need to initialize the heap, the standard C libraries (`sbrk`) must be made aware of the heap location and its size. The linker creates a variable to identify the beginning of the heap. The location of the heap is the end of the utilized KSEG0/KSEG1 data memory.

The linker allocates the heap to KSEG0 on devices that have an L1 cache. It allocates the heap to KSEG1 on devices that do not have an L1 cache.

This variable is named `_heap`. A user can change the minimum amount of heap space allocated by providing the command line option `--defsym=_min_heap_size=`*`M`* to the linker. If the heap is used when the heap size is set to zero, the behavior is the same as when the heap usage exceeds the minimum heap size. Namely, it overflows into the space allocated for the stack.

The heap and the stack use the unallocated KSEG0/KSEG1 data memory, with the heap starting from a low address in KSEG0/KSEG1 data memory, and growing upwards towards the stack while the stack starts at a higher address in KSEG1 data memory and grows downwards towards the heap. The linker attempts to allocate the heap and stack together in the largest gap of memory available in the KSEG0/KSEG1 data memory region. If enough space is not available based on the minimum amount of heap size and stack size requested, the linker issues an error.

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Figure 17-1. Stack and Heap Layout

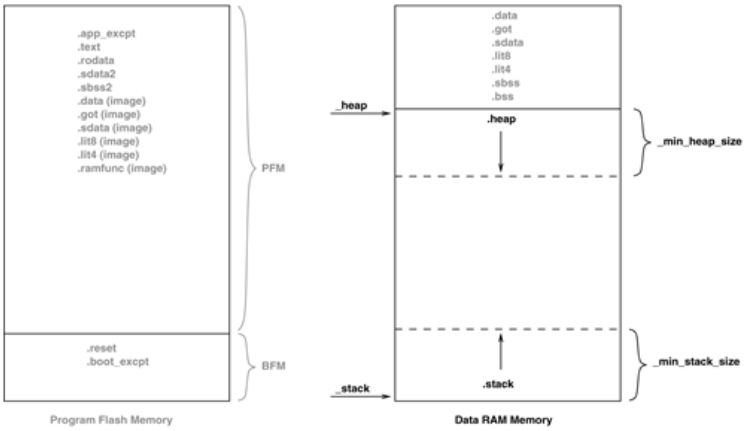
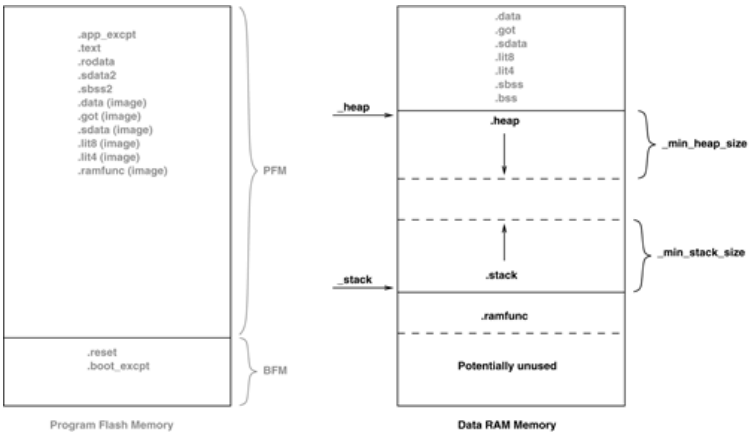


Figure 17-2. Stack and Heap Layout with RAM Functions



The linker must then group all of the above input sections together. This grouping is handled by the default linker script. The run-time start-up code must initialize the `gp` register to point to the "middle" of this output section. To enable the start-up code to initialize the `gp` register, the linker script must initialize a variable which is 32 KB from the start of the output section containing the "small" variables and constants. This variable is named `_gp` (to match core linker scripts). Besides being initialized in the standard GPR set, the Global Pointer must also be initialized in the register shadow set.

17.2.4. Initialize Global Pointer

The compiler toolchain supports Global Pointer (`gp`) relative addressing. Loads and stores to data residing within 32KB of either side of the address stored in the `gp` register can be performed in a single instruction using the `gp` register as the base register. Without the Global Pointer, loading data from a static memory area takes two instructions – one to load the Most Significant bits of the 32-bit constant address computed by the compiler/linker and one to do the data load.

To utilize `gp`-relative addressing, the compiler and assembler must group all of the "small" variables and constants into one of the following sections:

`.lit4.`	`lit8`
`.sdata.`	`sbss`
`.sdata.*`	`sbss.*`

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.gnu.linkonce.s.*	.gnu.linkonce.sb.*

The linker must then group all of the above input sections together. This grouping is handled by the default linker script. The run-time start-up code must initialize the gp register to point to the "middle" of this output section. To enable the start-up code to initialize the gp register, the linker script must initialize a variable which is 32 KB from the start of the output section containing the "small" variables and constants. This variable is named _gp (to match core linker scripts).

Some PIC32 MCUs have more than one register set. The additional register sets can be used as interrupt shadow register sets. The Global Pointer must be initialized in each of the register sets. The default start-up code does this by looping through each of the register sets.

In the loop, the CP0 SRSCtl register's PSS field must be set to the shadow set in which to initialize the global pointer. In the source code, we start with the highest register set, as defined by the PIC32_SRS_SET_COUNT macro, and work down to zero. By initializing the global pointer in the previous set as iterate through the register sets, we initialize the register in each of the sets on the device.

17.2.5. The "On Reset" Routine

Some hardware configurations require special initialization, often within the first few instruction cycles after Reset. For instance, you might need to initialize a DDR RAM controller before the program's variables are initialized. To achieve this, there is an On Reset hook provided, so that you do not need to customize the entire startup code sequence.

An empty weak implementation of the On Reset routine (_on_reset) is provided with the start-up code. It is called by the runtime startup code after minimal initialization of the C/C++ language context.

If you do need to implement your own version of this routine, you can modify the following stub (note the leading underscore character in the function's name).

```
void _on_reset(void)
{
  // Add code to be executed soon after reset here
}
```

This routine can be placed into any source file in your project and you do not need to adjust any compiler options to have it executed.

Special consideration needs to be taken when writing this routine in C or C++. The code should not assume that the runtime environment has been fulled established. See Runtime Start-Up Code for the order in which the environment is set up. Most importantly, statically allocated variables will not have been initialized (with either the specified initializer or a zero value, as required for uninitialized variables), nor will any static constructors have been called for C++ applications. References to non-automatic variables in C/C++ applications might yield unexpected or unpredictable results; however, the stack pointer will have been initialized.

17.2.6. Initialize L1 Cache

If the target device implements a L1 cache, this is automatically initialized by the runtime startup code. Based on the definition of the symbol INIT_L1_CACHE, the startup code will call the __pic32_init_cache assembly routine, which will initialize the primary instruction and primary data caches and ensure the cache and line sizes for both caches are appropriately configured. By default, the instruction cache will use a base address that corresponds to the kseg0_program_mem memory region and the data cache will use a base address that corresponds to the kseg0_data_mem memory region.

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17.2.7. Initialize Translation Lookaside Buffer

Some PIC32 devices feature a Memory Management Unit (MMU) with a Translation Lookaside Buffer (TLB). On some of these devices, the data sheet describes specific ranges of KSEG2/KSEG3 regions as being dedicated to the Serial Quad Interface (SQI) and/or the External Bus Interface (EBI).

For these devices, the default runtime startup code will call the `__pic32_tlb_init_ebi_sqi` assembly routine that initializes the TLB from a table of values (`.tlb_init_values`) defined in the linker script.

17.2.8. Clearing Objects

The runtime start-up code will clear all memory locations occupied by uninitialized variables so they will contain zero before `main()` is executed.

Variables whose contents should be preserved over a Reset should use the `persistent` attribute, see Standard Type Qualifiers for more information. Such variables are linked in a different area of memory and are not altered by the runtime start-up code in any way.

17.2.9. Initialize Objects and RAM Functions

Objects accessed from RAM and functions executed from RAM must have their allocated RAM initialized before execution of the `main()` function can commence, and this is a significant task performed by the runtime startup code.

Those non-`auto` objects that are uninitialized must be cleared (assigned the value 0) before execution of `main()` begins. Such objects are not assigned a value in their definition, for example `output` in the following example:

```
int output;
int main(void) { ...
```

Another task of the runtime start-up code is to ensure that any initialized objects contain their initial value before the program begins execution. Initialized objects are those that are not `auto` objects and that are assigned an initial value in their definition, for example `input` in the following example:

```
int input = 0x88;
int main(void) { ...
```

Such initialized objects have two components: their initial value (0x0088 in the above example) stored in program memory (that is, placed in the HEX file), and space reserved in RAM, where the objects will reside and be accessed during program execution (runtime).

Four initialized data sections exist: `.sdata`, `.data`, `.lit4`, and `.lit8`. The `.sdata` section is a data segment containing initialized objects less than or equal to *n* bytes, as specified by the `-Gn` command line option. The `.data` section is a data segment containing initialized objects not included in `.sdata`. The `.lit4` and `.lit8` sections contain constants, (usually floating-point) which the assembler stores in memory rather than in the instruction stream.

The runtime start-up code will copy all the blocks of initial values from program memory to RAM so the objects will contain the correct values before `main()` is executed.

Since `auto` objects are dynamically created, they require code to be positioned in the function in which they are defined to perform their initialization. It is possible that the initial value of an `auto` object may change on each instance of the function and so the initial values cannot be stored in program memory and copied. As a result, initialized `auto` objects are not considered by the runtime start-up code, but are instead initialized by assembly code in each function output.

Note: Initialized `auto` objects can impact code performance, particularly if the objects are large in size. Consider using global or `static` objects instead.

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Objects whose contents should be preserved over a Reset should be qualified with the `persistent` attribute, see Standard Type Qualifiers. Such objects are linked at a different area of memory and are not altered by the runtime start-up code in any way.

Any functions that use the `ramfunc` attribute are copied from program memory to RAM before they are executed. This is also performed by the runtime startup code, in much the same way that initialized objects have their initial value copied before they are accessed.

17.2.9.1. Data-initialization Template

In order to clear or initialize all the data and RAM function sections, the linker creates a data-initialization template, which is loaded into an output section named `.dinit` and allocated space in program memory. The code in the C/C++ start-up module, `crt0.o`, interprets this template, which indicates how the appropriate sections must be initialized.

The sections initialized by this template includes those holding intialized objects (such as the `.data` section) as well as sections containing `ramfunc` attributed functions, all of which must have values copied from the template in program to data memory where the objects and functions will be accessed at runtime. Other data sections holding unititialized objects (such as the `.bss` section) are cleared by the template before the `main()` function is called. The persistent data section (`.pbss`) is not considered by the runtime startup code. When the application's main program takes control, all objects and RAM functions in data memory will have been initialized.

When programming devices with Error Correction Code (ECC) RAM enabled, the initial write after a Power-on Reset to any memory location used by the program must be performed as a 32-bit write to properly set up the ECC and avoid runtime memory access failures. To achieve this, you can configure the compiler's runtime startup code to initialize data using 32-bit word writes. This feature also has a speed benefit on devices without ECC RAM, due to 32-bit word writes being faster than byte operations. Some applications might also see reduced flash usage, where the linker merges the initialization templates for data and bss sections that are allocated contiguously; however, any padding or alignment gaps added between data objects can sometimes result in larger flash usage. This feature groups data objects very aggressively to reduce flash space usage and padding. If an object is placed with an absolute address in RAM such that it partitions the memory space, there is an increased chance of memory allocation failing. Additionally, this feature does not support data initialization compression, so if the data in your application is suitable for compression, code size might be smaller with this feature disabled. For more details on the `--word-dinit` linker option and other linker settings that control data initialization, refer to the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide*.

The data initialization template contains one record for each output section that needs initializing. Each record has one of several formats, represented by a format code within the record. The record formats specify how the data values are stored in the record itself and how they should be used to initialize the corresponding section. The `--dinit-compression` linker option (see Dinit-compression Option) controls which of these records can be utilized by the template. The numerical format codes and the type of initialization they represent are as follows:

- **#0** Fill the RAM defined by the corresponding output section with zeros. No data bytes are stored in the record. Used by bss sections.
- **#1** Copy each byte of data from the record's array to the RAM associated with the output section. Used by data and lit sections, and sections associated with `ramfunc` functions.
- **#2** Copy the same 16-bit value into the RAM associated with the output section multiples times. Used by data and lit sections whose initial values are a repeating sequence.
- **#3** Copy the same 32-bit value into the RAM associated with the output section multiple times. Used by data and lit sections whose initial values are a repeating sequence.
- **#4** Copy and decompress a simplified version of PackBits encoded data_record. Used by data and lit sections, and sections that contain large numbers of consecutive zero bytes.

The data contained in each record type can be represented by the equivalent C structures that are presented below. The first element of the record is a pointer to the section in data memory. The

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second element is the section length or repeat count. The third element is the format code, which indicates the type of the record (listed above) and hence how the corresponding section should be initialized. The forth element is used for either alignment padding or an initial value. A fifth element, if present, is an array of data bytes.The template is terminated by a null instruction word.

```
/* For format values of 0 */
struct data_record_bss {
    uint32_t *dst;     /* destination address */
    uint32_t len;      /* length in bytes */
    uint16_t format;   /* format code */
    uint16_t padding;  /* padding for alignment */
};

/* For format values of 1 and 3 (also identical to format value 4) */
struct data_record_standard {
    uint32_t *dst;     /* destination address */
    uint32_t len;      /* length in bytes */
    uint16_t format;   /* format code */
    uint16_t padding;  /* padding for alignment or a 16-bit initialization value */
    uint32_t dat[0];   /* object-length data - holding initialization data */
};

/* For format values of 2 - objects are initialised with the same 16-bit value */
struct data_record_short_standard {
    uint32_t *dst;     /* destination address */
    uint32_t count;    /* count in bytes */
    uint16_t format;   /* format code */
    uint16_t dat       /* 16-bit repeated value data */
};

/* For format values of 4 - A simplified PackBits data compression is applied, where
each run of zeros is replaced by two 8-bit characters in the compressed array:
zero followed by the number of zeros in the original run. */
struct data_record_compressed {
    uint32_t *dst;               /* destination address */
    uint32_t count;              /* count in bytes */
    uint16_t format;             /* format code */
    uint16_t padding;            /* 16-bit repeated value data */
    uint32_t compressed_data[0]; /* compressed intialized data */
};
```

17.2.10. Initialize Bus Matrix Registers

On some of the PIC32 MCUs, the bus matrix registers (`BMXDKPBA`, `BMXDUDBA`, `BMXDUPBA`) must be initialized by the start-up code if any RAM functions exist. The startup code leaves these registers in their state when RAM functions do not exist in the projects. The linker collects all RAM functions and allocates them to a section of data memory that is aligned on a 2K-alignment boundary. To determine whether any RAM functions exist in the application, the linker provides a variable that contains the beginning address of this section. This variable is named `_ramfunc_begin`.

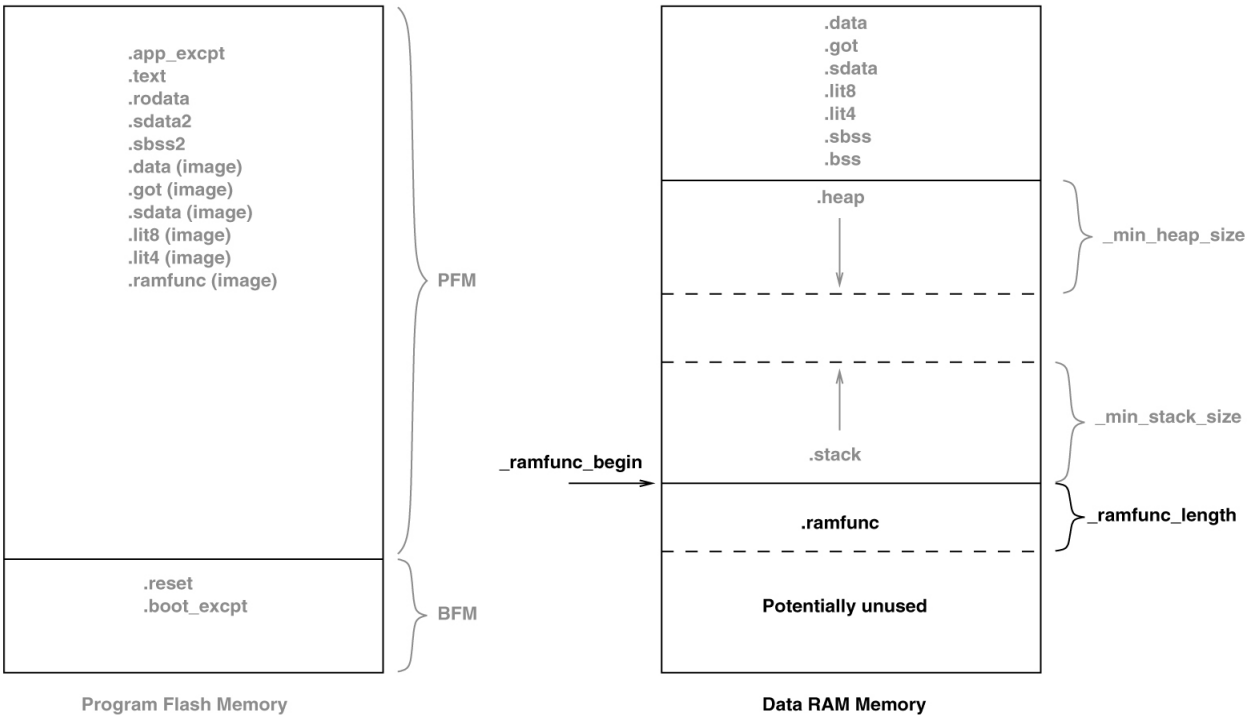
In addition, the linker provides a 2K-aligned variable required for the boundary register (BMXDKPBA). The variable is named `_bmxdkpba_address`. The linker also provides two variables that contains the addresses for the bus matrix register. These variables are named `_bmxdkpba_address`, `_bmxdudba_address`, and `_bmxdupba_address`.

The linker ensures that RAM functions are aligned to a 2K-alignment boundary as is required by the BMXDKPBA register.

On other PIC32 devices, no special bus initialization is required to execute RAM functions.

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Figure 17-3. Bus Matrix Initialization



Initialize CP0 Registers

The `CP0` registers are initialized in the following order:

1. `Count` register
2. `Compare` register
3. `EBase` register
4. `IntCtl` register
5. `Cause` register
6. `Status` register

Hardware Enable Register (`HWREna` – CP0 Register 7, Select 0)

This register contains a bit mask that determines which hardware registers are accessible via the `RDHWR` instruction. Privileged software may determine which of the hardware registers are accessible by the `RDHWR` instruction. In doing so, a register may be virtualized at the cost of handling a Reserved Instruction Exception, interpreting the instruction, and returning the virtualized value. For example, if it is not desirable to provide direct access to the `Count` register, access to the register may be individually dis-abled, and the return value can be virtualized by the operating system.

No initialization is performed on this register in the PIC32 start-up code.

Bad Virtual Address Register (`BadVAddr` – CP0 Register 8, Select 0)

This register is a read-only register that captures the most recent virtual address that caused an Address Error exception (`AdEL` or `AdES`).No initialization is performed on this register in the PIC32 start-up code.

Count Register (`Count` – CP0 Register 9, Select 0)

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This register acts as a timer, incrementing at a constant rate, whether or not an instruction is executed, retired, or any forward progress is made through the pipeline. The counter increments every other clock if the DC bit in the Cause register is '0'. The Count register can be written for functional or diagnostic purposes, including at Reset or to synchronize processors. By writing the CountDM bit in the Debug register, it is possible to control whether the Count register continues incrementing while the processor is in Debug mode. This register is cleared in the default PIC32 start-up code.

Status Register (Status – CP0 Register 12, Select 0)

This register is a read/write register that contains the operating mode, Interrupt Enabling, and the diagnostic states of the processor. Fields of this register combine to create operating modes for the processor.

The following settings are initialized by the default PIC32 start-up code (0b000000000x0xx0?0000000000000000):

- Access to Coprocessor 0 not allowed in User mode (CU0 = 0)
- User mode uses configured endianess (RE = 0)
- No change to exception vectors location (BEV = no change)
- No change to flag bits that indicate reason for entry to the Reset exception vector (SR, NMI = no change)
- Interrupt masks are cleared to disable any pending interrupt requests (IM7..IM2 = 0, IM1..IM0 = 0)
- Interrupt priority level is 0 (IPL = 0)
- Base mode is Kernel mode (UM = 0)
- Error level is normal (ERL = 0)
- Exception level is normal (EXL = 0)
- Interrupts are disabled (IE = 0)

The DSPr2 engine is enabled on target devices featuring the DSPr2 engine (MX = 1).

The IEEE 754 compliant Floating-Point Unit is enabled for target devices that support the FPU. The FPU is configured in the FR64 mode, which defines 32 64-bit float-ing-point general registers (FPRs) with all formats supported in each register (CU1=1) and (FR=1).

Interrupt Control Register (IntCtl – CP0 Register 12, Select 1)

This register controls the expanded interrupt capability added in Release 2 of the Architecture, including vectored interrupts and support for an external interrupt controller.

This register contains the vector spacing for interrupt handling. The vector spacing portion of this register (bits 9..5) is initialized with the value of the _vector_spacing symbol by the PIC32 start-up code. All other bits are set to '1'.

Shadow Register Control Register (SRSCtl – CP0 Register 12, Select 2)

This register controls the operation of the GPR shadow sets in the processor. The default startup code uses the SRSCtl register when it initializes the Global Pointer register in all register sets. However, it restores the original SRSCtl value after the GP register is initialized.

Shadow Register Map Register (SRSMap – CP0 Register 12, Select 3)

This register contains eight 4-bit fields that provide the mapping from a vector number to the shadow set number to use when servicing such an interrupt. The values from this register are not used for a non-interrupt exception, or a non-vectored interrupt (CauseIV = 0 or IntCtlVS = 0). In such cases, the shadow set number comes from SRSCtlESS. If SRSCtlHSS is zero, the results

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of a software read or write of this register are UNPREDICTABLE. The operation of the processor is UNDEFINED if a value is written to any field in this register that is greater than the value of SRSCtlHSS. The SRSMap register contains the shadow register set numbers for vector numbers 7..0. The same shadow set number can be established for multiple interrupt vectors, creating a many-to-one mapping from a vector to a single shadow register set number.

No initialization is performed on this register in the PIC32 start-up code.

Cause Register (Cause – CP0 Register 13, Select 0)

This register primarily describes the cause of the most recent exception. In addition, fields also control software interrupt requests and the vector through which interrupts are dispatched. With the exception of the DC, IV, and IP1..IP0 fields, all fields in the Cause register are read-only. Release 2 of the Architecture added optional support for an External Interrupt Controller (EIC) interrupt mode, in which IP7..IP2 are interpreted as the Requested Interrupt Priority Level (RIPL).

The following settings are initialized by the PIC32 start-up code:

- Enable counting of Count register (DC = no change)
- Use the special exception vector (16#200) (IV = 1)
- Disable software interrupt requests (IP1..IP0 = 0)

Exception Program Counter (EPC – CP0 Register 14, Select 0)

This register is a read/write register that contains the address at which processing resumes after an exception has been serviced. All bits of the EPC register are significant and must be writable. For synchronous (precise) exceptions, the EPC contains one of the following:

- The virtual address of the instruction that was the direct cause of the exception
- The virtual address of the immediately preceding branch or jump instruction, when the exception causing instruction is a branch delay slot and the Branch Delay bit in the Cause register is set.

On new exceptions, the processor does not write to the EPC register when the EXL bit in the Status register is set; however, the register can still be written via the MTC0 instruction.

No initialization is performed on this register in the PIC32 start-up code.

Processor Identification Register (PRId – CP0 Register 15, Select 0)

This register is a 32-bit read-only register that contains information identifying the manufacturer, manufacturer options, processor identification, and revision level of the processor.

No initialization is performed on this register in the PIC32 start-up code.

Exception Base Register (EBase – CP0 Register 15, Select 1)

This register is a read/write register containing the base address of the exception vectors used when StatusBEV equals 0, and a read-only CPU number value that may be used by software to distinguish different processors in a multi-processor system. The EBase register provides the ability for software to identify the specific processor within a multi-processor system, and allows the exception vectors for each processor to be different, especially in systems composed of heterogeneous processors. Bits 31..12 of the EBase register are concatenated with zeros to form the base of the exception vectors when StatusBEV is 0. The exception vector base address comes from fixed defaults when StatusBEV is 1, or for any EJTAG Debug exception. The Reset state of bits 31..12 of the EBase register initialize the exception base register to 16#8000-0000, providing backward compatibility with Release 1 implementations. Bits 31..30 of the EBase register are fixed with the value 2#10 to force the exception base address to be in KSEG0 or KSEG1 unmapped virtual address segments.

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If the value of the exception base register is to be changed, this must be done with `StatusBEV` equal 1. The operation of the processor is UNDEFINED if the Exception Base field is written with a different value when `StatusBEV` is 0.

Combining bits 31..30 with the Exception Base field allows the base address of the exception vectors to be placed at any 4K byte page boundary. If vectored interrupts are used, a vector offset greater than 4K byte can be generated. In this case, bit 12 of the Exception Base field must be zero. The operation of the processor is UNDEFINED if software writes bit 12 of the Exception Base field with a 1 and enables the use of a vectored interrupt whose offset is greater than 4K bytes from the exception base address.

This register is initialized with the value of the `_ebase_address` symbol by the PIC32 start-up code. `_ebase_address` is provided by the linker script with a default value of the start of KSEG1 program memory. The user can change this value by providing the command line option `--defsym _ebase_address=A` to the linker.

Config Register (`Config` – CP0 Register 16, Select 0)

This register specifies various configuration and capabilities information. Most of the fields in the `Config` register are initialized by hardware during the Reset exception pr-ocess, or are constant.

No initialization is performed on this register in the PIC32 start-up code.

Config1 Register (`Config1` – CP0 Register 16, Select 1)

This register is an adjunct to the `Config` register and encodes additional information about the capabilities present on the core. All fields in the `Config1` register are read-only.

No initialization is performed on this register in the PIC32 start-up code.

Config2 Register (`Config2` – CP0 Register 16, Select 2)

This register is an adjunct to the `Config` register and is reserved to encode additional capabilities information. `Config2` is allocated for showing the configuration of level 2/3 caches. These fields are reset to 0 because L2/L3 caches are not supported on the core. All fields in the `Config2` register are read-only.

No initialization is performed on this register in the PIC32 start-up code.

Config3 Register (`Config3` – CP0 Register 16, Select 3)

This register encodes additional capabilities. All fields in the `Config3` register are read-only.

No initialization is performed on this register in the PIC32 start-up code.

Debug Register (`Debug` – CP0 Register 23, Select 0)

This register is used to control the debug exception and provide information about the cause of the debug exception, and when re-entering at the debug exception vector due to a normal exception in Debug mode. The read-only information bits are updated every time the debug exception is taken, or when a normal exception is taken when already in Debug mode. Only the `DM` bit and the `EJTAGver` field are valid when read from non-Debug mode. The values of all other bits and fields are UNPREDICTABLE. Operation of the processor is UNDEFINED if the `Debug` register is written from non-Debug mode.

No initialization is performed on this register in the PIC32 start-up code.

Trace Control Register (`TraceControl` – CP0 Register 23, Select 1)

This register provides control and status information. The `TraceControl` register is only implemented if the EJTAG Trace capability is present.

No initialization is performed on this register in the PIC32 start-up code.

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Trace Control 2 Register (`TraceControl2` – CP0 Register 23, Select 2)

This register provides additional control and status information. The `TraceControl2` register is only implemented if the EJTAG Trace capability is present.

No initialization is performed on this register in the PIC32 start-up code.

User Trace Data Register (`UserTraceData` – CP0 Register 23, Select 3)

When this register is written to, a trace record is written indicating a type 1 or type 2 user format. This type is based on the `UT` bit in the `TraceControl` register. This register cannot be written in consecutive cycles. The trace output data is UNPREDICTABLE if this register is written in consecutive cycles. The `UserTraceData` register is only implemented if the EJTAG Trace capability is present.

No initialization is performed on this register in the PIC32 start-up code.

TraceBPC Register (`TraceBPC` – CP0 Register 23, Select 4)

This register is used to control start and stop of tracing using an EJTAG hardware breakpoint. The hardware breakpoint would then be set as a triggered source and optionally also as a Debug exception breakpoint. The `TraceBPC` register is only impl-emented if both the hardware breakpoints and the EJTAG Trace cap are present.

No initialization is performed on this register in the PIC32 start-up code.

Debug2 Register (`Debug2` – CP0 Register 23, Select 5)

This register holds additional information about complex breakpoint exceptions. The `Debug2` register is only implemented if complex hardware breakpoints are present.

No initialization is performed on this register in the PIC32 start-up code.

Debug Exception Program Counter (`DEPC` – CP0 Register 24, Select 0)

This register is a read/write register that contains the address at which processing resumes after a debug exception or Debug mode exception has been serviced. For synchronous (precise) debug and Debug mode exceptions, the `DEPC` contains either:

- The virtual address of the instruction that was the direct cause of the debug exception, or
- The virtual address of the immediately preceding branch or jump instruction, when the debug exception causing instruction is in a branch delay slot, and the Debug Branch Delay (`DBD`) bit in the `Debug` register is set.

For asynchronous debug exceptions (debug interrupt, complex break), the `DEPC` contains the virtual address of the instruction where execution should resume after the debug handler code is executed.

No initialization is performed on this register in the PIC32 start-up code.

Error Exception Program Counter (`ErrorEPC` – CP0 Register 30, Select 0)

This register is a read/write register, similar to the `EPC` register, except that it is used on error exceptions. All bits of the `ErrorEPC` are significant and must be writable. It is also used to store the program counter on Reset, Soft Reset, and Non-Maskable Interrupt (NMI) exceptions. The `ErrorEPC` register contains the virtual address at which instr-uction processing can resume after servicing an error. This address can be:

- The virtual address of the instruction that caused the exception, or
- The virtual address of the immediately preceding branch or jump instruction when the error causing instruction is a branch delay slot.

Unlike the `EPC` register, there is no corresponding branch delay slot indication for the `ErrorEPC` register.

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No initialization is performed on this register in the PIC32 start-up code.

Debug Exception Save Register (`DeSave` – CP0 Register 31, Select 0)

This register is a read/write register that functions as a simple memory location. This register is used by the debug exception handler to save one of the GPRs that is then used to save the rest of the context to a pre-determined memory area (such as in the EJTAG Probe). This register allows the safe debugging of exception handlers and other types of code where the existence of a valid stack for context saving cannot be assumed.

No initialization is performed on this register in the PIC32 start-up code.

17.2.11. Initialize CP0 Registers

The MIPS System Control Coprocessor 0 (CP0) controls interrupts and exceptions. This coprocessor implements many registers, which are initialized by the runtime startup code to reasonable values. Some registers (for example the `PRISS` register) should be explicitly reassigned by user code to ensure that they are correct for the application.

The registers in the coprocessor control the DSPr2 engine and Floating-Point Unit (FPU) where these are implemented on the device. These are both enabled as part of the coprocessor initialization.

17.2.12. The “On Bootstrap” Routine

Some hardware configurations require special initialization once most of the C/C++ runtime environment has been initialized, while `StatusBEV` is still set and before the `main()` function has been called. For instance, special hardware initialization and/or initialization of the environment might be required by an RTOS. To achieve this, there is an On Bootstrap hook provided, so that you do not need to customize the entire startup code sequence.

An empty weak implementation of the On Bootstrap routine (`_on_bootstrap`) is provided with the start-up code. It is called by the runtime startup code after most of the C/C++ language context initialization has been performed.

If you do need to implement your own version of this routine, you can modify the following stub (note the leading underscore character in the function’s name).

```
void _on_bootstrap(void)
{
  // Add code to be executed just before main() here
}
```

This routine can be placed into any source file in your project and you do not need to adjust any compiler options to have it executed.

This routine can be written assuming that the runtime environment has been mostly established. The `StatusBEV` is cleared immediately after this routine returns. See Runtime Start-Up Code for the order in which the environment is set up.

17.2.13. Change Location of Exception Vectors

Immediately before executing any application code, the `StatusBEV` is cleared to change the location of the exception vectors from the bootstrap location to the normal location.

17.2.14. Call the C++ Initialization Code

Invoke all constructors for C++ file-scope static-storage objects. The startup code must call the constructors last because the low-level initialization must be done before executing application code.

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17.2.15. Call Main

The last thing that the start-up code performs is a call to the main routine. If the user returns from main, the start-up code goes into an infinite loop. When you are compiling for use with a debugger in MPLAB X IDE with the `-mdebugger` option, this loop contains a software breakpoint.

17.2.16. Symbols Required by Start-Up Code and C/C++ Library

This section details the symbols that are required by the start-up code and C/C++ library. Currently the default device-specific linker script defines these symbols. If an application provides a custom linker script, the user must ensure that all of the following symbols are provided in order for the start-up code and C library to function:

Symbol Name	Description
`_bmxdkpba_address`	The address to place into the `BMXDKPBA` register if `_ramfunc_length` is greater than 0.
`_bmxdudba_address`	The address to place into the `BMXDUDBA` register if `_ramfunc_length` is greater than 0.
`_bmxdupba_address`	The address to place into the `BMXDUPBA` register if `_ramfunc_length` is greater than 0.
`_ebase_address`	The initialization value for the ExceptionBase field of the `EBASE` register. The ExceptionBase is the base address for the exception vectors, adjustable to a resolution of 4 Kbytes. The default device-specific linker scripts provided with the XC32 toolchain provide a default location for the ExceptionBase.
`_end`	The end of data allocation.
`_gp`	Points to the “middle” of the small variables region. By convention this is 0x8000 bytes from the first location used for small variables.
`_heap`	The starting location of the heap in DRM.
`_ramfunc_begin`	The starting location of the RAM functions. This should be located at a 2K boundary as it is used to initialize the `BMXDKPBA` register.
`_ramfunc_length`	The length of the `.ramfunc` section.
`_stack`	The starting location of the stack in DRM. Remember that the stack grows from the bottom of data memory so this symbol should point to the bottom of the section allocated for the stack.
`_vector_spacing`	The initialization value for the vector spacing field in the `IntCtl` register.

17.2.17. Exceptions

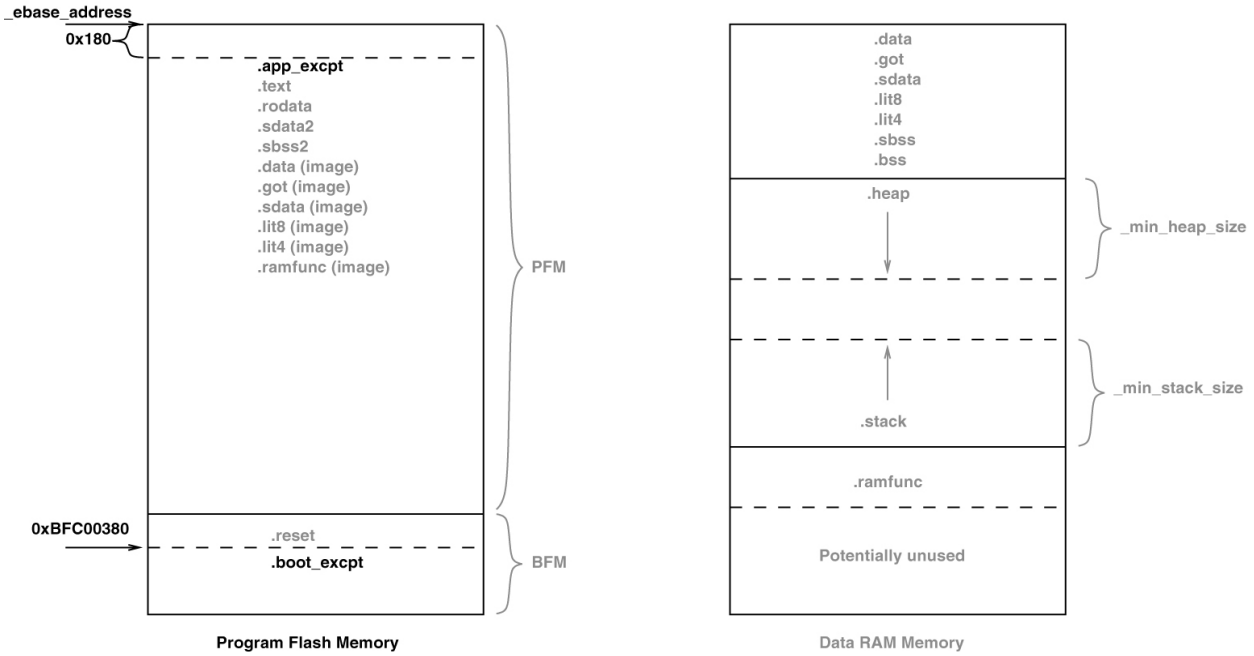
In addition, two weak general exception handlers are provided that can be overridden by the application — one to handle exceptions when `StatusBEV` is 1 (`_bootstrap_exception_handler`), and one to handle exceptions when `StatusBEV` is 0 (`_general_exception_handler`). Both the weak Reset exception handler and the weak general exception handler provided with the start-up code causes a software Reset. The start-up code arranges for a jump to the bootstrap exception handler to be located at `0xBFC00380`, and a jump to the general exception handler to be located at `EBASE + 0x180`.

Both handlers must be attributed with the `nomips16` [for example, `__attribute__ ((nomips16))`], since the start-up code jumps to these functions.

When the BOOTISA configuration bit is set for exceptions to be in the microMIPS mode, both handlers must be attributed with the `micromips` attribute [for example, `__attribute__((micromips))`].

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Figure 17-4. Exceptions



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18. Libraries

The MPLAB XC32 C/C++ Compiler provides C90- and C99-validated libraries of functions, macros, types, and objects that can assist with your code development.

The Standard C libraries are described in the separate *Microchip Unified Standard Library Reference Guide* document, whose content is relevant for all MPLAB XC C compilers.

The library includes functions for string manipulation, dynamic memory allocation, data conversion, timekeeping and math functions (trigonometric, exponential and hyperbolic). The standard I/O functions for file handling are also included, and, as distributed, they support full access to the host file system using the command-line simulator.

In addition to the libraries supplied with the compiler, you can create your own libraries from source code you have written.

18.1. Smart IO Routines

The library code associated with the print and scan families of IO functions can be customized by the compiler with each compilation, based on compiler options and how you use these functions in your project. This can reduce the amount of redundant library code being linked into the program image, hence can reduce the program memory and data memory used by a program.

The smart output (print family) functions are:

`printf`	`fprintf`	`snprintf`	`sprintf`
`vfprintf`	`vprintf`	`vsnprintf`	`vsprintf`

The smart input (scan family) functions are:

`scanf`	`fscanf`	`sscanf`
`vfscanf`	`vscanf`	`vsscanf`

When this feature is enabled, the compiler analyzes your project's C source code every time you build, searching for calls to any of the smart IO functions. The conversion specifications present in the format strings are collated across all calls, and their presence triggers inclusion of library routines with the associated functionality in the program image output.

For example, if a program contained only the following call:

```
printf("input is: %d\n", input);
```

when smart IO is enabled, the compiler will note that only the `%d` placeholder has been used by the `printf` function in the program, and the linked library routine defining `printf` will thus contain a basic functionality that can at least handle the printing of decimal integers. If the following call was added to the program:

```
printf("input is: %f\n", ratio);
```

the compiler will then see that both the `%d` and `%f` placeholders were used by `printf`. The linked library routine would then have additional functionality to ensure that all the requirements of the program can be met.

Specific details of how the smart IO feature operates for this compiler are detailed in the following section. The syntax and usage of all IO functions, which are part of the `<stdio.h>` header, are described in the *Microchip Unified Standard Library Reference Guide*.

18.1.1. Smart IO For PIC32M Devices

When using MPLAB XC32 C/C++ Compiler, multiple IO library variants, representing increasingly complex subsets of IO functionality, are available and are linked into your program based on the `-msmart-io` option and how you use the smart IO functions in your project's source code.

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When the smart IO feature is disabled (`-msmart-io=0`), a full implementation of the IO functions will be linked into your program. All features of the IO library functions will be available, and these may consume a significant amount of the available program and data memory on the target device.

When the smart IO feature is enabled (`-msmart-io=1` or `-msmart-io`), the compiler will link in the least complex variant of the IO library that implements all of the IO functionality required by the program, based on the conversion specifications detected in the program's IO function format strings. This can substantially reduce the memory requirements of your program, especially if you can eliminate in your program the use of floating-point features in calls to smart IO functions. This is the default setting.

The compiler analyzes the usage of each IO function independently, so while the code for a particular program might require that the `printf` function be full featured, only a basic implementation of the `snprintf` function might be required, for example.

If the format string in a call to an IO function is not a string literal, the compiler will not be able to detect the exact usage of the IO function, and a full-featured variant of the IO library will be linked into the program image, even with smart IO enabled. In this instance, the `-msmart-io=2` form of the option can be used. This has the compiler assume that no floating-point has been used by formatted IO functions and that it is safe to link in integer-only format IO libraries. You must ensure that your program only uses the indicated conversion specifications; otherwise, IO functions may not work as expected.

For example, consider the following four calls to smart IO functions.

```
vscanf("%d:%li", va_list1);
vprintf("%-s%d", va_list2);
vprintf(fmt1, va_list3); // ambiguous usage
vscanf(fmt2, va_list4);  // ambiguous usage
```

When processing the last two calls, the compiler cannot deduce any usage information from either of the format strings. If it is known that the format strings pointed to by `fmt1` and `fmt2` collectively use only the `%d`, `%i` and `%s` conversion specifiers, the `-msmart-io=2` form of the option can be used.

These options should be used consistently across all program modules to ensure an optimal selection of the library routines included in the program image.

18.2. Picolibc Library

The picolibc library implements the standard C and C++ library functions, types, and macros. It can be linked to a project using the `-mchp-stdlibc` option, see Mchp-stdlibc Option.

The picolibc library is available for C and C++ projects and supports all PIC32M MCU devices. Use of the picolibc library disables the smart IO features associated with functions like `printf()`. Math functions will also be linked from the picolibc library with this selection. You may select between speed- and space-orientated library alternatives of the picolibc library using the `-mlibc-variant` option.

The picolibc library also uses a global lock for APIs sharing global data. This includes the `malloc()` family of functions, `onexit()` and `atexit()`, and functions using timezones. This lock protects relevant functions from race conditions and provides data integrity, ensuring that your application is safe for use in a multithreaded environment. This prevents multiple threads from accessing and modifying memory simultaneously, which could lead to corruption or crashes.

Your application code must provide several functions to fully implement the retargetable locking API. The picolibc library provides stubs for all of these functions, which can be completed to suit your application. The stubs as provided do not perform locking, so a single-threaded application can still use the library, despite locking being enabled. See the document at github.com/picolibc/picolibc/blob/1.8.6/doc/locking.md for information. If you are using an RTOS, you might need to map these functions to the RTOS's mutex functions. Ensure that your application initializes and uses

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these locks correctly. Acquire the global lock before calling functions such as `malloc()`, which uses locking to share global data. Release the lock after the operation is complete.

Note that, like most standard C library implementations for bare-metal embedded systems, low-level system functions must be provided by the operating environment or application code. This includes functions such as `gettimeofday()`, `read()`, `write()`, `_exit()`, etc. The semihosting library does provide implementations of these functions, but these functions would typically need to be customised to work with your specific hardware. You may see an "undefined reference" error from the linker when linking.

18.3. Using Library Routines

Library functions or routines (and any associated variables) will be automatically linked into a program once they have been referenced in your source code. The use of a function from one library file will not include any other functions from that library. Only used library functions will be linked into the program output and consume memory.

Note: Do not specify an MPLAB XC32 system include directory (e.g., `/pic32m/include/`) in your project properties. The `xc32-gcc` compilation driver automatically selects the XC libc and their respective include-file directory for you; similarly, the `xc32-g++` compilation driver automatically select the C++ library respective include-file directory. Manually adding a system include file path may disrupt this mechanism and cause the incorrect libc include files to be compiled into your project, causing a conflict between the include files and the library. Note that adding a system include path to your project properties has never been a recommended practice.

Your program will require declarations for any functions or symbols used from libraries. These are contained in the standard C header (`.h`) files. Header files are not library files and the two files types should not be confused. Library files contain precompiled code, typically functions and variable definitions; the header files provide declarations (as opposed to definitions) for functions, variables and types in the library files, as well as other preprocessor macros.

```
#include <math.h> // declare function prototype for sqrt

int main(void) {
  double i;

  // sqrt referenced; sqrt will be linked in from library file
  i = sqrt(23.5);
}
```

MPLAB® Harmony includes a set of peripheral libraries, drivers, and system services that are readily accessible for application development. For access to the `plib.h` (peripheral header files), go to the Harmony web site (www.microchip.com/mplab/mplab-harmony) to download MPLAB Harmony.

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19. Mixing C/C++ and Assembly Language

Assembly language code can be mixed with C/C++ code using two different techniques: writing assembly code and placing it into a separate assembler module, or including it as in-line assembly in a C/C++ module. This section describes how to use assembly language and C/C++ modules together. It gives examples of using C/C++ variables and functions in assembly code, and examples of using assembly language variables and functions in C/C++.

The more assembly code a project contains, the more difficult and time consuming its maintenance will be. As the project is developed, the compiler may work in different ways as some optimizations look at the entire program. The assembly code is more likely to fail if the compiler is updated due to differences in the way the updated compiler may work. These factors do not affect code written in C/C++.

Note: If assembly must be added, it is preferable to write this as self-contained routine in a separate assembly module rather than in-lining it in C code.

19.1. Mixing Assembly Language and C Variables and Functions

The following guidelines indicate how to interface separate assembly language modules with C modules.

- Follow the register conventions described in Register Conventions. In particular, registers $4-$7 are used for parameter passing. An assembly -language function will receive parameters, and should pass arguments to called functions, in these registers.
- Table 13-1 describes which registers must be saved across non-interrupt function calls.
- Interrupt functions must preserve all registers. Unlike a normal function call, an interrupt may occur at any point during the execution of a program. When returning to the normal program, all registers must be as they were before the interrupt occurred.
- Variables or functions declared within a separate assembly file that will be referenced by any C source file should be declared as global using the assembler directive `.global`. Undeclared symbols used in assembly files will be treated as externally defined.

The following example shows how to use variables and functions in both assembly language and C regardless of where they were originally defined.

The file `ex1.c` defines `foo` and `cVariable` to be used in the assembly language file. The C file also shows how to call an assembly function, `asmFunction`, and how to access the assembly defined variable, `asmVariable`.

Example 19-1. Mixing C and Assembly

```
/*
** file: ex1.S
*/
#include <xc.h>

    /* define which section (for example "text")
     * does this portion of code resides in. Typically,
     * all your code will reside in .text section as
     * shown below.
     */
   .text

    /*  This is important for an assembly programmer. This
     * directive tells the assembler that don't optimize
     * the order of the instructions as well as don't insert
     * 'nop' instructions after jumps and branches.
     */
   .set noreorder

/*************************************************************************
* asmFunction(int bits)
```


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```
* This function clears the specified bites in IOPORT A.
*********************************************************************/
.global asmFunction
.ent asmFunction
asmFunction:
   /* function prologue - save registers used in this function
     * on stack and adjust stack-pointer
     */
   addiu   sp, sp, -4
   sw      s0, 0(sp)

   la      s0, LATACLR
   sw      a0, 0(s0)      /* clear specified bits */

   la      s0, PORTA
   lw      s1, 0(s0)
   la      s0, cVariable
   sw      s1, 0(s0)      /* keep a copy */

   /* function epilogue - restore registers used in this function
     * from stack and adjust stack-pointer
     */
   lw      s0, 0(sp)
   addiu   sp, sp,

   addu    s1, ra, zero
   jal     foo
   nop
   addu    ra, s1, zero
   nop
   /* return to caller */
   jr      ra
   nop
.end asmFunction

  .bss
  .global asmVariable
  .align 2
asmVariable: .space 4
```

The file `ex1.S` defines `asmFunction` and `asmVariable` as required for use in a linked application. The assembly file also shows how to call a C function, `foo`, and how to access a C defined variable, `cVariable`.

```
/*
 * file: ex2.c
 */
#include <xc.h>
extern void asmFunction(int bits);
extern unsigned int asmVariable;
volatile unsigned int cVariable = 0;
volatile unsigned int jak = 0;

int
main(void) {
    TRISA = 0;
    LATA = 0xC6FFul;
    asmFunction(0xA55Au);
    while (1) {
        asmVariable++;
    }
}

void
foo(void) {
    jak++;
}
```

In the C file, `ex2.c`, external references to symbols declared in an assembly file are declared using the standard `extern` keyword; note that `asmFunction` is a `void` function and is declared accordingly.

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In the assembly file, `ex1.S`, the symbols `asmFunction` and `asmVariable` are made globally visible through the use of the `.global` assembler directive and can be accessed by any other source file.

19.2. Using Inline Assembly Language

Within a C/C++ function, the `asm` statement may be used to insert a line of assembly-language code into the assembly language that the compiler generates. Inline -assembly has two forms: simple and extended.

Regardless of the form used to inline assembly into the body of a C function, care must be taken if the function containing this assembly is itself inlined by the compiler optimizer. This form of optimization replaces calls to a function with the statements contained by that function. If the inline assembly defines labels, these will appear in every instance of the inlined function and might trigger errors relating to multiply defined symbols. If your assembly code requires labels, you can prevent functions from being inlined by using the `noinline` attribute with the function containing the inline assembly, or use the `-fno-inline` or `-fno-inline-functions` options when building the project.

Using the simple form, assembler instruction can be inlined using the syntax:

`asm ("instruction");`

where `instruction` is a valid assembly-language construct. If you are writing inline assembly in ANSI C programs, write `__asm__` instead of `asm`.

Note: Only a single string can be passed to the simple form of inline assembly.

In the extended assembler instruction form,, the operands of the instruction are specified using C/C++ expressions. The extended syntax is:

```
asm("template" [ : [ "constraint"(output-operand) [ , ... ] ]
                 [ : [ "constraint"(input-operand) [ , ... ] ]
                       [ "clobber" [ , ... ] ]
             ]
           ]);
```

You must specify an assembler instruction `template`, plus an operand `constraint` string for each operand. The `template` specifies the instruction mnemonic, and optionally placeholders for the operands. The `constraint` strings specify operand constraints, for example, that an operand must be in a register (the usual case), or that an operand must be an immediate value.

Constraint letters and modifiers supported by the compiler are listed in the following tables.

Table 19-1. Register Constraint Letters Supported by the Compiler

Letter	Constraint
`c`	A register suitable for use in an indirect jump.
`d`	An address register. This is equivalent to `@code{r}` unless generating MIPS16 code.
`ka`	Registers that can be used as the target of multiply-accumulate instructions.
`l`	The `@code{lo}` register. Use this register to store values that are no bigger than a word.
`x`	The concatenated `@code{hi}` and `@code{lo}` registers. Use this register to store double-word values.

Table 19-2. Integer Constraint Letters Supported by the Compiler

Letter	Constraint
`I`	A signed 32-bit constant (for arithmetic instructions)
`J`	Integer zero

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Table 19-2. Integer Constraint Letters Supported by the Compiler (continued)

Letter	Constraint
K	An unsigned 32-bit constant (for logic instructions)
L	A signed 32-bit constant in which the lower 32 bits are zero. Such constants can be loaded using @code{lui}
M	A constant that cannot be loaded using @code{lui}, @code{addiu} or @code{ori}
N	A constant in the range -65535 to -1 (inclusive)
O	A signed 15-bit constant
P	A constant in the range 1 to 65535 (inclusive)

Table 19-3. General Constraint Letters Supported by the Compiler

Letter	Constraint
R	An address that can be used in a non-macro load or store.

Table 19-4. Constraint Modifiers Supported by the Compiler

Letter	Constraint
=	Means that this operand is write-only for this instruction: the previous value is discarded and replaced by output data.
+	Means that this operand is both read and written by the instruction.
&	Means that this operand is an earlyclobber operand, which is modified before the instruction is finished using the input operands. Therefore, this operand may not lie in a register that is used as an input operand or as part of any memory address.
d	Second register for operand number *n*, that is, %d*n*. .
q	Fourth register for operand number **n**, that is, %q*n*. .
t	Third register for operand number *n*, that is, %t*n*. .

19.2.1. Inline Examples

Insert Bit Field

This example demonstrates how to use the INS instruction to insert a bit field into a 32-bit wide variable. This function-like macro uses inline assembly to emit the INS instruction, which is not commonly generated from C/C++ code.

```
/* MIPS32r2 insert bits */
#define _ins(tgt,val,pos,sz) __extension__({                    \
    unsigned int __t = (tgt), __v = (val);                      \
    __asm__ ("ins %0,%z1,%2,%3"                  /* template */ \
             : "+d" (__t)                        /* output   */ \
             : "dJ" (__v), "I" (pos), "I" (sz)); /* input    */ \
    __t;                                                        \
})
```

Here __v, pos, and sz are input operands. The __v operand is constrained to be of type 'd' (an address register) or 'J' (integer zero). The pos and sz operands are constrained to be of type 'I' (a signed 32-bit constant).

The __t output operand is constrained to be of type 'd' (an address register). The '+' modifier means that this operand is both read and written by the instruction and so the operand is both an input and an output.

The following example shows this macro in use.

```
unsigned int result;
void example (void)
{
    unsigned int insertval = 0x12;
```


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```
    result = 0xAAAAAAAAu;
    result = _ins(result, insertval, 4, 8);
    /* result is now 0xAAAAA12A */
}
```

For this example, the compiler may generate assembly code similar to the following.

```
    li        $2,-1431699456            # 0xaaaa0000
    ori       $2,$2,0xaaaa        # 0xaaaa0000 | 0xaaaa

    li        $3,18             # 0x12
    ins       $2,$3,4,8             # inline assembly

    lui       $3,%hi(result)         # assign the result back
    j         $31             # return
    sw        $2,%lo(result)($3)
```

Multiple Assembler Instructions

This example demonstrates how to use the `WSBH` and `ROTR` instructions together for a byte swap. The `WSBH` instruction is a 32-bit byte swap within each of the two halfwords. The `ROTR` instruction is a rotate right by immediate. This function-like macro uses inline assembly to create a “byte-swap word” using instructions that are not commonly generated from C/C++ code.

The following shows the definition of the function-like macro, `_bswapw`.

```
/* MIPS32r2 byte-swap word */
#define _bswapw(x) __extension__({        \
    unsigned int __x = (x), __v;          \
    __asm__ ("wsbh %0,%1;\n\t"            \
             "rotr %0,16" /* template */ \
            : "=d" (__v)  /* output */   \
            : "d" (__x))  /* input*/ ;   \
    __v;                                  \
})
```

Here `__x` is the C expression for the input operand. The operand is constrained to be of type 'd', which denotes an address register.

The C expression `__v` is the output operand. This operand is also constrained to be of type 'd'. The '=' means that this operand is write-only for this instruction: the previous value is discarded and replaced by output data.

The function-like macro is shown in the following example assigning to `result` the content of `value`, swapped.

```
unsigned int result;
int example (void)
{
   unsigned int value = 0x12345678u;
   result = _bswapw(value);
   /* result == 0x78563412 */
}
```

The compiler may generate assembly code similar to the following for this example:

```
  li          $2,305397760          # 0x12340000
  addiu       $2,$2,22136           # 0x12340000 + 0x5678
  wsbh        $2,$2                 # From inline asm
  rotr        $2,16                 # From inline asm
  lui         $2,%hi(result)        # assign back to result
  j           $31                   # return
  sw          $3,%lo(result)($2)
```

19.2.2. Equivalent Assembly Symbols

C/C++ symbols can be accessed directly with no modification in extended assembly code.

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19.3. Predefined Macros

Several predefined macros are available once you include <xc.h>. The exact operation of these macros is dependent on the instruction set employed. The following table shows general purpose predefined macros and their operation.

Table 19-5. Predefined Macros in XC.H

Macro	Description
`_bcc0(rn, sel, clr)`	For the CP0 register specified by `rn` and `sel`, clear bits corresponding to those bits in `clr` which are non-zero.
`_bcsc0(rn, sel, clr, set)`	For the CP0 register specified by `rn` and `sel`, clear bits corresponding to those bits in `clr` which are non-zero, and set bits corresponding to those bits in `set` which are non-zero.
`_bsc0(rn, sel, set)`	For the CP0 register specified by `rn` and `sel`, clear bits corresponding to those bits in `clr` which are non-zero.
`_bswapw(x)`	See `<xc.h>` file. Byte-swap word.
`_cache(op,addr)`	Do an operation to a cache line. See the device documentation for details on the available operations.
`_clo(x)`	Count leading ones in `x`.
`_clz(x)`	Count leading zeros in `x`.
`_ctz(x)`	Count trailing zeros in `x`.
`_dclo(x)`	Simulate 64-bit count leading ones in `x`.
`_dclz(x)`	Simulate 64-bit count leading zeros in `x`.
`_dctz(x`	Simulate 64-bit count trailing zeros in `x`.
`_ehb()`	Insert Execution Hazard Barrier instruction.
`_ext(x,pos,sz)`	See `<xc.h>` file. Extract bitfield from a 32-bit variable.
`_get_byte(addr, errp)`	Return the least significant byte of addr.
`_get_dword(addr, errp)`	Return the least significant 64-bit word of addr.
`_get_half(addr, errp)`	Return the least significant 16-bit word of addr.
`_get_word(addr, errp)`	Return the least significant 32-bit word of addr.
`_ins(tgt,val,pos,sz)`	See `<xc.h>` file. Insert bits.
`_jr_hb()`	See `<xc.h>` file. Jump register with hazard barrier.
`_mfc0(rn, sel)`	See `<xc.h>` file. Move a value from a coprocessor 0 register.
`_mtc0(rn, sel, v)`	See `<xc.h>` file. Move a value to a coprocessor 0 register.
`_mxc0(rn, sel, v)`	See `<xc.h>` file. Exchange a value with a value in a coprocessor 0 register.
`_nop()`	Insert a No Operation instruction.
`_prefetch(hint,x)`	Prefetch instruction for memory reference optimization. An application that knows in advance it may need data can arrange for it to be brought into cache. 'hint' defines which sort of prefetch this is.
`_put_byte(addr, v)`	Write the least significant byte of addr with v.
`_put_dword(addr, v)`	Write the least significant 64-bit word of addr with v.
`_put_half(addr, v)`	Write the least significant 16-bit word of addr with v.
`_put_word(addr, v)`	Write the least significant 32-bit word of addr with v.
`_rdpgpr(regno)`	See `<xc.h>` file. Read register from previous register set.
`_sync()`	Insert Synchronize Shared Memory instruction.
`_synci(addr)`	Synchronize the I-cache with the D-cache; Run instruction for each cache-line-sized block after writing instructions but before executing them.
`_wait()`	Insert instruction to enter Standby mode.
`_wrpgpr(regno, val)`	See `<xc.h>` file. Write to a register in the previous register set.
`_wsbh(x)`	See `<xc.h>` file. 32-bit byte-swap within each of the two halfword.

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Table 19-5. Predefined Macros in XC.H (continued)

Macro	Description
__XC32_PART_SUPPORT_UPDATE	This macro expands to the letter corresponding to the part-support update version being used. The value is based upon the major and minor version numbers of the current release. For example, part-support update version v1.42(B) will have `#define __XC32_PART_SUPPORT_UPDATE B`
__XC32_PART_SUPPORT_VERSION	This macro expands to a numeric value corresponding to the part-support update version being used. The value is based upon the major and minor version numbers of the current release. For example, part-support update version v1.42(B) will have `#define __XC32_PART_SUPPORT_UPDATE 1420`.

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20. Optimizations

Activation of a compiler license controls which code optimizations are available.

An unlicensed compiler operating in Free mode allows access to only basic optimizations. You can purchase a PRO compiler license at any time. Activating the compiler with a PRO license unlocks all available speed- and space-orientated optimizations. Prior to purchase, you can, if desired, obtain and activate a free 60-day PRO license evaluation, which also permits full optimization of source code and shows the benefits that a PRO license would deliver.

Visit www.microchip.com/mplab/compilers for more information on C and C++ licenses.

MPLAB XC32 C/C++ Compiler license types are Free, EVAL and PRO. The initial compiler download begins as an Evaluation (EVAL) license allows 60 days to evaluate the compiler as a Professional (PRO) license with the most optimizations. The Free license has minimal optimizations.

Different MPLAB XC32 C/C++ Compiler editions support different levels of optimization. Some editions are free to download and others must be purchased. Visit www.microchip.com/mplab/compilers for more information on C and C++ licenses.

The compiler editions are:

Edition	Cost	Description
Professional (PRO)	Yes	Implemented with the highest optimizations and performance levels.
Free	No	Implemented with the most code optimizations restrictions.
Evaluation (EVAL)	No	PRO edition enabled for 60 days and then reverts to Free edition.

20.1. Optimization Feature Summary

Licensing your compiler entitles you to optimizations that are not available with the Free product. Those optimizations available with the Free and Licensed XC32 compiler are tabulated below. The optimization names are derived from the option that can typically be used to enable or disable them, for example the "Defer pop" optimization can be manually enabled using the `-fdefer-pop` option if it is not already enabled at the selected optimization level, or disabled using `-fno-defer-pop`. For details on compiler options used to set optimizations, see Options for Controlling Optimization.

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Table 20-1. License Optimization Features

Free	PRO License
• Align functions • Align labels • Align loops • Caller saves • Cse follow jumps • Cse skip blocks • Data sections • Defer pop • Expensive optimizations • Function cse • Function sections • Gcse • Gsce lm • Gsce sm • Inline functions • Inline limit • Keep inline functions • Keep static consts • Omit frame pointer • Optimize register move • Optimize sibling calls • Peephole/2 • Rename registers • Rerun cse after loop • Rerun loop opt • Schedule insns/2 • Strength reduce • Strict aliasing • Thread jumps • Toplevel reorder • Tree value range propagation • Unroll/all loops	All Free optimizations, plus: • Lto • Whole program

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21. Preprocessing

All C/C++ source files are preprocessed before compilation. Assembly source files that use the .S extension (upper case) are also preprocessed. A large number of options control the operation of the preprocessor and preprocessed code, see Options for Controlling the Preprocessor.

21.1. C/C++ Language Comments

A C/C++ comment is ignored by the compiler and can be used to provide information to someone reading the source code. They should be used freely.

Comments may be added by enclosing the desired characters within `/*` and `*/`. The comment can run over multiple lines, but comments cannot be nested. Comments can be placed anywhere in C/C++ code, even in the middle of expressions, but cannot be placed in character constants or string literals.

Since comments cannot be nested, it may be desirable to use the `#if` preprocessor directive to comment out code that already contains comments, for example:

```
#if 0
    result = read();  /* TODO: Jim, check this function is right */
#endif
```

Single-line, C++ style comments may also be specified. Any characters following // to the end of the line are taken to be a comment and will be ignored by the compiler, as shown below:

```
result = read(); // TODO: Jim, check this function is right
```

21.2. Preprocessor Directives

The XC32 accepts several specialized preprocessor directives, in addition to the standard directives. All of these are tabulated below.

Table 21-1. Preprocessor Directives

Directive	Meaning	Example
`#`	Preprocessor null directive, do nothing.	`#`
`#assert`	Generate error if condition false.	`#assert SIZE > 10`

`#define`	Define preprocessor macro.	`#define SIZE (5)`
		`#define FLAG`
		`#define add(a,b) ((a)+(b))`

`#elif`	Short for `#else #if`.	see `#ifdef`
`#else`	Conditionally include source lines.	see `#if`
`#endif`	Terminate conditional source inclusion.	see `#if`
`#error`	Generate an error message.	`#error Size too big`

`#if`	Include source lines if constant expression true.	`#if SIZE < 10`
		`  c = process(10)`
		`#else`
		`  skip();`
		`#endif`

`#ifdef`	Include source lines if preprocessor symbol defined.	`#ifdef FLAG`
		`  do_loop();`
		`#elif SIZE == 5`
		`  skip_loop();`
		`#endif`

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Table 21-1. Preprocessor Directives (continued)

Directive	Meaning	Example

`#ifndef`	Include source lines if preprocessor symbol not defined.	`#ifndef FLAG`
		`  jump();`
		`#endif`

`#include`	Include text file into source.	`#include <stdio.h>` `#include "project.h"`
`#line`	Specify line number and filename for listing	`#line 3 final`
`#nn filename`	(where *nn* is a number, and *filename* is the name of the source file) the following content originated from the specified file and line number.	`#20 init.c`
`#pragma`	Compiler specific options.	See the Pragma Directives section in this guide.
`#undef`	Undefines preprocessor symbol.	`#undef FLAG`
`#warning`	Generate a warning message.	`#warning Length not set`

Macro expansion using arguments can use the `#` operator to convert an argument to a string and the `##` operator to concatenate arguments. If two expressions are being concatenated, consider using two macros in case either expression requires substitution itself; for example

```
#define __paste1(a,b)   a##b
#define __paste(a,b)    __paste1(a,b)
```

lets you use the `paste` macro to concatenate two expressions that themselves might require further expansion. Remember that once a macro identifier has been expanded, it will not be expanded again if it appears after concatenation.

Preprocessor macros can take a variable number of arguments, just like C functions. Use an ellipsis (...) after any named arguments to define a variable argument list. Use the special token `__VA_ARGS__` to expand this argument list in the macro replacement text.

21.2.1. Preprocessor Arithmetic

Preprocessor macro replacement expressions are textual and do not utilize types. Unless they are part of the controlling expression to the inclusion directives (discussed below), macros are not evaluated by the preprocessor. Once macros have been textually expanded and preprocessing is complete, the expansion forms a C expression which is evaluated by the code generator along with other C code. Tokens within the expanded C expression inherit a type, with values then subject to integral promotion and type conversion in the usual way.

If a macro is part of the controlling expression to a conditional inclusion directive (`#if` or `#elif`), the macro must be evaluated by the preprocessor. The result of this evaluation is sometimes different from the C-domain result for the same sequence. The preprocessor processes unsigned and signed literal integer values in the controlling expression as if they had the respective type `uintmax_t` or `intmax_t`, defined in `<stdint.h>`. For the MPLAB XC32 C/C++ Compiler, the size of these types is 64 bits.

21.3. Pragma Directives

There are certain compile-time directives that can be used to modify the behavior of the compiler. These are implemented through the use of the ANSI standard `#pragma` facility. Any pragma which is not understood by the compiler will be ignored.

The format of a pragma is:

```
#pragma keyword options
```


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where *keyword* is one of a set of keywords, some of which are followed by certain *options*. A description of the keywords is given below.

#pragma config

The `#pragma config` directive specifies the processor-specific configuration settings (that is, Configuration bits) to be used by the application. See Configuration Bit Access.

#pragma interrupt

Mark a function as an interrupt handler. The prologue and epilogue code for the function will perform more extensive context preservation. Note that the `interrupt` attribute (rather than this pragma) is the recommended mechanism for marking a function as an interrupt handler. The interrupt pragma is provided for compatibility with other compilers. See Interrupts and Exception Handlers.

#pragma message

The `message = "`*text*`"` pragma prints the quoted text at build time, as neither a warning nor error, but purely as an advisory.

#pragma GCC optimize

The `#pragma GCC optimize ("`*string*`"...)` pragma sets default optimization attributes for function declarations and definitions that do not otherwise specify these attributes. All functions after the pragma will be optimized accordingly. The parentheses are optional. The arguments allowed may be:

- A number *n*, to be interpreted as an optimization level, i.e., the `-On` option.
- A string beginning with `O`, which is interpreted as an optimization option, i.e., `-O`*string*.
- Otherwise, *string* should be an option that can be used with a `-f` prefix.

The `#pragma GCC reset_options` pragma clears the default optimizations, so that the optimization of subsequent functions is not controlled by `optimize` pragma.

#pragma pack

The `#pragma pack` pragma allows the maximum alignment of members of structures (other than zero-width bit-fields), unions, and classes to be changed. All aggregate objects after the pragma will be packed accordingly. subsequently defined.

The `#pragma pack(`*n*`)` form of this pragma specifies the new packing alignment. The *n* value should be a small power of two and specifies the new packing alignment in bytes.

The `#pragma pack()` form of this pragma resets the packing alignment to that in effect when compilation started. This might have been specified with the `-fpack-struct` option.

The `#pragma pack(push[,`*n*`])` form of this pragma pushes the current alignment setting on an internal stack and then optionally sets the new packing alignment to the value *n*.

The `#pragma pack(pop)` form of this pragma restores the alignment setting to the one saved at the top of the internal stack by a previous `#pragma pack(push)` (and removes that stack entry).

#pragma vector

Generate a branch instruction at the indicated exception vector that targets the function. Note that the `vector` attribute (rather than this pragma) is the recommended mechanism for generating an exception/interrupt vector. See Interrupts and Exception Handlers.

#pragma weak

The `#pragma weak` pragma can be used to declare weak symbols and defining weak aliases.

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The `#pragma weak symbol` form of this pragma declares symbol to be weak, as if the declaration had used the `weak` attribute. The pragma can appear before or after the declaration of *`symbol`*, or can be used in situations where symbol is never defined.

The `#pragma weak symbol1 = symbol2` form of this pragma declares *`symbol1`* to be a weak alias of *`symbol2`*. The *`symbol2`* symbol must be defined in the current translation unit.

21.4. Predefined Macros

These predefined macros are available for use with the compiler.

21.4.1. 32-Bit C/C++ Compiler Macros

The compiler defines a number of macros, most with the prefix "`_MCHP_`", which characterize the various target specific options, the target processor and other aspects of the host environment.

`_MCHP_SZINT`	32 or 64, depending on command line options to set the size of an integer (`-mint32 -mint64`).
`_MCHP_SZLONG`	32 or 64, depending on command line options to set the size of an integer (`-mlong32 -mlong64`).
`_MCHP_SZPTR`	32 always since all pointers are 32 bits.
`__mchp_no_float`	Defined if `-mno-float` specified.
`__NO_FLOAT`	Defined if `-mno-float` specified.
`__SOFT_FLOAT`	Defined if `-mno-float` not specified and the specified device does not feature a hardware Floating-Point Unit (FPU). Indicates that floating-point operations are supported via library calls.
`__HARD_FLOAT`	Defined if `-mno-float` and `-msoft-float` are not specified and the specified device features a hardware Floating-Point Unit (FPU). Indicates that floating-point operations utilize the FPU.
`__PIC32MX` `__PIC32MX__`	Defined when a PIC32MX device is specified with the `-mprocessor` option.
`__PIC32MZ`	Defined when a PIC32MZ device is specified with the `-mprocessor` option.

`__PIC32_FEATURE_SET__`	The compiler predefines a macro based on the features available for the selected device. These macros are intended to be used when writing code to take advantage of features available on newer devices while maintaining compatibility with older devices.
	Examples: PIC32MX795F512L would use: `__PIC32_FEATURE_SET__ == 795`, and PIC32MX340F128H would use: `__PIC32_FEATURE_SET__ == 340`.
	Examples: PIC32MZ2048ECH100 would use:
	`__PIC32_FEATURE_SET "EC" /* PIC32MZ2048ECH100 */`
	`__PIC32_FEATURE_SET0 69 /* PIC32MZ2048ECH100 */`
	`__PIC32_FEATURE_SET1 67 /* PIC32MZ2048ECH100 */`

`PIC32MX`	Defined if `-ansi` is not specified.

`__LANGUAGE_ASSEMBLY`
`__LANGUAGE_ASSEMBLY__`
`_LANGUAGE_ASSEMBLY`
	Defined if compiling a pre-processed assembly file (.S files).

`LANGUAGE_ASSEMBLY`	Defined if compiling a pre-processed assembly file (.S files) and `-ansi` is not specified.

`__LANGUAGE_C`
`__LANGUAGE_C__`
`_LANGUAGE_C`
	Defined if compiling a C file.

`LANGUAGE_C`	Defined if compiling a C file and `-ansi` is not specified.

`__LANGUAGE_C_PLUS_PLUS`
`__cplusplus`
`_LANGUAGE_C_PLUS_PLUS__`
	Defined if compiling a C++ file.

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__EXCEPTIONS	Defined if X++ exceptions are enabled.
__GXX_RTTI	Defined if runtime type information is enabled.
__processor__	Where "processor" is the capitalized argument to the -mprocessor option. for example, -mprocessor=32mx12f3456 will define __32MX12F3456__
__XC	Always defined to indicate that this is a Microchip XC compiler.
__XC32	Always defined to indicate this the XC32 compiler.
__VERSION__	The __VERSION__ macro expands to a string constant describing the compiler in use. Do not rely on its contents having any particular form, but it should contain at least the release number. Use the __XC32_VERSION macro for a numeric version number.
__XC32_VERSION or __C32_VERSION__	The C compiler defines the constant __XC32_VERSION, giving a numeric value to the version identifier. This macro can be used to construct applications that take advantage of new compiler features while still remaining backward compatible with older versions. The value is based upon the major and minor version numbers of the current release. For example, release version 1.03 will have a __XC32_VERSION definition of 1030. This macro can be used, in conjunction with standard preprocessor comparison statements, to conditionally include/exclude various code constructs.
__mips_dsp 1 __mips_dspr2 1 __mips_dsp_rev 2	The C compiler defines these constants when the selected target device supports the DSPr2 engine.
__mips_micromips 1	The compiler defines these constants when we are building for the microMIPS compressed ISA as the default using the -mmicromips option.
__mips_soft_float 1	The compiler defines this constant when we are compiling for software floating-point operations.

In the Device Family Packs (DFPs) downloaded for your target device, see the device-specific include files for other macros that can be used to determine the features available on the selected device. You will find these macros near the end of the header file.

21.4.2. SDE Compatibility Macros

The MIPS® SDE (Software Development Environment) defines a number of macros, most with the prefix "_MIPS_", which characterize various target specific options, some determined by command line options (for example, -mint64). Where applicable, these macros will be defined by the compiler in order to ease porting applications and middleware from the SDE to the compiler.

_MIPS_SZINT	
_MIPS_SZLONG	
_MIPS_SZPTR	
__mips_no_float	
__mips__ _mips _MIPS_ARCH_PIC32MX _MIPS_TUNE_PIC32MX _R3000 __R3000 __R3000__ __mips_soft_float __MIPSEL __MIPSEL__ _MIPSEL	Always defined.
R3000 MIPSEL	Defined if -ansi is not specified.
_mips_fpr	Defined as 32.

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__mips16	Defined if -mips16 specified.
__mips	Defined as 32.
__mips_isa_rev	Defined as 2.
_MIPS_ISA	Defined as _MIPS_ISA_MIPS32.

21.4.3. Processor-Specific Macros

The proc/p*.h header files define a number of processor-specific macros. To use these macros, #include <xc.h> in your source file. This list is not comprehensive.

__PIC32_HAS_L1CACHE	Defined if and only if the target device supports an L1 cache
__PIC32_HAS_MIPS32R2	Defined if and only if the target device supports the MIPS32r2 Instruction Set
__PIC32_HAS_MICROMIPS	Defined if and only if the target device supports the microMIPS32 Instruction Set
__PIC32_HAS_MIPS16	Defined if and only if the target device supports the MIPS16 Instruction Set
__PIC32_HAS_DSPR2	Defined if and only if the target device supports the DSP-enhanced core
__PIC32_HAS_FPU64	Defined if and only if the target device supports the 64-bit Hardware Floating-Point Unit. Also check __mips_hard_float to determine if the compiler is set to compile for the FPU.
_<Interrupt-Source>_VECTOR	Defined to the vector number for the interrupt source and intended to be used with the vector function attribute. for example, #define _CORE_TIMER_VECTOR 0
_<Interrupt-Source>_IRQ	Defined to the IRQ number for the interrupt source. for example, #define _CORE_SOFTWARE_0_IRQ 1
<SFR><Bitfield>_POSITION	Defined to the position of a bitfield within a special function register (SFR). for example, #define _WDTCON_ON_POSITION 0x0000000F
<SFR><Bitfield>_MASK	Defined to a mask of the bitfield within a special function register (SFR). for example, #define _WDTCON_ON_MASK 0x00008000
<SFR><Bitfield>_LENGTH	Defined to the length of the bitfield within a special function register (SFR). for example, #define _WDTCON_ON_LENGTH 0x00000001

<Special-Function-Register>	Defined to the Special Function Register name. for example, #define T5CON T5CON
	This macro allows preprocessor testing for the existence of an SFR before using it. For example:
	`#if defined(T5CON)`
	`  T5CONbits.ON = 1;`
	`#endif`

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22. Linking Programs

See the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186) for more detailed information on the linker.

The compiler will automatically invoke the linker unless the compiler has been requested to stop after producing an intermediate file.

Linker scripts are used to specify the available memory regions and where sections should be positioned in those regions.

The linker creates a map file which details the memory assigned to sections. The map file is the best place to look for memory information.

22.1. Replacing Library Symbols

Unlike with the Microchip MPLAB XC8 compiler, not all library functions can be replaced with user-defined routines using MPLAB XC32 C/C++ Compiler. Only weak library functions (see Variable Attributes) can be replaced in this way. For those that are weak, any function you write in your code will replace an identically named function in the library files.

22.2. Linker-Defined Symbols

The 32-bit linker defines several symbols that can be used in your C code development. Please see the *MPLAB® XC32 Assembler, Linker and Utilities User's Guide* (DS50002186) for more information.

The linker defines the symbols `_ramfunc_begin` and `_bmxdkpba_address`, which represent the starting address in RAM where ram functions will be accessed, and the corresponding address in the program memory from which the functions will be copied. They are used by the default runtime start-up code to initialize the bus matrix if ram functions exist in the project, see Allocation of Function Code.

The linker also defines the symbol `_stack`, which is used by the runtime start-up code to initialize the stack pointer. This symbol represents the starting address for the software stack.

All the above symbols are rarely required for most programs, but may assist you if you are writing your own runtime start-up code.

22.3. Default Linker Script

For PIC32MX Devices Only:

If no linker script or alternative Device Family Pack (DFP) is specified on the command line, the linker will use an internal version known as the built-in default linker script. The default linker script has section mapping that is appropriate for all PIC32 MCUs. It uses an `INCLUDE` directive to include the device-specific memory regions.

The default linker script is appropriate for most PIC32 MCU applications. Only applications with specific memory-allocation needs will require an application-specific linker script. The default linker script can be examined by invoking the linker with the `--verbose` option:

```
xc32-ld --verbose
```

In a normal tool-suite installation, a copy of the default linker script is located at `/pic32m/lib/ldscripts/pic32m.x`. Note that this file is only a copy of the default linker script. The script that the linker uses is internal to the linker.

The device-specific portion of the linker script is located in `xc32/<device>/procdefs.ld`, where `<device>` is the device value specified to the `-mprocessor` compilation-driver (`xc32-gcc`) option.

For PIC32MZ and Later Devices:

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The linker script for PIC32MZ devices are contained within a single file (for example, `xc32/<device>/p32MZ2064DAG176.ld`). Like before, the `xc32-gcc` compilation driver will pass the device-specific linker script to the linker when building with `-mprocessor` option.

The default linker script contains the following categories of information:

- Output Format and Entry Points
- Default Values for Minimum Stack and Heap Sizes
- Processor Definitions Include File for PIC32MX Family
  - Inclusion of Processor-Specific Object File(s)
  - Optional Inclusion of Processor-Specific Peripheral Libraries
  - Base Exception Vector Address and Vector Spacing Symbols
  - Memory Address Equates
  - Memory Regions
  - Configuration Words Input/Output Section Map
- Input/Output Section Map

Note: All addresses specified in the linker scripts should be specified as virtual addresses, not physical addresses.

22.3.1. Output Format and Entry Points

The first several lines of the default linker script define the output format and the entry point for the application.

```
OUTPUT_FORMAT("elf32-tradlittlemips")

OUTPUT_ARCH(pic32mx)

ENTRY(_reset)
```

The `OUTPUT_FORMAT` line selects the object file format for the output file. The output object file format generated by the 32-bit language tools is a traditional, little-endian, MIPS, ELF32 format.

The `OUTPUT_ARCH` line selects the specific machine architecture for the output file. The output files generated by the 32-bit language tools contain information that identifies the file was generated for the PIC32 architecture.

The `ENTRY` line selects the entry point of the application. This is the symbol identifying the location of the first instruction to execute. The 32-bit language tools begins execution at the instruction identified by the `_reset` label.

22.3.2. Default Values for Minimum Stack and Heap Sizes

The next section of the default linker script provides default values for the minimum stack and heap sizes.

```
/*
 * Provide for a minimum stack and heap size
 * - _min_stack_size - represents the minimum space that must
 *                     be made available for the stack. Can
 *                     be overridden from the command line
 *                     using the linker's --defsym option.
 * - _min_heap_size  - represents the minimum space that must
 *                     be made available for the heap. Can
 *                     be overridden from the command line
 *                     using the linker's --defsym option.
 */
EXTERN (_min_stack_size _min_heap_size)
PROVIDE(_min_stack_size = 0x400) ;
PROVIDE(_min_heap_size = 0) ;
```


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The EXTERN line ensures that the rest of the linker script has access to the default values of _min_stack_size and _min_heap_size assuming that the user does not override these values using the linker's --defsym command line option.

The two PROVIDE lines ensure that a default value is provided for both _min_stack_size and _min_heap_size. The default value for the minimum stack size is 1024 bytes (0x400). The default value for the minimum heap size is 0 bytes.

22.3.3. Processor Definitions Include File for PIC32MX Family

The next line in the default linker script pulls in information specific to the processor.

```
INCLUDE procdefs.ld
```

The file procdefs.ld is included in the linker script at this point. The file is searched for in the current directory and in any directory specified with the -L command line option. The compiler shell ensures that the correct directory is passed to the linker with the -L command line option based on the processor selected with the -mprocessor command line option.

The processor definitions linker script contains the following pieces of information:

- Inclusion of Processor-Specific Object File(s)
- Base Exception Vector Address and Vector Spacing Symbols
- Memory Address Equates
- Memory Regions
- Configuration Words Input/Output Section Map

22.3.3.1. Inclusion of Processor-Specific Object File(s)

This section of the processor definitions linker script ensures that the processor-specific object file(s) get included in the link.

```
/*************************************************************
  * Processor-specific object file. Contains SFR
        definitions.
*************************************************************/

INPUT("processor.o")
```

The INPUT line specifies that processor.o should be included in the link as if this file were named on the command line. The linker attempts to find this file in the current directory. If it is not found, the linker searches through the library search paths (that is, the paths specified with the -L command line option).

22.3.3.2. Optional Inclusion of Processor-Specific Peripheral Libraries

Note: The legacy peripheral libraries are deprecated and are replaced by the MPLAB Harmony libraries, installed separately.

This section of the processor definitions linker script ensures that the processor-specific peripheral libraries get included, but only if the files exist.

```
/*********************************************************************
  * Processor-specific peripheral libraries are
        optional
*********************************************************************/

OPTIONAL("libmchp_peripheral.a")

OPTIONAL("libmchp_peripheral_32MX795F512L.a")
```


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The OPTIONAL lines specify that `libmchp_peripheral.a` and `libmchp_peripheral_32MX795F512L.a` should be included in the link as if the files were named on the command line. The linker attempts to find these files in the current directory. If they are not found in the current directory, the linker searches through the library search paths. If they are not found in the library search paths, the link process continues without error. The linker will error only when a symbol from the -peripheral library is required but not found elsewhere.

22.3.3.3. Base Exception Vector Address and Vector Spacing Symbols

This section of the processor definitions linker script defines values for the base exception vector address and vector spacing.

```
/*************************************************************
* For interrupt vector handling
*************************************************************/
_vector_spacing = 0x00000001;
_ebase_address = 0x9FC01000;
```

The first line defines a value of `1` for `_vector_spacing`. The available memory for exceptions only supports a vector spacing of `1`. The second line defines the location of the base exception vector address (`EBASE`).

On some devices, the base exception vector address is located in the KSEG0 boot segment. On other devices, the size of the KSEG0 boot segment is not sufficient for the vector table, so the base exception vector address is located in the KSEG0 program segment. In general, devices with at least 12 KB in the KSEG0 boot segment use the boot flash for the exception vector table. Devices with less than 12 KB in the KSEG0 boot segment use the KSEG0 program segment for the exception vector table. Be sure to check the `procdefs.ld` include file for the default address for your target device.

22.3.3.4. Memory Address Equates

This section of the processor definitions linker script provides information about certain memory addresses required by the default linker script.

```
/*************************************************************
* Memory Address Equates
*************************************************************/
_RESET_ADDR                 =
        0xBFC00000;
_BEV_EXCPT_ADDR                 =
        0xBFC00380;
_DBG_EXCPT_ADDR                 =
        0xBFC00480;
_DBG_CODE_ADDR                  =
        0xBFC02000;
_GEN_EXCPT_ADDR                 =
        _ebase_address + 0x180;
```

The `_RESET_ADDR` defines the processor's Reset address. This is the virtual begin address of the IFM boot section in Kernel mode.

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The _BEV_EXCPT_ADDR defines the address that the processor jumps to when an exception is encountered and $Status_{BEV} = 1$.

The _DBG_EXCPT_ADDR defines the address that the processor jumps to when a debug exception is encountered.

The _DBG_CODE_ADDR defines the address that is the start address of the debug executive. Note that this address may vary depending on the size of the KSEG0 boot segment on your target device.

The _GEN_EXCPT_ADDR defines the address that the processor jumps to when an exception is encountered and $Status_{BEV} = 0$.

22.3.3.5. Memory Regions

This section of the processor definitions linker script provides information about the memory regions that are available on the device.

```
/*************************************************************

* Memory Regions

*

  * Memory regions without attributes cannot be
        used for

  * orphaned sections. Only sections specifically
        assigned to

  * these regions can be allocated into these
        regions.

*************************************************************/

MEMORY

{

   kseg0_program_mem (rx) : ORIGIN = 0x9D000000,
        LENGTH = 0x8000

kseg0_boot_mem : ORIGIN = 0x9FC00490, LENGTH = 0x970

exception_mem : ORIGIN = 0x9FC01000, LENGTH = 0x1000

kseg1_boot_mem : ORIGIN = 0xBFC00000, LENGTH = 0x490

debug_exec_mem : ORIGIN = 0xBFC02000, LENGTH = 0xFF0

   config3               : ORIGIN = 0xBFC02FF0, LENGTH =
       0x4

   config2               : ORIGIN = 0xBFC02FF4, LENGTH =
       0x4

   config1               : ORIGIN = 0xBFC02FF8, LENGTH =
       0x4

   config0               : ORIGIN = 0xBFC02FFC, LENGTH =
       0x4
```


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```
kseg1_data_mem : ORIGIN = 0xA0000000, LENGTH = 0x2000

   sfrs                  : ORIGIN = 0xBF800000, LENGTH =
         0x10000

}
```

Note: L1 cache devices use `kseg1_data_mem`.

Eleven memory regions are defined with an associated start address and length:

- Program memory region (`kseg0_program_mem`) for application code
- Boot memory regions (`kseg0_boot_mem` and `kseg1_boot_mem`)
- Exception memory region (`exception_mem`)
- Debug executive memory region (`debug_exec_mem`)
- Configuration memory regions (`config3`, `config2`, `config1`, and `config0`)
- Data memory region (`kseg1_data_mem`)
- SFR memory region (`sfrs`)

The default linker script uses these names to locate sections into the correct regions. Sections which are non-standard become orphaned sections. The attributes of the memory regions are used to locate these orphaned sections. The attributes (`rx`) specify that read-only sections or executable sections can be located into the program memory regions. Similarly, the attributes (`w!x`) specify that sections that are not read-only and not executable can be located in the data memory region. Since no attributes are specified for the boot memory region, the configuration memory regions, or the SFR memory region, only specified sections may be located in these regions (that is, orphaned sections may not be located in the boot memory regions, the exception memory region, the configuration memory regions, the debug executive memory region, or the SFR memory region).

22.3.3.6. Configuration Words Input/Output Section Map

The last section in the processor definitions linker script is the input/output section map for Configuration Words. This section map is additive to the Input/Output Section Map found in the default linker script (see Input/Output Section Map). It defines how input sections for Configuration Words are mapped to output sections for Configuration Words. Note that input sections are portions of an application that are defined in source code, while output sections are created by the linker. Generally, several input sections may be combined into a single output section. All output sections are specified within a `SECTIONS` command in the linker script.

For each Configuration Word that exists on the specific processor, a distinct output section named `.config_`*`address`* exists where address is the location of the Configuration Word in memory. Each of these sections contains the data created by the `#pragma config` directive (see Pragma Directives) for that Configuration Word. Each section is assigned to their respective memory region (`con-fign`).

```
SECTIONS

{

.config_BFC02FF0 : {

*(.config_BFC02FF0)

} > config3

.config_BFC02FF4 : {

*(.config_BFC02FF4)

} > config2
```


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```
.config_BFC02FF8 : {
*(.config_BFC02FF8)
} > config1
.config_BFC02FFC : {
*(.config_BFC02FFC)
} > config0
}
```

22.3.4. Input/Output Section Map

The last section in the default linker script is the input/output section map. The section map is the heart of the linker script. It defines how input sections are mapped to output sections. Note that input sections are portions of an application that are defined in source code, while output sections are created by the linker. Generally, several input sections may be combined into a single output section. All output sections are specified within a `SECTIONS` command in the linker script.

22.3.4.1. .Config_<Address> Sections

These sections map the Configuration Words to their corresponding absolute addresses on the target device. The compiler's config pragma generates the input sections using this naming convention, and the linker script then maps the compiler-generated input section to the output section mapped to the corresponding absolute address.

22.3.4.2. .Reset Section

This section contains the code that is executed when the processor performs a Reset. This section is located at the Reset address (`_RESET_ADDR`), as specified in the processor definitions linker script and is assigned to the boot memory region (`kseg1_boot_mem`). The `.reset` output section also contains the C start-up code from the `.reset.startup` input section.

```
.reset _RESET_ADDR :
{
  KEEP(*(.reset))
  KEEP(*(.reset.startup))
 } > kseg1_boot_mem
```

22.3.4.3. .bev_excpt Section

This section contains the handler for exceptions that occur when $Status_{BEV} = 1$. This section is located at the `BEV` exception address (`_BEV_EXCPT_ADDR`) as specified in the processor definitions linker script and is assigned to the boot memory region (`kseg1_boot_mem`).

```
(kseg1_boot_mem).
.bev_excpt _BEV_EXCPT_ADDR :
{
  (*(.bev_handler))
} > kseg1_boot_mem
```

22.3.4.4. .dbg_excpt Section

This section reserves space for the debug exception vector. This section is only allocated if the symbol `_DEBUGGER` has been defined. (This symbol is defined if the `-mde-bugger` command line option is specified to the shell.) This section is located at the debug exception address (`_DBG_EXCPT_ADDR`) as specified in the processor definitions linker script and is assigned to the boot memory region (`kseg1_boot_mem`). The section is marked as `NOLOAD` as it is only intended to ensure that application code cannot be placed at locations reserved for the debug executive.

```
.dbg_excpt _DBG_EXCPT_ADDR (NOLOAD) :
{
  . += (DEFINED (_DEBUGGER) ? 0x8 : 0x0);
} > kseg1_boot_mem
```


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22.3.4.5. .dbg_code Section

This section reserves space for the debug exception handler. This section is only allocated if the symbol `_DEBUGGER` has been defined. (This symbol is defined if the `-mde-bugger` command line option is specified to the shell.) This section is located at the debug code address (`_DBG_CODE_ADDR`) as specified in the processor definitions linker script and is assigned to the debug executive memory region (`debug_exec_mem`). The section is marked as `NOLOAD` because it is only intended to ensure that application code cannot be placed at locations reserved for the debug executive.

```
.dbg_code _DBG_CODE_ADDR (NOLOAD) :
{
  . += (DEFINED (_DEBUGGER) ? 0xFF0 : 0x0);
} > debug_exec_mem
```

22.3.4.6. .app_excpt Section

This section contains the handler for exceptions that occur when `StatusBEV = 0`. This section is located at the general exception address (`_GEN_EXCPT_ADDR`) as specified in the processor definitions linker script and is assigned to the exception memory region (`exception_mem`).

```
.app_excpt _GEN_EXCPT_ADDR :
{
  KEEP(*(.gen_handler))
} > exception_mem
```

22.3.4.7. .vector_0 .. .vector_63 Sections (PIC32MX Interrupt Vector Tables)

PIC32MX devices use an Interrupt Vector Controller that provides 64 interrupt vectors with uniform, user-configurable spacing.

For these devices, each vector in the table is created as an output section located at an absolute address based on values of the `_ebase_address` and `_vector_spacing` symbols. There is one `.vector_n` output section for each of the 64 vectors in the table.

These sections contain the handler for each of the interrupt vectors. These sections are located at the correct vectored addresses using the formula:

`_ebase_address + 0x200 + (_vector_spacing << 5) * n`

where `n` is the respective vector number.

Each of the sections is followed by an assert that ensures the code located at the vector does not exceed the vector spacing specified.

```
.vector_n _ebase_address + 0x200 + (_vector_spacing << 5) * n :
  {
    KEEP(*(.vector_n))
  } > exception_mem
ASSERT (SIZEOF(.vector_n) < (_vector_spacing << 5), "function at exception vector n too
large")
```

22.3.4.8. .vectors Section

Some PIC32 families feature variable offsets for vector spacing. This feature allows the interrupt vector spacing to be configured according to application needs. A specific interrupt vector offset can be set for each vector using its associated `OFFxxx` register. For details on the interrupt vector-table variable offset feature, refer to the "*PIC32 -Family Reference Manual*" (DS61108) and also the data sheet for your specific PIC32 MCU.

The application source code is responsible for creating a `.vector_n` input section for each interrupt vector. The C/C++ compiler creates this section when either the `-vector(n)` or the `at_vector(n)` attribute is applied to the interrupt service routine. In assembly code, use the `.section` directive to create a new named section.

The device-specific linker script creates a single output section named `.vectors` that groups all of the individual `.vector_n` input sections from the project. The start of the interrupt-vector table is

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mapped to the address (`_ebase_address + 0x200`). The default value of the `_ebase_address` symbol is also provided in the linker script.

For each vector, the linker script also creates a symbol named `__vector_offset_n`, whose value is the offset of the vector address from the `_ebase_address` address.

```
PROVIDE(_ebase_address = 0x9D000000);
SECTIONS {
 /* Interrupt vector table with vector offsets */
 .vectors _ebase_address + 0x200 :
 {
 /* Symbol __vector_offset_n points to .vector_n if it exists,
  * otherwise points to  the default handler. The
  * vector_offset_init.o module then provides a .data section
  * containing values used to initialize the vector-offset SFRs
  * in the crt0 startup code.
  */
 __vector_offset_0 = (DEFINED(__vector_dispatch_0) ? (. - _ebase_address) :
__vector_offset_default); KEEP(*(.vector_0))
 __vector_offset_1 = (DEFINED(__vector_dispatch_1) ? (. - _ebase_address) :
__vector_offset_default); KEEP(*(.vector_1))
 __vector_offset_2 = (DEFINED(__vector_dispatch_2) ? (. - _ebase_address) :
__vector_offset_default); KEEP(*(.vector_2))
 /* ... */
 __vector_offset_190 = (DEFINED(__vector_dispatch_190) ? (. - _ebase_address) :
__vector_offset_default); KEEP(*(.vector_190))
 }
}
```

The vector-offset initialization module (`vector_offset_init.o`) uses the `__vector_offset_n` symbols defined in the default linker script. The value of each symbol is the offset of the vector's address from the ebase register's address. The vector-offset initialization module, uses the symbol value to create a `.data` section using the address of the corresponding `OFFxxx` special function register. This means that the standard linker-generated data-initialization template contains the values used to initialize the `OFFxxx` registers.

With these `.data` sections added to the project and the linker-generated data-initialization template, the standard runtime startup code initializes the `OFFxxx` special function registers as regular initialized data. No special code is required in the startup code to initialize the `OFFxxx` registers.

22.3.4.9. .text Section

The standard executable code sections are no longer mapped to the `.text` output section. However, a few special executable sections are still mapped here as shown below. This section is assigned to the program memory region (`kseg0_program_mem`) and has a fill value of `NOP (0)`.

The built-in linker script no longer maps standard `.text` executable code input sections. By not mapping these sections in the linker script, we allow these sections to be allocated using the best-fit allocator rather than the sequential allocator. Sections that are unmapped in the linker script can flow around absolute sections specified in code, whereas sections that are linker-script mapped are grouped together and allocated sequentially. This potentially causes conflicts with absolute sections (using the `address` function attribute).

```
.text ORIGIN(kseg0_program_mem) :
{
*(.stub .gnu.linkonce.t.*)
  KEEP (*(.text.*personality*))
  *(.gnu.warning)
  *(.mips16.fn.*)
  *(.mips16.call.*)
} > kseg0_program_mem =0
```


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22.3.4.10. C++ Initilization Sections

The sections `.init`, `.preinit_array`, `.init_array`, `.fini_array`, `.ctors`, and `.dtors` are all used for the construction and destruction of file-scope static-storage C++ objects.

```
  /* Global-namespace object initialization */
  .init   :
  {
    KEEP (*crti.o(.init))
    KEEP (*crtbegin.o(.init))
    KEEP (*(EXCLUDE_FILE (*crtend.o *crtend?.o *crtn.o ).init))
    KEEP (*crtend.o(.init))
    KEEP (*crtn.o(.init))
    . = ALIGN(4) ;
  } >kseg0_program_mem
  .fini   :
  {
    KEEP (*(.fini))
    . = ALIGN(4) ;
  } >kseg0_program_mem
  .preinit_array   :
  {
    PROVIDE_HIDDEN (__preinit_array_start = .);
    KEEP (*(.preinit_array))
    PROVIDE_HIDDEN (__preinit_array_end = .);
    . = ALIGN(4) ;
  } >kseg0_program_mem
  .init_array   :
  {
    PROVIDE_HIDDEN (__init_array_start = .);
    KEEP (*(SORT(.init_array.*)))
    KEEP (*(.init_array))
    PROVIDE_HIDDEN (__init_array_end = .);
    . = ALIGN(4) ;
  } >kseg0_program_mem
  .fini_array   :
  {
    PROVIDE_HIDDEN (__fini_array_start = .);
    KEEP (*(SORT(.fini_array.*)))
    KEEP (*(.fini_array))
    PROVIDE_HIDDEN (__fini_array_end = .);
    . = ALIGN(4) ;
  } >kseg0_program_mem
  .ctors   :
  {
    /* XC32 uses crtbegin.o to find the start of
       the constructors, so we make sure it is
       first.  Because this is a wildcard, it
       doesn't matter if the user does not
       actually link against crtbegin.o; the
       linker won't look for a file to match a
       wildcard.  The wildcard also means that it
       doesn't matter which directory crtbegin.o
       is in.  */
    KEEP (*crtbegin.o(.ctors))
    KEEP (*crtbegin?.o(.ctors))
    /* We don't want to include the .ctor section from
       the crtend.o file until after the sorted ctors.
       The .ctor section from the crtend file contains the
       end of ctors marker and it must be last */
    KEEP (*(EXCLUDE_FILE (*crtend.o *crtend?.o ) .ctors))
    KEEP (*(SORT(.ctors.*)))
    KEEP (*(.ctors))
    . = ALIGN(4) ;
  } >kseg0_program_mem
  .dtors   :
  {
    KEEP (*crtbegin.o(.dtors))
    KEEP (*crtbegin?.o(.dtors))
    KEEP (*(EXCLUDE_FILE (*crtend.o *crtend?.o ) .dtors))
    KEEP (*(SORT(.dtors.*)))
    KEEP (*(.dtors))
    . = ALIGN(4) ;
  } >kseg0_program_mem
The order of the input sections within each output section is significant.
```


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Note: The order of the input sections within each output section is significant.

22.3.4.11. .rodata Section

Standard read-only sections are not mapped in the linker script. A few special read-only sections are still mapped in the linker script, but most sections are unmapped, allowing them to be handled by the best fit allocator. This section is assigned to the program memory region (`kseg0_program_mem`).

```
.rodata   :
{
  *(.gnu.linkonce.r.*)
  *(.rodata1)
} > kseg0_program_mem
```

22.3.4.12. .sdata2 Section

This section collects the small initialized constant global and static data from all of the application's input files. Because of the constant nature of the data, this section is also a read-only section. This section is assigned to the program memory region (`kseg0_program_mem`).

```
/*
 * Small initialized constant global and static data can be
 * placed in the .sdata2 section. This is different from
 * .sdata, which contains small initialized non-constant
 * global and static data.
 */
.sdata2   :
{
  *(.sdata2 .sdata2.* .gnu.linkonce.s2.*)
} > kseg0_program_mem
```

22.3.4.13. .sbss2 Section

This section collects the small uninitialized constant global and static data from all of the application's input files. Because of the constant nature of the data, this section is also a read-only section. This section is assigned to the program memory region (`kseg0_program_mem`).

```
/*
 * Uninitialized constant global and static data (that is,
 * variables which will always be zero). Again, this is
 * different from .sbss, which contains small non-initialized,
 * non-constant global and static data.
 */
.sbss2   :
{
  *(.sbss2 .sbss2.* .gnu.linkonce.sb2.*)
} > kseg0_program_mem
```

22.3.4.14. .dbg_data Section

This section reserves space for the data required by the debug exception handler. This section is only allocated if the symbol `_DEBUGGER` has been defined. (This symbol is defined if the `-mdebugger` command line option is specified to the shell.) This section is assigned to the data memory region (`kseg1_data_mem`). The section is marked as `NOLOAD` as it is only intended to ensure that application data cannot be placed at locations reserved for the debug executive.

```
.dbg_data (NOLOAD) :
{
  . += (DEFINED (_DEBUGGER) ? 0x200 : 0x0);
} > kseg1_data_mem
```

22.3.4.15. .data Section

The linker generates a data-initialization template that the C start-up code uses to initialize variables.

22.3.4.16. .got Section

This section collects the global offset table from all of the application's input files. This section is assigned to the data memory region (`kseg1_data_mem`) with a load address located in the program

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memory region (kseg0_program_mem). A symbol is defined to represent the location of the Global Pointer (_gp).

```
  _gp = ALIGN(16) + 0x7FF0 ;
  .got   :
  {
     *(.got.plt) *(.got)
  } > kseg1_data_mem AT> kseg0_program_mem
```

22.3.4.17. .sdata Section

This section collects the small initialized data from all of the application's input files. This section is assigned to the data memory region (kseg1_data_mem) with a load address located in the program memory region (kseg0_program_mem). Symbols are defined to represent the virtual begin (_sdata_begin) and end (_sdata_end) addresses of this section.

```
/*
 * We want the small data sections together, so
 * single-instruction offsets can access them all, and
 * initialized data all before uninitialized, so
 * we can shorten the on-disk segment size.
 */
.sdata   :
{
  _sdata_begin = . ;
  *(.sdata .sdata.* .gnu.linkonce.s.*)
  _sdata_end = . ;
} > kseg1_data_mem AT> kseg0_program_mem
```

22.3.4.18. .lit8 Section

This section collects the 8-byte constants (usually floating-point) which the assembler decides to store in memory rather than in the instruction stream from all of the application's input files. This section is assigned to the data memory region (kseg1_data_mem) with a load address located in the program memory region (kseg0_program_mem).

```
.lit8           :
{
  *(.lit8)
} > kseg1_data_mem AT> kseg0_program_mem
```

22.3.4.19. .lit4 Section

This section collects the 4-byte constants (usually floating-point) which the assembler decides to store in memory rather than in the instruction stream from all of the application's input files. This section is assigned to the data memory region (kseg1_data_mem) with a load address located in the program memory region (kseg0_program_mem). A symbol is defined to represent the virtual end address of the initialized data (_data_end).

```
  .lit4           :
  {
    *(.lit4)
  } > kseg1_data_mem AT> kseg0_program_mem
  _data_end = . ;
```

22.3.4.20. .sbss Section

This section collects the small uninitialized data from all of the application's input files. This section is assigned to the data memory region (kseg1_data_mem). A symbol is defined to represent the virtual begin address of uninitialized data (_bss_begin). Symbols are also defined to represent the virtual begin (_sbss_begin) and end (_sbss_end) addresses of this section.

```
  _bss_begin = . ;
  .sbss   :
  {
    _sbss_begin = . ;
    *(.dynsbss)
```


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```
    *(.sbss .sbss.* .gnu.linkonce.sb.*)
    *(.scommon)
    _sbss_end = . ;
  } > kseg1_data_mem
```

22.3.4.21. .bss Section

This section collects the uninitialized data from all of the application's input files. This section is assigned to the data memory region (`kseg1_data_mem`). A symbol is defined to represent the virtual end address of uninitialized data (`_bss_end`). A symbol is also to represent the virtual end address of data memory (`_end`).

```
.bss   :
{
  *(.dynbss)
  *(.bss .bss.* .gnu.linkonce.b.*)
  *(COMMON)
  /*
   * Align here to ensure that the .bss section occupies
   * space up to _end.  Align after .bss to ensure correct
   * alignment even if the .bss section disappears because
   * there are no input sections.
   */
  . = ALIGN(32 / 8) ;
} > kseg1_data_mem
. = ALIGN(32 / 8) ;
_end = . ;
_bss_end = . ;
```

22.3.4.22. .heap Section

The linker now dynamically reserves an area of memory for the heap. The `.heap` section is no longer mapped in the linker script. The linker finds the largest unused gap of memory after all other sections are allocated and uses that gap for both the heap and the stack. The minimum amount of space reserved for the heap is determined by the symbol `_min_heap_size`.

22.3.4.23. .stack Section

The linker now dynamically reserves an area of memory for the stack. The `.stack` section is no longer mapped in the linker script. The linker finds the largest unused gap of memory after all other sections are allocated and uses that gap for both the heap and the stack. The minimum amount of space reserved for the stack is determined by the symbol `_min_stack_size`.

22.3.4.24. .ramfunc Section

The linker now dynamically collects the '`ramfunc`' attributed and "`.ramfunc`" named sections and allocates them sequentially in an appropriate range of memory. The first `ramfunc` attributed function is placed at the highest appropriately aligned address.

The presence of a `ramfunc` section causes the linker to emit the symbols necessary for the crt0.S start-up code to initialize the PIC32 bus matrix appropriately.

```
/*
 * RAM functions go at the end of our stack and heap allocation.
 * Alignment of 2K required by the boundary register (BMXDKPBA).
 *
 * RAM functions are now allocated by the linker. The linker generates
 * _ramfunc_begin and _bmxdkpba_address symbols depending on the
 * location of RAM functions.
 */

_bmxdudba_address = LENGTH(kseg1_data_mem) ;
_bmxdupba_address = LENGTH(kseg1_data_mem) ;
```

22.3.4.25. Stack Location

A symbol is defined to represent the location of the Stack Pointer (`_stack`). As described previously, the heap and the stack are now allocated to the largest available gap of memory after other sections have been allocated.

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For PIC32 devices with more than 64K of data memory, GP relative addressing mode should not be used. To avoid conflict of using GP-relative addressing to the linker generated symbols, allocate the symbols in section "_linkergenerated": `extern unsigned int __attribute__((section("_linkergenerated"))) _splim;`

22.3.4.26. Debug Sections

The debug sections contain DWARF2 debugging information. They are not loaded into program Flash.

```
/* Stabs debugging sections.  */
.stab          0 : { *(.stab) }
.stabstr       0 : { *(.stabstr) }
.stab.excl     0 : { *(.stab.excl) }
.stab.exclstr  0 : { *(.stab.exclstr) }
.stab.index    0 : { *(.stab.index) }
.stab.indexstr 0 : { *(.stab.indexstr) }
.comment       0 : { *(.comment) }
/* DWARF debug sections.
   Symbols in the DWARF debugging sections are relative to the beginning
   of the section so we begin them at 0.  */
/* DWARF 1 */
.debug          0 : { *(.debug) }
.line           0 : { *(.line) }
/* GNU DWARF 1 extensions */
.debug_srcinfo  0 : { *(.debug_srcinfo) }
.debug_sfnames  0 : { *(.debug_sfnames) }
/* DWARF 1.1 and DWARF 2 */
.debug_aranges  0 : { *(.debug_aranges) }
.debug_pubnames 0 : { *(.debug_pubnames) }
/* DWARF 2 */
.debug_info     0 : { *(.debug_info .gnu.linkonce.wi.*) }
.debug_abbrev   0 : { *(.debug_abbrev) }
.debug_line     0 : { *(.debug_line) }
.debug_frame    0 : { *(.debug_frame) }
.debug_str      0 : { *(.debug_str) }
.debug_loc      0 : { *(.debug_loc) }
.debug_macinfo  0 : { *(.debug_macinfo) }
/* SGI/MIPS DWARF 2 extensions */
.debug_weaknames 0 : { *(.debug_weaknames) }
.debug_funcnames 0 : { *(.debug_funcnames) }
.debug_typenames 0 : { *(.debug_typenames) }
.debug_varnames  0 : { *(.debug_varnames) }
.debug_pubtypes 0 : { *(.debug_pubtypes) }
.debug_ranges   0 : { *(.debug_ranges) }
/DISCARD/ : { *(.rel.dyn) }
.gnu.attributes 0 : { KEEP (*(.gnu.attributes)) }
/DISCARD/ : { *(.note.GNU-stack) }
/DISCARD/ : { *(.note.GNU-stack) *(.gnu_debuglink) *(.gnu.lto_*) *(.discard) }
```

22.3.4.27. Variables Allocated to L1 Cached Memory

For devices featuring an L1 data cache, data variables are now allocated to the KSEG0 data-memory region (`kseg0_data_mem`) making it accessible through the L1 cache. Likewise, the linker-allocated heap and stack are allocated to the KSEG0 region. The startup code initializes the L1 cache using symbols defining the base addresses in the linker script.

Example:

```
EXTERN  (__pic32_init_cache_program_base_addr)
PROVIDE (__pic32_init_cache_program_base_addr = 0x9D000000) ;
EXTERN  (__pic32_init_cache_data_base_addr)
PROVIDE (__pic32_init_cache_data_base_addr = 0x80000000) ;
```

22.3.4.28. .tlb_init_values Section

Some PIC32 devices feature a Memory Management Unit (MMU) with a Translation Lookaside Buffer (TLB). On some of these devices, the data sheet describes specific ranges of KSEG2/KSEG3 regions as dedicated to the Serial Quad Interface (SQI) and/or the External Bus Interface (EBI).

For these devices, the default startup code calls a module that initializes the TLB for this dedicated memory mapping. The TLB initialization module, `pic32_init_tlb_ebi_sqi.o`, uses the table

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created by this section to initialize the TLB. For more information on this format, see the copy of the `pic32_init_tlb_ebi_sqi.S` source file located in your `pic32m-libs/libpic32/stubs` directory.

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23. Embedded Compiler Compatibility Mode

All four MPLAB XC C compilers can be placed into a compatibility mode. In this mode, they are syntactically compatible with non-standard C language extensions, some used by other non-Microchip embedded compiler vendors. This compatibility can allow C source code written for other compilers to be compiled with minimum modification when using the appropriate MPLAB XC compiler.

Since very different device architectures may be targeted by other compilers, the semantics of the non-standard extensions associated with these compilers might be different to that in the MPLAB XC compilers. This document indicates when the original C code may need to be reviewed.

23.1. Compiling in Compatibility Mode

The `-mext=vendor` option is used to enable vendor-specific syntax compatibility. The argument vendor is a key that is used to represent the syntax. See the following table for a list of all keys usable with the MPLAB XC compilers.

Table 23-1. Vendor Keys

Vendor key	Syntax	XC8 Support	XC16/XC-DSC Support	XC32 Support
`cci`	Common Compiler Interface	Yes	Yes	Yes
`iar`	IAR C/C++ Compiler™ for Arm	No	Yes	Yes

The Common Compiler Interface is a language standard that is common to all Microchip MPLAB XC compilers (although this is not implemented by XC32 when targeting PIC32C/SAM devices). The non-standard extensions associated with this syntax are already described in Common C Interface and are not repeated here.

23.2. Syntax Compatibility

The goal of this syntax compatibility feature is to ease the migration process when porting source code from other C compilers to the native MPLAB XC compiler syntax.

Many non-standard extensions are not required when compiling for Microchip devices and, for these, there are no equivalent extensions offered by MPLAB XC compilers. These extensions are then simply ignored by the MPLAB XC compilers, although a warning message is usually produced to ensure that you are aware of the different compiler behavior. You should confirm that your project will still operate correctly with these features disabled.

Other non-standard extensions are not compatible with Microchip devices. Errors will be generated by the MPLAB XC compiler if these extensions are not removed from the source code. You should review the ramifications of removing the extension and decide whether changes are required to other source code in your project.

The following table indicates the various levels of compatibility used in the tables that are presented throughout this guide.

Table 23-2. Level of Support Indicators

Level	Explanation
support	The syntax is accepted in the specified compatibility mode, and its meaning will mimic its meaning when it is used with the original compiler.
support (no args)	In the case of pragmas, the base pragma is supported in the specified compatibility mode, but the arguments are ignored.
native support	The syntax is equivalent to that which is already accepted by the MPLAB XC compiler, and the semantics are compatible. You can use this feature without a vendor compatibility mode having been enabled.

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Table 23-2. Level of Support Indicators (continued)

Level	Explanation
ignore	The syntax is accepted in the specified compatibility mode, but the implied action is not required or performed. The extension is ignored and a warning will be issued by the compiler.
error	The syntax is not accepted in the specified compatibility mode. An error will be issued and compilation will be terminated.

Note that even if a C feature is supported by an MPLAB XC compiler, addresses, register names, assembly instructions, or any other device-specific argument is unlikely to be valid when compiling for a Microchip device. Always review code which uses these items in conjunction with the data sheet of your target Microchip device.

23.3. Data Type

Some compilers allow use of the boolean type, `bool`, as well as associated values `true` and `false`, as specified by the C99 C Language Standard. This type and these values may be used by all MPLAB XC compilers when in compatibility mode (see note), as shown in the table below.

As indicated by the Standard, the `<stdbool.h>` header must be included for this feature to work as expected when it is used with MPLAB XC compilers.

Table 23-3. Support for C99 Bool Type

IAR Compatibility Mode		
Type	XC16/XC-DSC	XC32
`bool`	support	support

Note: Not all C99 features have been adopted by all Microchip MPLAB XC compilers.

23.4. Operator

The @ operator may be used with other compilers to indicate the desired memory location of an object. As the table below indicates, this syntax in MPLAB XC compilers is not supported.

Any address specified with another device is unlikely to be correct on a new architecture. Review the address in conjunction with the data sheet for your target Microchip device. For MPLAB XC16, XC-DSC and XC32, consider using the `address` attribute with the revised address.

Table 23-4. Support for Non-Standard Operator

IAR Compatibility Mode		
Operator	XC16/XC-DSC	XC32
`@`	error	error

23.5. Extended Keywords

Non-standard extensions often specify how objects are defined or accessed. Keywords are usually used to indicate the feature. The non-standard C keywords corresponding to other compilers are listed in the following table, as well as the level of compatibility offered by MPLAB XC compilers. The table notes offer more information about extensions.

Table 23-5. Support for Non-Standard Keywords

IAR Compatibility Mode		
Keyword	**XC16/XC-DSC**	**XC32**
`__section_begin`	support	support
`__section_end`	support	support
`__section_size`	support	support
`__segment_begin`	support	support

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__segment_end	support	support
__segment_size	support	support
__sfb	support	support
__sfe	support	support
__sfs	support	support
__asm or asm[1]	native support	native support
__arm	ignore	ignore
__big_endian	error	error
__fiq	error	error
__intrinsic	ignore	ignore
__interwork	ignore	ignore
__irq	error	error
__little_endian[2]	ignore	ignore
__nested	ignore	ignore
__no_init	support	support
__noreturn	support	support
__ramfunc	ignore	support[3]
__packed	support	support
__root	support	support
__swi	ignore	ignore
__task	support	support
__weak	support	support
__thumb	ignore	ignore
__farfunc	ignore	ignore
__huge	ignore	ignore
__nearfunc	ignore	ignore
__inline	native support	native support

Notes:

1. All assembly code specified by this construct is device-specific and will need review when porting to any Microchip device.
2. This is the default (and only) endianism used by all MPLAB XC compilers.
3. When used with MPLAB XC32, this must be used with the __longcall__ macro for full compatibility.

23.6. Intrinsic Functions

Intrinsic functions can be used to perform common tasks in the source code. The MPLAB XC compilers' support for the intrinsic functions offered by other compilers is shown in the following table.

Table 23-6. Support for Non-Standard Intrinsic Functions

IAR Compatibility Mode		
Function	**XC16/XC-DSC**	**XC32**
__disable_fiq	ignore	ignore
__disable_interrupt	support	support
__disable_irq	ignore	ignore
__enable_fiq	ignore	ignore
__enable_interrupt	support	support

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__enable_irq	ignore	ignore
__get_interrupt_state	support	support
__set_interrupt_state	support	support

The header file <xc.h> must be included for supported functions to operate correctly.

23.7. Pragmas

Pragmas may be used by a compiler to control code generation. Any compiler will ignore an unknown pragma, but many pragmas implemented by another compiler have also been implemented by the MPLAB XC compilers in compatibility mode. The table below shows the pragmas and the level of support when using each of the MPLAB XC compilers.

Many of these pragmas take arguments. Even if a pragma is supported by an MPLAB XC compiler, this support may not apply to all of the pragma's arguments. This is indicated in the table.

Table 23-7. Support for Non-Standard Pragmas

IAR Compatibility Mode		
Pragma	**XC16/XC-DSC**	**XC32**
bitfields	ignore	ignore
data_alignment	support	support
default_variable_attributes	ignore	native support (section attribute)
default_function_attributes	ignore	native support (section attribute)
diag_default	ignore	ignore
diag_error	ignore	ignore
diag_remark	ignore	ignore
diag_suppress	ignore	ignore
diag_warning	ignore	ignore
include_alias	ignore	ignore
inline	support (no args)	support (no args)
language	ignore	ignore
location	support	support
message	native support	native support
object_attribute	ignore	ignore
optimize	native support	native support
pack	native support	native support
__printf_args	support	support
required	support	support
rtmodel	ignore	ignore
__scanf__args	support	support
section	support	support
segment	support	support
swi_number	ignore	ignore
type_attribute	ignore	ignore
weak	native support	native support

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24. Common C Interface

The Common C Interface (CCI) is available with all MPLAB XC C compilers and is designed to enhance code portability between these compilers. For example, CCI-conforming code would make it easier to port from a PIC18 MCU using the MPLAB XC8 C compiler to a PIC32 MCU using the MPLAB XC32 C/C++ Compiler.

The CCI assumes that your source code already conforms to the C90 or C99 Language Standard. If you intend to use the CCI, it is your responsibility to write code that conforms. Legacy projects will need to be migrated to achieve conformance. A compiler option must also be set to ensure that the operation of the compiler is consistent with the interface when the project is built.

24.1. Background - The Desire for Portable Code

All programmers want to write portable source code.

Portability means that the same source code can be compiled and run in a different execution environment than that for which it was written. Rarely can code be one hundred percent portable, but the more tolerant it is to change, the less time and effort it takes to have it running in a new environment.

Embedded engineers typically think of code portability as being across target devices, but this is only part of the situation. The same code could be compiled for the same target but with a different compiler. Differences between those compilers might lead to the code failing at compile time or runtime, so this must be considered as well.

You can only write code for one target device and only use one brand of compiler; but if there is no regulation of the compiler's operation, simply updating your compiler version can change your code's behavior.

Code must be portable across targets, tools, and time to be truly flexible.

Clearly, this portability cannot be achieved by the programmer alone, since the compiler vendors can base their products on different technologies, implement different features and code syntax, or improve the way their product works. Many a great compiler optimization has broken many an unsuspecting project.

Standards for the C language have been developed to ensure that change is managed and code is more portable. The International Standards Organization (ISO) publishes standards for many disciplines, including programming languages. Standards such as the ISO/IEC 9899:1999 are universally adopted for the C programming language.

24.1.1. The C Language Standard

A C Language Standard, such as ISO/IEC 9899:1999 Standard (C99), has to reconcile two opposing goals: freedom for compilers vendors to target new devices and improve code generation, against the known functional operation of source code for programmers. If both goals can be met, source code can be made portable.

The C Language Standards are implemented as a set of rules that detail not only the syntax that a conforming C program must follow, but the semantic rules by which that program will be interpreted. Thus, for a compiler to conform to the standard, it must ensure that a conforming C program functions as described by the standard.

Language Standards describe *implementation* as the set of tools and the runtime environment on which the code will run. If any of these change; for example, you build for and run on a different target device, or if you update the version of the compiler you use to build, then you are using a different implementation.

The standards uses the term *behavior* to mean the external appearance or action of the program. This has nothing to do with how a program is encoded.

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Since the Language Standard is trying to achieve goals that could be construed as conflicting, some specifications appear somewhat vague. For example, C standards states that an `int` type must be able to hold at least a 16-bit value, but it does not go as far as saying what the size of an `int` actually is; and the action of right-shifting a signed integer can produce different results on different implementations; yet these different results are still compliant with the standard.

If a standard is too strict, device architectures cannot allow the compiler to conform. But if it is too weak, programmers would see wildly differing results within different compilers and architectures, causing the standard to lose its effectiveness.

For example, the mid-range PIC® microcontrollers do not have a data stack. Because a compiler targeting this device cannot implement recursion, it (strictly speaking) cannot conform to the C Language Standard. This example illustrates a situation in which the standard is too strict for mid-range devices and tools.

The standard organizes source code whose behavior is not fully defined into groups that include the following behaviors:

Implementation-defined behavior	This is unspecified behavior in which each implementation documents how the choice is made.
Unspecified behavior	The standard provides two or more possibilities and imposes no further requirements on which possibility is chosen in any particular instance.
Undefined behavior	This is behavior for which the standard imposes no requirements.

Code that strictly conforms to a Language Standard does not produce output that is dependent on any unspecified, undefined, or implementation-defined behavior. The size of an `int`, which was used as an example earlier, falls into the category of behavior that is defined by implementation. That is to say, the size of an `int` is defined by which compiler is being used, how that compiler is being used, and the device that is being targeted.

The MPLAB XC compilers are freestanding implementations that conform to the ISO/IEC 9899:1990 Standard (referred to as the C90 standard) as well the ISO/IEC 9899:1999 Standard (C99) for programming languages, unless otherwise stated.

For freestanding implementations (or for what are typically called embedded applications), the standard allows non-standard extensions to the language, but obviously does not enforce how they are specified or how they work. When working so closely to the device hardware, a programmer needs a means of specifying device setup and interrupts, as well as utilizing the often complex world of small-device memory architectures. This cannot be offered by the standard in a consistent way.

While the C Language Standards provides a mutual understanding for programmers and compiler vendors, programmers need to consider the implementation-defined behavior of their tools and the probability that they may need to use extensions to the C language that are non-standard. Both of these circumstances can have an impact on code portability.

24.1.2. The Common C Interface

The Common C Interface (CCI) supplements the C Language Standard, such as ISO/IEC 9899:1999, and makes it easier for programmers to achieve consistent outcomes on all Microchip devices when using MPLAB XC C compilers.

It delivers the following improvements, all designed with portability in mind.

Refinement of the C Language Standard	The CCI documents specific behavior for some code in which actions are implementation-defined behavior under the C Language Standard. For example, the result of right-shifting a signed integer is fully defined by the CCI. Note that many implementation-defined items that closely couple with device characteristics, such as the size of an `int`, are not defined by the CCI.

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Consistent syntax for non-standard extensions	The CCI non-standard extensions are mostly implemented using keywords with a uniform syntax. They replace keywords, macros and attributes that are the native compiler implementation. The interpretation of the keyword can differ across each compiler, and any arguments to the keywords can be device specific.
Coding guidelines	The CCI can indicate advice on how code should be written so that it can be ported to other devices or compilers. While you may choose not to follow the advice, it will not conform to the CCI.

24.2. Using the CCI

The CCI allows enhanced portability by refining implementation-defined behavior and standardizing the syntax for extensions to the language.

The CCI is something you choose to follow and put into effect, thus it is relevant for new projects, although you can choose to modify existing projects so they conform.

For your project to conform to the CCI, you must do the following things.

- **Enable the CCI**
  Select the MPLAB X IDE widget **Use CCI Syntax** in your project, or use the command-line option that is equivalent.
- **Include <xc.h> in every module**
  Some CCI features are only enabled if this header is seen by the compiler.
- **Ensure C Language Standard compliance**
  Code that does not conform to the C Language Standard does not conform to the CCI.
- **Observe refinements to the Language Standard by the CCI**
  Some implementation-defined behavior is defined explicitly by the CCI.
- **Use the CCI extensions to the language**
  Use the CCI extensions rather than the native language extensions.

The next sections detail specific items associated with the CCI. These items are segregated into those that refine the standard, those that deal with the C Language Standard extensions, and other miscellaneous compiler options and usage. Guidelines are indicated with these items.

If any implementation-defined behavior or any non-standard extension is not discussed in this document, then it is not part of the CCI. For example, GCC case ranges, label addresses and 24-bit `short long` types are not part of the CCI. Programs which use these features do not conform to the CCI. The compiler may issue a warning or error to indicate a non-CCI feature has been used and the CCI is enabled.

24.3. C Language Standard Refinement

The following topics describe how the CCI refines the implementation-defined behaviors outlined in the C Langauge Standard.

24.3.1. Source File Encoding

Under the CCI, a source file must be written using characters from the 7-bit ASCII set. Lines can be terminated using a *line feed* `(\n)` or *carriage return* `(\r)` that is immediately followed by a *line feed*. Escaped characters can be used in character constants or string literals to represent extended characters that are not in the basic character set.

Example

The following shows a string constant being defined that uses escaped characters.

```
const char myName[] = "Bj\370rk\n";
```

Differences

All compilers have used this character set.

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Migration to the CCI

No action required.

24.3.2. The Prototype for `main`

The prototype for the `main()` function is:

```
int main(void);
```

Example

The following shows an example of how `main()` might be defined:

```
int main(void)
{
  while(1)
    process();
}
```

Differences

When targeting PIC MCUs using MPLAB XC8 a `void` return type for this function has been assumed.

Migration to the CCI

Each program has one definition for the `main()` function. Confirm the return type for `main()` in all projects previously compiled for 8-bit targets.

24.3.3. Header File Specification

Header file specifications that use directory separators do not conform to the CCI.

Example

The following example shows two conforming include directives.

```
#include <usb_main.h>
```

```
#include "global.h"
```

Differences

Header file specifications that use directory separators have been allowed in previous versions of all compilers. Compatibility problems arose when Windows-style separators "\" were used and the code was compiled under other host operating systems. Under the CCI, no directory separators should be used.

Migration to the CCI

Any `#include` directives that use directory separators in the header file specifications should be changed. Remove all but the header file name in the directive. Add the directory path to the compiler's include search path or MPLAB X IDE equivalent. This will force the compiler to search the directories specified with this option.

For example, the following code:

```
#include <inc/lcd.h>
```

should be changed to:

```
#include <lcd.h>
```

and the path to the `inc` directory added to the compiler's header search path in your MPLAB X IDE project properties, or on the command-line as follows:

```
-Ilcd
```


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24.3.4. Include Search Paths

When you include a header file under the CCI, the file should be discoverable in the paths searched by the compiler that are detailed below.

Header files specified in angle bracket delimiters < > should be discoverable in the search paths that are specified by `-I` options (or the equivalent MPLAB X IDE option), or in the standard compiler `include` directories. The `-I` options are searched in the order in which they are specified.

Header files specified in quote characters " " should be discoverable in the current working directory or in the same directories that are searched when the header files are specified in angle bracket delimiters (as above). In the case of an MPLAB X project, the current working directory is the directory in which the C source file is located. If unsuccessful, the search paths should be to the same directories searched when the header file is specified in angle bracket delimiters.

Any other options to specify search paths for header files do not conform to the CCI.

Example

If including a header file, as in the following directive:

```
#include "myGlobals.h"
```

the header file should be locatable in the current working directory, or the paths specified by any `-I` options, or the standard compiler directories. A header file being located elsewhere does not conform to the CCI.

Differences

The compiler operation under the CCI is not changed. This is purely a coding guideline.

Migration to the CCI

Remove any option that specifies header file search paths other than the `-I` option (or the equivalent MPLAB X IDE option), and use the `-I` option in place of this. Ensure the header file can be found in the directories specified in this section.

24.3.5. The Number of Significant Initial Characters in an Identifier

At least the first 255 characters in an identifier (internal and external) are significant. This extends upon the requirement of the C Language Standard, which states a lower number of significant characters are used to identify an object.

Example

The following example shows two poorly named variables, but names that are considered unique under the CCI.

```
int stateOfPortBWhenTheOperatorHasSelectedAutomaticModeAndMotorIsRunningFast;

int stateOfPortBWhenTheOperatorHasSelectedAutomaticModeAndMotorIsRunningSlow;
```

Differences

When using MPLAB XC8 for PIC targets and in C90 mode, only 31 significant characters have been accepted by default, but an option allowed this to be extended. When building in C99 mode for these devices, there has been no limit on the number of significant characters. There has also been no character limit when using MPLAB XC8 to target AVR MCUs, or when using any other compiler.

Migration to the CCI

No action required. You can take advantage of the less restrictive naming scheme.

24.3.6. Sizes of Types

The sizes of the basic C types, for example `char`, `int` and `long`, are *not* fully defined by the CCI. These types, by design, reflect the size of registers and other architectural features in the target

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device. They allow the device to efficiently access objects of this type. The C Language Standard does, however, indicate minimum requirements for these types, as specified in `<limits.h>`.

If you need fixed-size types in your project, use the types defined in `<stdint.h>`, for example, `uint8_t` or `int16_t`. These types are consistently defined across all XC compilers, even outside of the CCI.

Essentially, the C language offers a choice of two groups of types: those that offer sizes and formats that are tailored to the device you are using; or those that have a fixed size, regardless of the target.

Example

The following example shows the definition of a variable, `native`, whose size will allow efficient access on the target device; and a variable, `fixed`, whose size is clearly indicated and remains fixed, even though it may not allow efficient access on every device.

```
int native;
int16_t fixed;
```

Differences

This is consistent with previous types implemented by the compiler.

Migration to the CCI

If you require a C type that has a fixed size, regardless of the target device, use one of the types defined by `<stdint.h>`.

24.3.7. Plain `char` Types

The type of a plain `char` is `unsigned char`. It is generally recommended that all definitions for the `char` type explicitly state the signedness of the object.

Example

The following example:

```
char foobar;
```

defines an `unsigned char` object called `foobar`.

Differences

When targeting PIC MCUs, the MPLAB XC8 compiler has always treated plain `char` as an unsigned type. When targeting AVR MCUs, the compiler has used `signed char` as the default plain `char` type. Use of `signed char` has been true for MPLAB XC16, XC-DSC, and XC32. The `-funsigned-char` option on these compilers changes the default type to be `unsigned char`.

Migration to the CCI

Any definition of an object defined as a plain `char` needs review. Any plain `char` that was intended to be a signed quantity should be replaced with an explicit definition, for example:

```
signed char foobar;
```

which is the recommended method of defining such an object.

You can alternatively use the `-funsigned-char` option to change the type of plain `char`.

24.3.8. Signed Integer Representation

The value of a signed integer is determined by taking the two's complement of the integer.

Example

The following shows a variable, `test`, that is assigned the value -28 decimal.

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```
signed char test = 0xE4;
```

Differences

All compilers have represented signed integers in the way described in this section.

Migration to the CCI

No action required.

24.3.9. Integer Conversion

When converting an integer type to a signed integer of insufficient size, the original value is truncated from the most-significant bit to accommodate the target size.

Example

The following shows an assignment of a value that is truncated.

```
signed char destination;
unsigned int source = 0x12FE;
destination = source;
```

Under the CCI, the value of `destination` after the alignment is -2 (that is, the bit pattern 0xFE).

Differences

All compilers have performed integer conversion in an identical fashion to that described in this section.

Migration to the CCI

No action required.

24.3.10. Bitwise Operations on Signed Values

Bitwise operations on signed values act on the two's complement representation, including the sign bit. See also Right-Shifting Signed Values.

Example

The following shows an example of a negative quantity involved in a bitwise AND operation.

```
signed char output, input = -13;
output = input & 0x7E;
```

Under the CCI, the value of output after the assignment is 0x72.

Differences

All compilers have performed bitwise operations in an identical fashion to that described in this section.

Migration to the CCI

No action required.

24.3.11. Right-Shifting Signed Values

Right-shifting a signed value will involve sign extension. This will preserve the sign of the original value.

Example

The following example shows a negative quantity involved in a right-shift operation.

```
signed char output, input = -13;

output = input >> 3;
```


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Under the CCI, the value of `output` after the assignment is -2 (that is, the bit pattern 0xFE).

Differences

All compilers have performed right-shifting as described in this section.

Migration to the CCI

No action required.

24.3.12. Conversion of Union Member Accessed Using Member with Different Type

If a union defines several members of different types and you use one member identifier to try to access the contents of another (whether any conversion is applied to the result) is implementation-defined behavior in the standard. In the CCI, no conversion is applied and the bytes of the union object are interpreted as an object of the type of the member being accessed, without regard for alignment or other possible invalid conditions.

Example

The following shows an example of a union defining several members.

```
union {
    signed char code;
    unsigned int data;
    float offset;
} foobar;
```

Code that attempts to extract `offset` by reading `data` is not guaranteed to read the correct value.

```
float result;
result = foobbar.data;
```

Differences

All compilers have not converted union members accessed via other members.

Migration to the CCI

No action required.

24.3.13. Default Bit-field `int` Type

The type of a bit-field specified as a plain `int` is identical to that of one defined using `unsigned int`. This is quite different from other objects where the types `int`, `signed` and `signed int` are synonymous. It is recommended that the signedness of the bit-field be explicitly stated in all bit-field definitions.

Example

The following shows an example of a structure tag containing bit-fields that are unsigned integers and with the size specified.

```
struct OUTPUTS {
    int direction :1;
    int parity    :3;
    int value     :4;
};
```

Differences

When targeting PIC devices, the MPLAB XC8 compiler has issued a warning if an `int` type was specified for bit-fields, and it has instead implemented the bit-field with an `unsigned int` type. For other devices, this compiler has implemented bit-fields defined using `int` as having a `signed int` type, unless the option `-funsigned-bitfields` was specified. Use of a `signed int` type is also true for the MPLAB XC16, XC-DSC, and XC32 compilers.

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Migration to the CCI

Any code that defines a bit-field with the plain `int` type should be reviewed. If the intention was for these to be signed quantities, then the type of these should be changed to `signed int`. In the following example:

```
struct WAYPT {
    int log          :3;
    int direction    :4;
};
```

the bit-field type should be changed to `signed int`, as in:

```
struct WAYPT {
    signed int log       :3;
    signed int direction :4;
};
```

24.3.14. Bit-Fields Straddling a Storage Unit Boundary

The standard indicates that implementations can determine whether bit-fields cross a storage unit boundary. In the CCI, bit-fields do not straddle a storage unit boundary; a new storage unit is allocated to the structure, and padding bits fill the gap.

Note that the size of a storage unit differs with each compiler and target device, as this is based on the size of the base data type (for example, `int`) from which the bit-field type is derived. For MPLAB XC8, this unit is 8-bits in size; for MPLAB XC16, it is 16 bits; and for MPLAB XC32, it is 32 bits in size. For MPLAB XC-DSC compiler, the size depends on the device used.

Example

The following shows a structure containing bit-fields being defined.

```
struct {
        unsigned first  : 6;
        unsigned second : 6;
} order;
```

Under the CCI and using MPLAB XC8, the storage allocation unit is byte sized. The bit-field `second` is allocated a new storage unit since there are only 2 bits remaining in the first storage unit in which `first` is allocated. The size of this structure, `order`, is 2 bytes.

Differences

This allocation is identical with that used by all previous compilers.

Migration to the CCI

No action required.

24.3.15. The Allocation Order of Bit-Field

The memory ordering of bit-fields into their storage unit is not specified by the C Language Standard. In the CCI, the first bit defined is the least significant bit (LSb) of the storage unit in which it is allocated.

Example

The following shows a structure containing bit-fields being defined.

```
struct {
        unsigned lo  : 1;
        unsigned mid :6;
        unsigned hi  : 1;
} foo;
```


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The bit-field `lo` is assigned the least significant bit of the storage unit assigned to the structure `foo`. The bit-field `mid` is assigned the next 6 least significant bits, and `hi`, the most significant bit of that same storage unit byte.

Differences

This is identical with the previous operation of all compilers.

Migration to the CCI

No action required.

24.3.16. The NULL Macro

The NULL macro is defined by `<stddef.h>`; however, its definition is implementation-defined. Under the CCI, the definition of `NULL` is the expression `(0)`.

Example

The following shows a pointer being assigned a null pointer constant via the `NULL` macro.

```
int * ip = NULL;
```

The value of `NULL`, `(0)`, is implicitly converted to the destination type.

Differences

MPLAB XC32 has assigned `NULL` the expression `((void *)0)`. The same is true for MPLAB XC8 when targeting AVR MCUs.

Migration to the CCI

No action required.

24.3.17. Floating-Point Sizes

Under the CCI, floating-point types must not be smaller than 32 bits in size.

Example

The following shows the definition for `outY`, which is at least 32-bit in size.

```
float outY;
```

Differences

The MPLAB XC8 when targeting PIC MCUs and building with C90 language standard has allowed the use of 24-bit `float` and `double` types.

Migration to the CCI

When using MPLAB XC8, the `float` and `double` type will be made 32 bits in size once the CCI is enabled, regardless of target device or operating mode. Review any source code that assumes a `float` or `double` type is 24 bits in size.

No migration is required for other compilers.

24.4. C Language Standard Extensions

The following topics describe how the CCI provides device-specific extensions to the C Language Standard.

24.4.1. Generic Header File

A single header file `<xc.h>` must be used to declare all compiler- and device-specific types and SFRs. You *must* include this file into every module to conform with the CCI. Some CCI definitions depend on this header being seen.

Example

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The following shows this header file being included, thus allowing conformance with the CCI, as well as allowing access to SFRs.

```
#include <xc.h>
```

Differences

Although device-specific headers are shipped with the compilers, always include the top-level `<xc.h>` header.

Early compilers for 8-bit PIC devices used `<htc.h>` as the equivalent header. Other compilers used a variety of device-related headers to do the same job.

Migration to the CCI

Change for example:

```
#include <p32xxxx.h>
#include <p30fxxxx.h>
#include <pic16lf18324.h> /* or */
#include "p30f6014.h"
```

to:

```
#include <xc.h>
```

24.4.2. Absolute Addressing

Variables and functions can be placed at an absolute address by using the `__at()` construct. Stack-based (`auto` and parameter) variables cannot use the `__at()` specifier.

Example

The following shows two variables and a function being made absolute.

```
int scanMode __at(0x200);
const char keys[] __at(124) = { 'r', 's', 'u', 'd'};

__at(0x1000) int modify(int x) {
   return x * 2 + 3;
}
```

Differences

The legacy syntax used by MPLAB XC8 when targeting PIC MCUs has been an `@` symbol to specify an absolute address.

When targeting AVR MCUs, MPLAB XC8 has used the `address` attribute to specify an object's address. This attribute has also been used by the other compilers.

Migration to the CCI

Avoid making objects and functions absolute if possible.

If any source code uses the legacy MPLAB XC8 syntax, for example:

```
int scanMode @ 0x200;
```

change this to:

```
int scanMode __at(0x200);
```

When building for AVR MCUs with the MPLAB XC8 compiler or when using any other compiler, change code, for example, from:

```
int scanMode __attribute__((address(0x200)));
```


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to:

```
int scanMode __at(0x200);
```

Caveats

If building for PIC device using MPLAB XC8 and the `__at()` and `__section()` specifiers have both been applied to an object, the `__section()` specifier is currently ignored.

The MPLAB XC32 compiler for PIC32C/SAM devices supports only 4-byte aligned absolute addresses.

24.4.3. Far Objects and Functions

The `__far` qualifier can be used to indicate that variables or functions are located in 'far memory'. Exactly what constitutes far memory is dependent on the target device, but it is typically memory that requires more complex code to access. Expressions involving far-qualified objects usually generate slower and larger code.

Use the native keywords discussed in the Differences section to look up information on the semantics of this qualifier.

Some devices may not have such memory implemented, in which case, use of this qualifier is ignored. Stack-based (`auto` and parameter) variables cannot use the `__far` specifier.

Example

The following shows a variable and function qualified using `__far`.

```
__far int serialNo;

__far int ext_getCond(int selector);
```

Differences

When targeting PIC devices, the MPLAB XC8 compiler has allowed the `far` specifier to be used with variables. This specifier has not been allowed with functions. When targeting AVR devices, MPLAB XC8 has not implemented any "far" memory.

The MPLAB XC16 and XC-DSC compilers have used the `far` attribute with both variables and functions.

The MPLAB XC32 compiler has used the `far` attribute with functions only.

Migration to the CCI

When targeting PIC devices with the MPLAB XC8 compiler, change any occurrence of the `far` qualifier to `__far`, for example, from:

```
far char template[20];
```

to:

```
__far char template[20];
```

When using MPLAB XC16, XC-DSC or XC32 compilers, change any occurrence of the `far` attribute to the `__far` specifier, for example, from:

```
void bar(void) __attribute__ ((far));

int tblIdx __attribute__ ((far));
```

to:

```
void __far bar(void);

int __far tblIdx;
```

Caveats

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None.

24.4.4. Near Objects

The `__near` qualifier can be used to indicate that variables or functions are located in 'near memory'. Exactly what constitutes near memory is dependent on the target device, but it is typically memory that can be accessed with less complex code. Expressions involving near-qualified objects generally are faster and result in smaller code.

Use the native keywords discussed in the Differences section to look up information on the semantics of this qualifier.

Some devices may not have such memory implemented, in which case, use of this qualifier is ignored. Stack-based (`auto` and parameter) variables cannot use the `__near` specifier.

Example

The following shows a variable and function qualified using `__near`.

```
__near int serialNo;

__near int ext_getCond(int selector);
```

Differences

When targeting PIC devices, the MPLAB XC8 compiler has allowed the `near` specifier to be used with variables. This specifier has not been allowed with functions. When targeting AVR devices, MPLAB XC8 has not implemented any "near" memory.

The MPLAB XC16 and XC-DSC compilers have used the `near` attribute with both variables and functions.

The MPLAB XC32 compiler has used the `near` attribute for functions, only.

Migration to the CCI

When targeting PIC devices with the MPLAB XC8 compiler, change any occurrence of the `near` qualifier to `__near`, for example, from:

```
near char template[20];
```

to:

```
__near char template[20];
```

When using the other compilers, change any occurrence of the `near` attribute to the `__near` specifier, for example, from:

```
void bar(void) __attribute__ ((near));

int tblIdx __attribute__ ((near));
```

to

```
void __near bar(void);

int __near tblIdx;
```

Caveats

None.

24.4.5. Persistent Objects

The `__persistent` qualifier can be used to indicate that variables should not be cleared by the runtime startup code.

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Use the native keywords discussed in the Differences section to look up information on the semantics of this qualifier.

Example

The following shows a variable qualified using `__persistent`.

```
__persistent int serialNo;
```

Differences

When targeting PIC devices, the MPLAB XC8 compiler has allowed use of the `persistent` specifier to indicate that variables should not be cleared at startup. When targeting AVR devices, this compiler has allowed the use of the `persistent` attribute with variables to indicate they were not to be cleared.

The MPLAB XC16, XC-DSC and XC32 compilers have also used the `persistent` attribute for this purpose.

Migration to the CCI

When building with the MPLAB XC8 compiler for PIC MCUs, change any occurrence of the `persistent` qualifier to `__persistent`, for example, from:

```
persistent char template[20];
```

to:

```
__persistent char template[20];
```

When building with MPLAB XC16, XC-DSC or XC32 compilers, or with the MPLAB XC8 compiler for AVR MCUs, change any occurrence of the `persistent` attribute to the `__persistent` specifier, for example, from:

```
int tblIdx __attribute__ ((persistent));
```

to

```
int __persistent tblIdx;
```

Caveats

None.

24.4.6. X and Y Data Objects

The `__xdata` and `__ydata` qualifiers can be used to indicate that variables are located in special memory regions. Exactly what constitutes X and Y memory is dependent on the target device, but it is typically memory that can be accessed independently on separate buses. Such memory is often required for some DSP instructions.

Use the native keywords discussed in the Differences section to look up information on the semantics of these qualifiers.

Some devices may not have such memory implemented; in which case, use of these qualifiers is ignored.

Example

The following shows a variable qualified using `__xdata`, as well as another variable qualified with `__ydata`.

```
__xdata char data[16];

__ydata char coeffs[4];
```

Differences

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The MPLAB XC16 and XC-DSC compilers have used the `xmemory` and `ymemory` space attribute with variables.

Equivalent specifiers have never been defined for any other compiler.

Migration to the CCI

For MPLAB XC16 and XC-DSC compilers, change any occurrence of the `space` attributes `xmemory` or `ymemory` to `__xdata`, or `__ydata` respectively, for example, from:

```
char __attribute__((space(xmemory)))template[20];
```

to:

```
__xdata char template[20];
```

Caveats

None.

24.4.7. Banked Data Objects

The `__bank(num)` qualifier can be used to indicate that variables are located in a particular data memory bank. The number, *num*, represents the bank number. Exactly what constitutes banked memory is dependent on the target device, but it is typically a subdivision of data memory to allow for assembly instructions with a limited address width field.

Use the native keywords discussed in the Differences section to look up information on the semantics of these qualifiers.

Some devices may not have banked data memory implemented, in which case, use of this qualifier is ignored. The number of data banks implemented will vary from one device to another.

Example

The following shows a variable qualified using `__bank()`.

```
__bank(0) char start;

__bank(3) char stop;
```

Differences

When targeting PIC devices, the MPLAB XC8 compiler has used the four qualifiers `bank0`, `bank1`, `bank2` and `bank3` to indicate memory placement in a specific data bank.

Equivalent specifiers have never been defined for any other compiler.

Migration to the CCI

When building for PIC devices using MPLAB XC8, change any occurrence of the `bank`*num* qualifiers to `__bank(`*num*`)`, for example, from:

```
bank2 int logEntry;
```

to:

```
__bank(2) int logEntry;
```

Caveats

Only banks 0 through 3 are currently supported.

24.4.8. Alignment of Objects

The `__align(`*alignment*`)` specifier can be used to indicate that variables must be aligned on a memory address that is a multiple of the alignment specified. The alignment term must be a power of 2. Positive values request that the object's start address be aligned.

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Use the native keywords discussed in the Differences section to look up information on the semantics of this specifier.

Example

The following shows variables qualified using `__align()` to ensure they end on an address that is a multiple of 8, and start on an address that is a multiple of 2, respectively.

```
__align(-8) int spacer;
__align(2) char coeffs[6];
```

Differences

The MPLAB XC16, XC-DSC and XC32 compilers have used the `aligned` attribute with variables. This has also been true when targeting AVR MCUs with MPLAB XC8 An alignment feature has never been available for PIC devices when using the MPLAB XC8 compiler.

Migration to the CCI

When building for AVR MCUs with the MPLAB XC8 compiler or when using any other compiler, change any occurrence of the `aligned` attribute to the `__align` specifier, for example, from:

```
char __attribute__((aligned(4)))mode;
```

to:

```
__align(4) char mode;
```

Caveats

This feature is not needed nor implemented when targeting PIC devices using MPLAB XC8.

When targeting PIC32C/SAM devices with MPLAB XC32 only positive alignment values are supported.

24.4.9. EEPROM Objects

The `__eeprom` qualifier can be used to indicate that variables should be positioned in EEPROM.

Use the native keywords discussed in the Differences section to look up information on the semantics of this qualifier.

Some devices may not implement EEPROM. Use of this qualifier for such devices generates a warning. Stack-based (`auto` and parameter) variables cannot use the `__eeprom` specifier.

Example

The following shows a variable qualified using `__eeprom`.

```
__eeprom int serialNos[4];
```

Differences

When targeting PIC devices, the MPLAB XC8 compiler has used the `eeprom` qualifier to indicate that objects should be placed in EEPROM.

The MPLAB XC16 and XC-DSC compilers have used the `space` attribute to allocate variables to the memory space used for EEPROM.

Migration to the CCI

When using MPLAB XC8 to build for PIC devices, change any occurrence of the `eeprom` qualifier to `__eeprom`, for example, from:

```
eeprom char title[20];
```

to:

```
__eeprom char title[20];
```


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When using MPLAB XC16 or XC-DSC compilers, change any occurrence of the `eedata space` attribute to the `__eeprom` specifier, for example, from:

```
int mainSw __attribute__ ((space(eedata)));
```

to:

```
int __eeprom mainSw;
```

Caveats

The MPLAB XC8 compiler only permits the `__eeprom` specifier for those Baseline and Mid-range devices that support this memory. It is not permitted for other 8-bit devices.

24.4.10. Interrupt Functions

The `__interrupt(`*`type`*`)` specifier can be used to indicate that a function is to act as an interrupt service routine. The *`type`* is a comma-separated list of keywords that indicate information about the interrupt function.

The current interrupt types are shown in the following table.

Interrupt type	Description	Compiler
<empty>	Implement the default interrupt function.	
`low_priority`	The interrupt function corresponds to the low priority interrupt source.	MPLAB XC8 - PIC18 only
`high_priority`	The interrupt function corresponds to the high priority interrupt source.	MPLAB XC8
`save(symbol-list)`	Save on entry and restore on exit the listed symbols.	MPLAB XC16, MPLAB XC-DSC
`irq(`*`irqid`*`)`	Specify the interrupt vector associated with this interrupt.	MPLAB XC8, MPLAB XC16, MPLAB XC-DSC
`altirq(`*`altirqid`*`)`	Specify the alternate interrupt vector associated with this interrupt.	MPLAB XC16, MPLAB XC-DSC
`preprologue(`*`asm`*`)`	Specify assembly code to be executed before any compiler-generated interrupt code.	MPLAB XC16, MPLAB XC-DSC
`shadow`	Allow the ISR to utilize the shadow registers for context switching.	MPLAB XC16, MPLAB XC-DSC
`auto_psv`	The ISR will set the PSVPAG register and restore it on exit.	MPLAB XC16, MPLAB XC-DSC
`no_auto_psv`	The ISR will not set the PSVPAG register.	MPLAB XC16, MPLAB XC-DSC

Use the native keywords discussed in the Differences section to look up information on the semantics of this specifier.

Some devices may not implement interrupts. Use of this qualifier for such devices generates a warning. If the argument to the `__interrupt()` specifier does not make sense for the target device, a warning or error is issued by the compiler.

Example

The following shows a function qualified using `__interrupt` for an 8-bit PIC device.

```
__interrupt(low_priority) void getData(void) {
    if (TMR0IE && TMR0IF) {
        TMR0IF=0;
        ++tick_count;
    }
}
```

Differences

The legacy interrupt function syntax used by MPLAB XC8 when targeting PIC MCUs has been the `interrupt` specifier and optionally the `low_priority` specifier. When targeting AVR devices, the MPLAB XC8 compiler has used the `ISR()` macro to define interrupt functions.

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The MPLAB XC16, XC-DSC, and XC32 compilers have used the `interrupt` attribute to define interrupt functions.

Migration to the CCI

When building with the MPLAB XC8 compiler for PIC MCUs, change any instance of the `interrupt` specifier to `__interrupt`, for example, from:

```
void interrupt low_priority tckI(void)
```

to:

```
void __interrupt(low_priority) tckI(void)
```

When building with the MPLAB XC8 compiler for AVR MCUs, change any instance of the `ISR()` macro, for example, from:

```
ISR(TIMER1_OVF_vect)
```

to:

```
void __interrupt(TIMER1_OVF_vect_num) spi_Isr(void)
```

When building with XC16 or XC-DSC compilers, change any occurrence of the `interrupt` attribute, for example, from:

```
void _attribute_((interrupt(auto_psv,irq(52)))) _T1Interrupt(void);
```

to:

```
void __interrupt(auto_psv,irq(52))) _T1Interrupt(void);
```

For MPLAB XC32, the `__interrupt()` keyword takes two parameters, the vector number and the (optional) IPL value. Change code that uses the `interrupt` attribute, similar to these examples:

```
void __attribute__((vector(0), interrupt(IPL7AUTO), nomips16)) myisr0_7A(void) {}

void __attribute__((vector(1), interrupt(IPL6SRS), nomips16)) myisr1_6SRS(void) {}

/* Determine IPL and context-saving mode at runtime */
void __attribute__((vector(2), interrupt(), nomips16)) myisr2_RUNTIME(void) {}
```

to:

```
void __interrupt(0,IPL7AUTO) myisr0_7A(void) {}

void __interrupt(1,IPL6SRS) myisr1_6SRS(void) {}

/* Determine IPL and context-saving mode at runtime */
void __interrupt(2) myisr2_RUNTIME(void) {}
```

Caveats

None.

24.4.11. Packing Objects

The `__pack` specifier can be used to indicate that structures should not use memory gaps to align structure members, or that individual structure members should not be aligned.

Use the native keywords discussed in the Differences section to look up information on the semantics of this specifier.

Some compilers cannot pad structures with alignment gaps for some devices, and use of this specifier for such devices is ignored.

Example

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The following shows a structure qualified using __pack, as well as a structure where one member has been explicitly packed.

```
struct DATAPOINT {
    unsigned char type;
    int value;
} __pack x_point;
struct LINETYPE {
    unsigned char type;
    __pack int start;
    long total;
} line;
```

Differences

The __pack specifier is a new CCI specifier that can be used with PIC devices and MPLAB XC8. This specifier has no observable effect since the device memory is byte addressable for all data objects. When targeting AVR devices, the MPLAB XC8 compiler has used the packed attribute.

The MPLAB XC16, XC-DSC, and XC32 compilers have used the packed attribute to indicate that a structure member was not aligned with a memory gap.

Migration to the CCI

No migration is required for the MPLAB XC8 compiler when building for PIC MCUs. When building for AVR MCUs or when building with any other compiler, change any occurrence of the packed attribute to the __packed specifier, for example, from:

```
struct DOT
{
    char a;
    int x[2] __attribute__ ((packed));
};
```

to

```
struct DOT
{
    char a;
    __pack int x[2];
};
```

Alternatively, you can pack the entire structure, if required.

Caveats

None.

24.4.12. Indicating Antiquated Objects

The __deprecate specifier can be used to indicate that an object has limited longevity and should not be used in new designs. It is commonly used by the compiler vendor to indicate that compiler extensions or features can become obsolete, or that better features have been developed and should be used in preference.

Use the native keywords discussed in the Differences section to look up information on the semantics of this specifier.

Example

The following shows a function that uses the __deprecate keyword.

```
void __deprecate getValue(int mode)
{
//...
}
```

Differences

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When targeting AVR MCUs using the MPLAB XC8 compiler or when using the other compilers, the `deprecated` attribute (note the different spelling to the CCI specifier) has been used to indicate that use of certain objects should be avoided, if possible.

Migration to the CCI

When building with MPLAB XC16, XC-DSC or XC32 compilers, or with the MPLAB XC8 compiler for AVR MCUs, change any occurrence of the `deprecated` attribute to `__deprecate`, for example, from:

```
int __attribute__(deprecated) intMask;
```

to:

```
int __deprecate intMask;
```

Caveats

None.

24.4.13. Assigning Objects to Sections

The `__section()` specifier can be used to indicate that an object should be located in the named section. This is typically used when the object has special and unique linking requirements that cannot be addressed by existing compiler features.

Use the native keywords discussed in the Differences section to look up information on the semantics of this specifier.

Example

The following shows a variable which uses the `__section` keyword.

```
int __section("comSec") commonFlag;
```

Differences

When targeting AVR MCUs using the MPLAB XC8 compiler or when using the other compilers, the `section` attribute has been used to indicate a different destination section name. The `__section()` specifier works in a similar way to the attribute.

Migration to the CCI

When building with MPLAB XC16, XC-DSC or XC32 compilers, or with the MPLAB XC8 compiler for AVR MCUs, change any occurrence of the `section` attribute, for example, from:

```
int __attribute__((section("myVars"))) intMask;
```

to:

```
int __section("myVars") intMask;
```

Caveats

None.

24.4.14. Specifying Configuration Bits

The `#pragma config` directive can be used to program the Configuration bits for a device. The pragma has the form:

`#pragma config` *`setting`* `=` *`state`*`|`*`value`*

where *`setting`* is a configuration setting descriptor (for example, `WDT`), *`state`* is a descriptive value (for example, `ON`) and *`value`* is a numerical value.

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Use the native keywords discussed in the Differences section to look up information on the semantics of this directive.

Example

The following shows Configuration bits being specified using this pragma.

```
#pragma config WDT=ON, WDTPS = 0x1A
```

Differences

When targeting PIC MCUs, MPLAB XC8 has provided a legacy `__CONFIG()` macro, but more recently has accepted `#pragma config`. When targeting AVR devices, it has used a predefined `FUSES` structure to allow the configuration bits to be specified.

The MPLAB XC16 and XC-DSC compilers have used a number of macros to specify the configuration settings.

The MPLAB XC32 compiler has supported the use of `#pragma config`.

Migration to the CCI

When building for PIC MCUs with MPLAB XC8, change any occurrence of the `__CONFIG()` macro, for example,

```
__CONFIG(WDTEN & XT & DPROT)
```

to the `#pragma config` directive, for example:

```
#pragma config WDTE=ON, FOSC=XT, CPD=ON
```

When building for AVR MCUs with MPLAB XC8, change any occurrence of the `FUSES` structure, for example:

```
#include <avr/io.h>
FUSES = {
    .high = (FUSE_SPIEN)
};
```

to:

```
#pragma config SPIEN=SET
```

For the MPLAB XC16 and XC-DSC compilers, change any occurrence of the `_FOSC()` or `_FBORPOR()` macros attribute, for example, from:

```
_FOSC(CSW_FSCM_ON & EC_PLL16);
```

to:

```
#pragma config FCKSMEM = CSW_ON_FSCM_ON, FPR = ECIO_PLL16
```

No migration is required for 32-bit code.

Caveats

None.

24.4.15. Manifest Macros

The CCI defines the general form for macros that manifest the compiler and target device characteristics. These macros can be used to conditionally compile alternate source code based on the compiler or the target device.

The macros and macro families are details in the following table.

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Table 24-1. Manifest Macros Defined by the CCI

Name	Meaning if defined	Example
__XC__	Compiled with an MPLAB XC compiler	__XC__
__CCI__	Compiler is CCI compliant and CCI enforcement is enabled	__CCI__
__XC#__	The specific XC compiler used (# can be 8, 16, _DSC or 32)	__XC32__
__DEVICEFAMILY__	The family of the selected target device	__dsPIC30F__
__DEVICENAME__	The selected target device name	__33ck256mp508__

Example

The following shows code that is conditionally compiled dependent on the device having EEPROM memory.

```
#ifdef __XC_DSC__
void __interrupt(__auto_psv__) myIsr(void)
#else
void __interrupt(low_priority) myIsr(void)
#endif
```

Differences

Some of these CCI macros are new (for example, __CCI__), and others have different names to previous symbols with identical meaning (for example, __33ck256mp508 is now __33ck256mp508__).

Migration to the CCI

Any code that uses compiler-defined macros needs review. Old macros continue to work as expected, but they are not compliant with the CCI.

Caveats

None.

24.4.16. In-Line Assembly

The asm() statement can be used to insert assembly code in-line with C code. The argument is a C string literal that represents a single assembly instruction. Obviously, the instructions contained in the argument are device specific.

Use the native keywords discussed in the Differences section to look up information on the semantics of this statement.

Example

The following shows a MOVLW 8-bit PIC MCU instruction being inserted in-line.

```
asm("MOVLW _foobar");
```

Differences

When targeting PIC devices with MPLAB XC8, the asm() or #asm ... #endasm constructs have been used to insert in-line assembly code.

The MPLAB XC16, XC-DSC and XC32 compilers, as well as the MPLAB XC8 compiler for AVR MCUs use the same syntax as the CCI.

Migration to the CCI

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When building with the MPLAB XC8 compiler for PIC MCUs, change any instance of `#asm ... #endasm` so that each instruction in this `#asm` block is placed in its own `asm()` statement, for example, from:

```
#asm
    MOVLW         20
    MOVWF _i
    CLRF         Ii+1
#endasm
```

to:

```
asm("MOVLW         20");
asm("MOVWF _i");
asm("CLRF         Ii+1");
```

No migration is required for MPLAB XC8 when targeting AVR MCUs or when using the other compilers.

Caveats

None.

24.5. Compiler Features

The following item details the compiler options used to control the CCI.

24.5.1. Enabling the CCI

It is assumed that you are using the MPLAB X IDE to build projects that use the CCI. The location of the widget in the **Project Properties** window to enable CCI conformance is shown in the table below.

Table 24-2. Project Property Path to Enable CCI

Compiler	Category	Category Option
MPLAB XC8	XC8 Compiler	Preprocessing and messages > Use CCI Syntax
MPLAB XC16	xc16-gcc	Preprocessing and messages > Use CCI Syntax
MPLAB XC-DSC	xc-dsc-gcc	Preprocessing and messages > Use CCI Syntax
MPLAB XC32	xc32-gcc, xc32-g++	Preprocessing and messages > Use CCI Syntax

If you are not using this IDE, use the command-line option `-mext=cci`. For MPLAB XC16, MPLAB XC-DSC and MPLAB XC32, you may also use the option `-mcci`.

Differences

This option has never been implemented previously.

Migration to the CCI

Enable the option.

Caveats

None.

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25. C Implementation-Defined Behavior

This section discusses the choices for implementation-defined behavior when using the C compiler.

25.1. Overview

ISO C requires a conforming implementation to document the choices for behaviors defined in the standard as "implementation-defined." The following sections list all such areas, the choices made for the compiler, and the corresponding section number from the ISO/IEC 9899:1999 standard.

25.2. Translation

ISO Standard:	"How a diagnostic is identified (3.10, 5.1.1.3)."
Implementation:	All output to `stderr` is a diagnostic.
ISO Standard:	"Whether each nonempty sequence of white-space characters other than new-line is retained or replaced by one space character in translation phase 3 (5.1.1.2)."
Implementation:	Each sequence of whitespace is replaced by a single character.

25.3. Environment

ISO Standard:	"The name and type of the function called at program start-up in a freestanding environment (5.1.2.1)."
Implementation:	`int main (void);`
ISO Standard:	"The effect of program termination in a freestanding environment (5.1.2.1)."
Implementation:	An infinite loop (branch to self) instruction will be executed.
ISO Standard:	"An alternative manner in which the main function may be defined (5.1.2.2.1)."
Implementation:	`int main (void);`
ISO Standard:	"The values given to the strings pointed to by the `argv` argument to `main` (5.1.2.2.1)."
Implementation:	No arguments are passed to main. Reference to `argc` or `argv` is undefined.
ISO Standard:	"What constitutes an interactive device (5.1.2.3)."
Implementation:	Application defined.
ISO Standard:	"Signals for which the equivalent of `signal(sig, SIG_IGN);` is executed at program start-up (7.14.1.1)."
Implementation:	Signals are application defined.
ISO Standard:	"The form of the status returned to the host environment to indicate unsuccessful termination when the `SIGABRT` signal is raised and not caught (7.20.4.1)."
Implementation:	The host environment is application defined.
ISO Standard:	"The forms of the status returned to the host environment by the `exit` function to report successful and unsuccessful termination (7.20.4.3)."
Implementation:	The host environment is application defined.
ISO Standard:	"The status returned to the host environment by the exit function if the value of its argument is other than zero, `EXIT_SUCCESS`, or `EXIT_FAILURE` (7.20.4.3)."
Implementation:	The host environment is application defined.
ISO Standard:	"The set of environment names and the method for altering the environment list used by the `getenv` function (7.20.4.4)."
Implementation:	The host environment is application defined.
ISO Standard:	"The manner of execution of the string by the system function (7.20.4.5)."
Implementation:	The host environment is application defined.

25.4. Identifiers

ISO Standard:	"Which additional multibyte characters may appear in identifiers and their correspondence to universal character names (6.4.2)."
Implementation:	No.

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ISO Standard:	"The number of significant initial characters in an identifier (5.2.4.1, 6.4.2)."
Implementation:	All characters are significant.

25.5. Characters

ISO Standard:	"The number of bits in a byte (C90 3.4, C99 3.6)."
Implementation:	8.
ISO Standard:	"The values of the members of the execution character set (C90 and C99 5.2.1)."
ISO Standard:	"The unique value of the member of the execution character set produced for each of the standard alphabetic escape sequences (C90 and C99 5.2.2)."
Implementation:	The execution character set is ASCII.
ISO Standard:	"The value of a char object into which has been stored any character other than a member of the basic execution character set (C90 6.1.2.5, C99 6.2.5)."
Implementation:	The value of the char object is the 8-bit binary representation of the character in the source character set. That is, no translation is done.
ISO Standard:	"Which of signed char or unsigned char has the same range, representation, and behavior as "plain" char (C90 6.1.2.5, C90 6.2.1.1, C99 6.2.5, C99 6.3.1.1)."
Implementation:	By default on PIC32M, signed char is functionally equivalent to plain char.
ISO Standard:	"The mapping of members of the source character set (in character constants and string literals) to members of the execution character set (C90 6.1.3.4, C99 6.4.4.4, C90 and C99 5.1.1.2)."
Implementation:	The binary representation of the source character set is preserved to the execution character set.
ISO Standard:	"The value of an integer character constant containing more than one character or containing a character or escape sequence that does not map to a single-byte execution character (C90 6.1.3.4, C99 6.4.4.4)."
Implementation:	The compiler determines the value for a multi-character character constant one character at a time. The previous value is shifted left by eight, and the bit pattern of the next character is masked in. The final result is of type `int`. If the result is larger than can be represented by an `int`, a warning diagnostic is issued and the value truncated to `int` size.
ISO Standard:	"The value of a wide character constant containing more than one multibyte character, or containing a multibyte character or escape sequence not represented in the extended execution character set (C90 6.1.3.4, C99 6.4.4.4)."
Implementation:	See previous.
ISO Standard:	"The current locale used to convert a wide character constant consisting of a single multibyte character that maps to a member of the extended execution character set into a corresponding wide character code (C90 6.1.3.4, C99 6.4.4.4)."
Implementation:	LC_ALL
ISO Standard:	"The current locale used to convert a wide string literal into corresponding wide character codes (C90 6.1.4, C99 6.4.5)."
Implementation:	LC_ALL
ISO Standard:	"The value of a string literal containing a multibyte character or escape sequence not represented in the execution character set (C90 6.1.4, C99 6.4.5)."
Implementation:	The binary representation of the characters is preserved from the source character set.

25.6. Integers

ISO Standard:	"Any extended integer types that exist in the implementation (C99 6.2.5)."
Implementation:	There are no extended integer types.
ISO Standard:	"Whether signed integer types are represented using sign and magnitude, two's complement, or one's complement and whether the extraordinary value is a trap representation or an ordinary value (C99 6.2.6.2)."
Implementation:	All integer types are represented as two's complement, and all bit patterns are ordinary values.

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25.7. Floating-Point

ISO Standard:	"The accuracy of the floating-point operations and of the library functions in <math.h> and <complex.h> that return floating-point results (C90 and C99 5.2.4.2.2)."
Implementation:	The accuracy is unknown.
ISO Standard:	"The accuracy of the conversions between floating-point internal representations and string representations performed by the library functions in <stdio.h>, <stdlib.h>, and <wchar.h> (C90 and C99 5.2.4.2.2)."
Implementation:	The accuracy is unknown.
ISO Standard:	"The rounding behaviors characterized by non-standard values of FLT_ROUNDS (C90 and C99 5.2.4.2.2)."
Implementation:	No such values are used.
ISO Standard:	"The evaluation methods characterized by non-standard negative values of FLT_EVAL_METHOD (C90 and C99 5.2.4.2.2)."
Implementation:	No such values are used.
ISO Standard:	"The direction of rounding when an integer is converted to a floating-point number that cannot exactly represent the original value (C90 6.2.1.3, C99 6.3.1.4)."
Implementation:	C99 Annex F is followed.
ISO Standard:	"The direction of rounding when a floating-point number is converted to a narrower floating-point number (C90 6.2.1.4, 6.3.1.5)."
Implementation:	C99 Annex F is followed.
ISO Standard:	"How the nearest representable value or the larger or smaller representable value immediately adjacent to the nearest representable value is chosen for certain floating constants (C90 6.1.3.1, C99 6.4.4.2)."
Implementation:	C99 Annex F is followed.
ISO Standard:	"Whether and how floating expressions are contracted when not disallowed by the FP_CONTRACT pragma (C99 6.5)."
Implementation:	The pragma is not implemented.
ISO Standard:	"The default state for the FENV_ACCESS pragma (C99 7.6.1)."
Implementation:	This pragma is not implemented.
ISO Standard:	"Additional floating-point exceptions, rounding modes, environments, and classifications, and their macro names (C99 7.6, 7.12)."
Implementation:	None supported.
ISO Standard:	"The default state for the FP_CONTRACT pragma (C99 7.12.2)."
Implementation:	This pragma is not implemented.
ISO Standard:	"Whether the "inexact" floating-point exception can be raised when the rounded result actually does equal the mathematical result in an IEC 60559 conformant implementation (C99 F.9)."
Implementation:	Unknown.
ISO Standard:	"Whether the "underflow" (and "inexact") floating-point exception can be raised when a result is tiny but not inexact in an IEC 60559 conformant implementation (C99 F.9)."
Implementation:	Unknown.

25.8. Arrays and Pointers

ISO Standard:	"The result of converting a pointer to an integer or vice versa (C90 6.3.4, C99 6.3.2.3)."
Implementation:	A cast from an integer to a pointer or vice versa results uses the binary representation of the source type, reinterpreted as appropriate for the destination type. If the source type is larger than the destination type, the Most Significant bits are discarded. When casting from a pointer to an integer, if the source type is smaller than the destination type, the result is sign extended. When casting from an integer to a pointer, if the source type is smaller than the destination type, the result is extended based on the signedness of the source type.
ISO Standard:	"The size of the result of subtracting two pointers to elements of the same array (C90 6.3.6, C99 6.5.6)."

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Implementation:	32-bit signed integer.

25.9. Hints

ISO Standard:	"The extent to which suggestions made by using the register storage-class specifier are effective (C90 6.5.1, C99 6.7.1)."
Implementation:	The register storage class specifier generally has no effect.
ISO Standard:	"The extent to which suggestions made by using the inline function specifier are effective (C99 6.7.4)."
Implementation:	If `-fno-inline` or `-O0` are specified, no functions will be inlined, even if specified with the inline specifier. Otherwise, the function may or may not be `inlined` dependent on the optimization heuristics of the compiler.

25.10. Structures, Unions, Enumerations, and Bit Fields

ISO Standard:	"A member of a union object is accessed using a member of a different type (C90 6.3.2.3)."
Implementation:	The corresponding bytes of the union object are interpreted as an object of the type of the member being accessed without regard for alignment or other possible invalid conditions.
ISO Standard:	"Whether a "plain" `int` bit field is treated as a `signed int` bit field or as an `unsigned int` bit field (C90 6.5.2, C90 6.5.2.1, C99 6.7.2, C99 6.7.2.1)."
Implementation:	By default on PIC32M, a plain `int` bit field is treated as a signed integer. This behavior can be altered by use of the `-funsigned-bitfields` command line option.
ISO Standard:	"Allowable bit field types other than `_Bool`, `signed int`, and `unsigned int` (C99 6.7.2.1)."
Implementation:	No other types are supported.
ISO Standard:	"Whether a bit field can straddle a storage unit boundary (C90 6.5.2.1, C99 6.7.2.1)."
Implementation:	No.
ISO Standard:	"The order of allocation of bit fields within a unit (C90 6.5.2.1, C99 6.7.2.1)."
Implementation:	Bit fields are allocated left to right.
ISO Standard:	"The alignment of non-bit field members of structures (C90 6.5.2.1, C99 6.7.2.1)."
Implementation:	Each member is located to the lowest available offset allowable according to the alignment restrictions of the member type.
ISO Standard:	"The integer type compatible with each enumerated type (C90 6.5.2.2, C99 6.7.2.2)."
Implementation:	If the enumeration values are all non-negative, the type is `unsigned int`, else it is `int`. The `-fshort-enums` command line option can change this.

25.11. Qualifiers

ISO Standard:	"What constitutes an access to an object that has volatile-qualified type (C90 6.5.3, C99 6.7.3)."
Implementation:	Any expression which uses the value of or stores a value to a volatile object is considered an access to that object. There is no guarantee that such an access is atomic.If an expression contains a reference to a volatile object but neither uses the value nor stores to the object, the expression is considered an access to the volatile object or not depending on the type of the object. If the object is of scalar type, an aggregate type with a single member of scalar type, or a union with members of (only) scalar type, the expression is considered an access to the volatile object. Otherwise, the expression is evaluated for its side effects but is not considered an access to the volatile object. For example: `volatile int a;` a; /* access to 'a' since 'a' is scalar */

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25.12. Declarators

ISO Standard:	"The maximum number of declarators that may modify an arithmetic, structure or union type (C90 6.5.4)."
Implementation:	No limit.

25.13. Statements

ISO Standard:	"The maximum number of case values in a switch statement (C90 6.6.4.2)."
Implementation:	No limit.

25.14. Pre-Processing Directives

ISO Standard:	"How sequences in both forms of header names are mapped to headers or external source file names (C90 6.1.7, C99 6.4.7)."
Implementation:	The character sequence between the delimiters is considered to be a string which is a file name for the host environment.
ISO Standard:	"Whether the value of a character constant in a constant expression that controls conditional inclusion matches the value of the same character constant in the execution character set (C90 6.8.1, C99 6.10.1)."
Implementation:	Yes.
ISO Standard:	"Whether the value of a single-character `character` constant in a constant expression that controls conditional inclusion may have a negative value (C90 6.8.1, C99 6.10.1)."
Implementation:	Yes.
ISO Standard:	"The places that are searched for an included < > delimited header, and how the places are specified or the header is identified (C90 6.8.2, C99 6.10.2)."
Implementation:	`<install directory>/lib/gcc/pic32m/<version>/include<install directory>/pic32m/include`
ISO Standard:	"How the named source file is searched for in an included "" delimited header (C90 6.8.2, C99 6.10.2)."
Implementation:	The compiler first searches for the named file in the directory containing the including file, the directories specified by the `-iquote` command line option (if any), then the directories which are searched for a < > delimited header.
ISO Standard:	"The method by which preprocessing tokens are combined into a header name (C90 6.8.2, C99 6.10.2)."
Implementation:	All tokens, including whitespace, are considered part of the header file name. Macro expansion is not performed on tokens inside the delimiters.
ISO Standard:	"The nesting limit for `#include` processing (C90 6.8.2, C99 6.10.2)."
Implementation:	No limit.
ISO Standard:	"The behavior on each recognized non-`STDC #pragma` directive (C90 6.8.6, C99 6.10.6)."
Implementation:	See Pragma Directives.
ISO Standard:	"The definitions for `__DATE__` and `__TIME__` when respectively, the date and time of translation are not available (C90 6.8.8, C99 6.10.8)."
Implementation:	The date and time of translation are always available.

25.15. Library Functions

ISO Standard:	"The Null Pointer constant to which the macro NULL expands (C90 7.1.6, C99 7.17)."
Implementation:	`(void *)0`
ISO Standard:	"Any library facilities available to a freestanding program, other than the minimal set required by clause 4 (5.1.2.1)."
Implementation:	See the *32-Bit Language Tools Libraries* (DS51685).
ISO Standard:	"The format of the diagnostic printed by the `assert` macro (7.2.1.1)."
Implementation:	"Failed assertion '*message*' at line *line* of '*filename*'.\n"

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ISO Standard:	"The default state for the `FENV_ACCESS` pragma (7.6.1)."
Implementation:	Unimplemented.
ISO Standard:	"The representation of floating-point exception flags stored by the `fegetexceptflag` function (7.6.2.2)."
Implementation:	Unimplemented.
ISO Standard:	"Whether the `feraiseexcept` function raises the inexact exception in addition to the overflow or underflow exception (7.6.2.3)."
Implementation:	Unimplemented.
ISO Standard:	"Floating environment macros other than `FE_DFL_ENV` that can be used as the argument to the `fesetenv` or `feupdateenv` function (7.6.4.3, 7.6.4.4)."
Implementation:	Unimplemented.
ISO Standard:	"Strings other than `"C"` and `""` that may be passed as the second argument to the `setlocale` function (7.11.1.1)."
Implementation:	None.
ISO Standard:	"The types defined for `float_t` and `double_t` when the value of the `FLT_EVAL_METHOD` macro is less than 0 or greater than 2 (7.12)."
Implementation:	Unimplemented.
ISO Standard:	"The infinity to which the `INFINITY` macro expands, if any (7.12)."
Implementation:	Unimplemented.
ISO Standard:	"The quiet `NaN` to which the NAN macro expands, when it is defined (7.12)."
Implementation:	Unimplemented.
ISO Standard:	"Domain errors for the mathematics functions, other than those required by this International Standard (7.12.1)."
Implementation:	None.
ISO Standard:	"The values returned by the mathematics functions, and whether `errno` is set to the value of the macro `EDOM`, on domain errors (7.12.1)."
Implementation:	`errno` is set to `EDOM` on domain errors.
ISO Standard:	"Whether the mathematics functions set `errno` to the value of the macro `ERANGE` on overflow and/or underflow range errors (7.12.1)."
Implementation:	Yes.
ISO Standard:	"The default state for the `FP_CONTRACT` pragma (7.12.2)
Implementation:	Unimplemented.
ISO Standard:	"Whether a domain error occurs or zero is returned when the `fmod` function has a second argument of zero (7.12.10.1)."
Implementation:	NaN is returned.
ISO Standard:	"The base-2 logarithm of the modulus used by the `remquo` function in reducing the quotient (7.12.10.3)."
Implementation:	Unimplemented.
ISO Standard:	"The set of signals, their semantics, and their default handling (7.14)."
Implementation:	The default handling of signals is to always return failure. Actual signal handling is application defined.
ISO Standard:	"If the equivalent of `signal(sig, SIG_DFL);` is not executed prior to the call of a signal handler, the blocking of the signal that is performed (7.14.1.1)."
Implementation:	Application defined.
ISO Standard:	"Whether the equivalent of `signal(sig, SIG_DFL);` is executed prior to the call of a signal handler for the signal `SIGILL` (7.14.1.1)."
Implementation:	Application defined.
ISO Standard:	"Signal values other than `SIGFPE`, `SIGILL`, and `SIGSEGV` that correspond to a computational exception (7.14.1.1)."
Implementation:	Application defined.
ISO Standard:	"Whether the last line of a text stream requires a terminating new-line character (7.19.2)."

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Implementation:	Yes.
ISO Standard:	"Whether space characters that are written out to a text stream immediately before a new-line character appear when read in (7.19.2)."
Implementation:	Yes.
ISO Standard:	"The number of null characters that may be appended to data written to a binary stream (7.19.2)."
Implementation:	No null characters are appended to a binary stream.
ISO Standard:	"Whether the file position indicator of an append-mode stream is initially positioned at the beginning or end of the file (7.19.3)."
Implementation:	Application defined. The system level function `open` is called with the `O_APPEND` flag.
ISO Standard:	"Whether a write on a text stream causes the associated file to be truncated beyond that point (7.19.3)."
Implementation:	Application defined.
ISO Standard:	"The characteristics of file buffering (7.19.3)."
ISO Standard:	"Whether a zero-length file actually exists (7.19.3)."
Implementation:	Application defined.
ISO Standard:	"The rules for composing valid file names (7.19.3)."
Implementation:	Application defined.
ISO Standard:	"Whether the same file can be open multiple times (7.19.3)."
Implementation:	Application defined.
ISO Standard:	"The nature and choice of encodings used for multibyte characters in files (7.19.3)."
Implementation:	Encodings are the same for each file.
ISO Standard:	"The effect of the `remove` function on an open file (7.19.4.1)."
Implementation:	Application defined. The system function `unlink` is called.
ISO Standard:	"The effect if a file with the new name exists prior to a call to the `rename` function (7.19.4.2)."
Implementation:	Application defined. The system function `link` is called to create the new file name, then `unlink` is called to remove the old file name. Typically, `link` will fail if the new file name already exists.
ISO Standard:	"Whether an open temporary file is removed upon abnormal program termination (7.19.4.3)."
Implementation:	No.
ISO Standard:	"What happens when the `tmpnam` function is called more than `TMP_MAX` times (7.19.4.4)."
Implementation:	Temporary names will wrap around and be reused.
ISO Standard:	"Which changes of mode are permitted (if any), and under what circumstances (7.19.5.4)."
Implementation:	The file is closed via the system level `close` function and re-opened with the `open` function with the new mode. No additional restriction beyond those of the application defined `open` and `close` functions are imposed.
ISO Standard:	"The style used to print an infinity or NaN, and the meaning of the *n-char-sequence* if that style is printed for a NaN (7.19.6.1, 7.24.2.1)."
Implementation:	No char sequence is printed.NaN is printed as "NaN".Infinity is printed as "[-/+]Inf".
ISO Standard:	"The output for `%p` conversion in the `fprintf` or `fwprintf` function (7.19.6.1, 7.24.2.1)."
Implementation:	Functionally equivalent to `%x`.
ISO Standard:	"The interpretation of a – character that is neither the first nor the last character, nor the second where a ^ character is the first, in the scanlist for `%[` conversion in the `fscanf` or `fwscanf` function (7.19.6.2, 7.24.2.1)."
Implementation:	Unknown
ISO Standard:	"The set of sequences matched by the `%p` conversion in the `fscanf` or `fwscanf` function (7.19.6.2, 7.24.2.2)."
Implementation:	The same set of sequences matched by `%x`.

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ISO Standard:	"The interpretation of the input item corresponding to a `%p` conversion in the `fscanf` or `fwscanf` function (7.19.6.2, 7.24.2.2)."
Implementation:	If the result is not a valid pointer, the behavior is undefined.
ISO Standard:	"The value to which the macro `errno` is set by the `fgetpos`, `fsetpos`, or `ftell` functions on failure (7.19.9.1, 7.19.9.3, 7.19.9.4)."
Implementation:	If the result exceeds `LONG_MAX`, `errno` is set to `ERANGE`.Other errors are application defined according to the application definition of the `lseek` function.
ISO Standard:	"The meaning of the *n-char-sequence* in a string converted by the `strtod`, `strtof`, `strtold`, `wcstod`, `wcstof`, or `wcstold` function (7.20.1.3, 7.24.4.1.1)."
Implementation:	No meaning is attached to the sequence.
ISO Standard:	"Whether or not the `strtod`, `strtof`, `strtold`, `wcstod`, `wcstof`, or `wcstold` function sets `errno` to `ERANGE` when underflow occurs (7.20.1.3, 7.24.4.1.1)."
Implementation:	Yes.
ISO Standard:	"Whether the `calloc`, `malloc`, and `realloc` functions return a Null Pointer or a pointer to an allocated object when the size requested is zero (7.20.3)."
Implementation:	A pointer to a statically allocated object is returned.
ISO Standard:	"Whether open output streams are flushed, open streams are closed, or temporary files are removed when the `abort` function is called (7.20.4.1)."
Implementation:	No.
ISO Standard:	"The termination status returned to the host environment by the `abort` function (7.20.4.1)."
Implementation:	By default, there is no host environment.
ISO Standard:	"The value returned by the `system` function when its argument is not a Null Pointer (7.20.4.5)."
Implementation:	Application defined.
ISO Standard:	"The local time zone and Daylight Saving Time (7.23.1)."
Implementation:	Application defined.
ISO Standard:	"The era for the `clock` function (7.23.2.1)."
Implementation:	Application defined.
ISO Standard:	"The positive value for `tm_isdst` in a normalized `tmx` structure (7.23.2.6)."
Implementation:	1
ISO Standard:	"The replacement string for the `%Z` specifier to the `strftime`, `strfxtime`, `wcsftime`, and `wcsfxtime` functions in the "`C`" locale (7.23.3.5, 7.23.3.6, 7.24.5.1, 7.24.5.2)."
Implementation:	Unimplemented.
ISO Standard:	"Whether or when the trigonometric, hyperbolic, base-*e* exponential, base-*e* logarithmic, error, and log gamma functions raise the inexact exception in an IEC 60559 conformant implementation (F.9)."
Implementation:	No.
ISO Standard:	"Whether the inexact exception may be raised when the rounded result actually does equal the mathematical result in an IEC 60559 conformant implementation (F.9)."
Implementation:	No.
ISO Standard:	"Whether the underflow (and inexact) exception may be raised when a result is tiny but not inexact in an IEC 60559 conformant implementation (F.9)."
Implementation:	No.
ISO Standard:	"Whether the functions honor the Rounding Direction mode (F.9)."
Implementation:	The Rounding mode is not forced.

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ISO Standard:	"The values or expressions assigned to the macros specified in the headers `<float.h>`, `<limits.h>`, and `<stdint.h>` (C90 and C99 5.2.4.2, C99 7.18.2, 7.18.3)."

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Implementation:	See limits.h.
ISO Standard:	"The number, order, and encoding of bytes in any object (when not explicitly specified in the standard) (C99 6.2.6.1)."
Implementation:	Little endian, populated from Least Significant Byte first. See Data Representation.
ISO Standard:	"The value of the result of the `size of` operator (C90 6.3.3.4, C99 6.5.3.4)."
Implementation:	See Data Representation.

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26. C++ Implementation-Defined Behavior

The ISO C++ standard requires a conforming implementation to document the compiler's choices for behaviors defined in the standard as “implementation-defined.” The following table lists all such areas, the choices made for the compiler, and the corresponding section number from the ISO/IEC 14882:2014 C++ Standard.

Table 26-1. Implementation-Defined Behavior

ISO Standard	Implementation
Which of the compiler's output messages are diagnostic messages (1.3.6)	
	All output to `stderr` is a diagnostic.
The required libraries for a freestanding implementation (1.4)	
	See the response for *The set of headers for a freestanding implementation (17.6.1.3)*
The number of bits in a byte (1.7)	
	8 bits
What constitutes an interactive device (1.9)	
	If `isatty()` is true, then interactive stream support is implied.
The number of threads in a program under a freestanding implementation (1.10)	
	Threads are not directly supported
How physical source file characters are mapped to the basic source character set (2.2)	
	The locale settings determine the default source character set or UTF-8 if this cannot be determined by the locale. The basic source character set is UTF-8.
Physical source file characters (2.2)	
	Defaults to the set locale, and if that doesn't work, defaults to UTF-8. Can be any encoding supported by the system's `iconv()` library routine.
The execution character member chosen for a source character that does not map to an equivalent execution character. (2.2)	
	ABI Defined
Whether source of translation units must be available to locate template definitions (2.2)	
	The source must be available.
The execution character-set and execution wide-character set (2.3)	
	The execution character set contains [`a-zA-Z0-9_{}[]#()<>%:;.?*+-/^&|~!=,\"'`], space, control characters representing horizontal tab, vertical tab, form feed, new-line, alert, backspace, carriage return, and a null character. The execution wide-character set is the same, except instead of a null character it has a null wide character. Encoding can be anything supported by the system's `iconv()` library routine, defaulting to UTF-8 (or UTF-32, for the wide-character set).
The mapping header name to header or external source file (2.9)	
	Same name as the header, in UTF-8.
The encoding of universal character name not in the execution character set (2.14.3)	
	`\U`*NNNNNNNN* or `\u`*NNNN*, where *N* is a hex-quad, corresponding to the character short name in ISO/IEC 10646 *NNNNNNNN* or `0000`*NNNN*, respectively.
The semantics of non-standard escape sequences (2.14.3)	
	As an extension, GCC supports the sequence `'\e'` to act as the ASCII `ESC` character.
The value of a character literal outside the range of the corresponding type (2.14.3)	
	The last byte of the series of bytes making up the literal.
The wide-character literal with single *c-char* that is not in execution wide-character set (2.14.3)	
	The last four bytes of the series of bytes making up the literal.
The choice of a larger or smaller value of floating literal when the value is not in the range of representable values for its type (2.14.4)	
	As per Annex F of C99
The concatenation of string literals other than those fully specified by the standard (2.14.5)	

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Table 26-1. Implementation-Defined Behavior (continued)

ISO Standard	Implementation
	No extra concatenations are supported.
Whether all string literals are distinct (that is, are stored in nonoverlapping objects) (2.14.5)	
	String literals are not necessarily distinct.
The linkage of `main()` (3.6.1)	
	External linkage
The parameters to main (3.6.1)	

	`int main(void)`
	or
	`int main(int argc, char** argv)`

What constitutes start-up and termination in freestanding environment (3.6.1)	
	Determined by the device-specific startup code. The default code shipped in a DFP calls constructors before `main()` for objects of namespace scope with static storage duration but does not call destructors after return from `main()`.
Whether defining main is required in a freestanding environment (3.6.1)	
	Yes - The device-specific startup code can be customized to not call `main()`, but some features such as the stack-usage report require `main()`.
Whether dynamic initialization of a non-local variable with static or thread storage duration is done before the first statement of the initial function of the thread (3.6.2)	
	Threads are not directly supported
Whether dynamic initialization of a non-local variable with static storage duration is done before the first statement of `main()` (3.6.2)	
	Determined by the device-specific startup code, but the default startup code provided in a DFP does call the constructors.
Whether an implementation has relaxed or strict pointer safety (3.7.4.3)	
	Relaxed pointer safety
The extended signed integer types (3.9.1)	
	None
The representation of `char` (3.9.1)	
	One byte.
The signedness of a plain `char` (3.9.1)	
	A plain `char` is signed.
The value representation of floating-point types (3.9.1)	
	IEEE-754
The value representation of pointer types (3.9.2)	
	32 bits.
The number of bytes between successive addresses at which a given object can be allocated alignment (3.11)	
	Valid alignments are powers of 2 up to and including 2^{28}.
Whether any extended object alignments are supported and the contexts in which they are supported (3.11)	
	Extended alignments up to 2^{28} are allowed, subject to the device memory layout.
The value of the result of unsigned to signed conversion (4.7)	
	For conversion to a type of width *N*, the value is reduced modulo 2^N to be within range of the type.
The result of an inexact floating-point conversion (4.8)	
	Software emulation uses Round to Nearest but the mode can be changed when using a hardware FPU.
The value of result of inexact integer to floating-point conversions (4.9)	
	As per C99 Annex F.
The rank of extended signed integer type (4.13)	

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Table 26-1. Implementation-Defined Behavior (continued)

ISO Standard	Implementation
	Extended signed integer types are not supported.
Passing an argument of class type through ellipsis (5.2.2)	
	Supported
The class publicly derived from `std::type_info` which can be returned by `typeid` (5.2.8)	
	No extra class is defined. The result is `std::type_info`.
The conversions between pointers and integers (5.2.10)	
	A cast from an integer to a pointer or vice versa uses the binary representation of the source type, reinterpreted as appropriate for the destination type. If the source type is larger than the destination type, the Most Significant bits are discarded. When casting from a pointer to an integer, if the source type is smaller than the destination type, the result is sign extended. When casting from an integer to a pointer, if the source type is smaller than the destination type, the result is extended based on the signedness of the source type.
The meaning of converting a function pointer to an object pointer type or vice versa (5.2.10)	
	Conversion is supported. The binary representation is preserved.
The result of `sizeof` when applied to fundamental types other than `char`, `signed char`, and `unsigned char` (5.3.3)	
	See Integer Data Types, noting that `sizeof()` returns a size in bytes
Whether over-aligned types are supported (5.3.4, 20.7.9.1, 20.7.11)	
	Yes.
The type of `ptrdiff_t` (5.7, 18.2)	
	`int`
The result of a right shift of negative values (5.8)	
	Bitwise operators act on the representation of the value including both the sign and value bits, where the sign bit is considered immediately above the highest-value value bit.
The meaning of `attribute` declaration (7)	
	See Variable Attributes and Function Attributes and Specifiers.
The underlying type for enumeration (7.2)	
	If the enumeration values are all non-negative, the type is `unsigned int`, else it is `int`.
The meaning of the `asm` declaration (7.4)	
	See Using Inline Assembly Language.
The semantics of linkage specifiers (7.5)	
	Only “C” and “C++” linkage are supported.
The behavior of non-standard attributes (7.6.1)	
	See Variable Attributes and Function Attributes and Specifiers.
The behavior of an attribute-scoped-token (7.6.1)	
	Attributes are available in the “gnu” namespace and are equivalent to `__attribute__`.
The string resulting from `__func__` (8.4.1)	
	Treated as a constant expression and can be used in *constexpr* contexts. The string contains the function name only.
The allocation of bit-fields within a class object (9.6)	
	Bit fields are allocated left to right.
The alignment of bit-fields within a class object (9.6)	
	Each member is located to the lowest available offset allowable according to the alignment restrictions of the member type.
The semantics of linkage specification on templates (14)	
	Only `"C"` and `"C++"` linkage are supported.
Whether the stack is unwound before a call to `std::terminate()` (15.3, 15.5.1)	
	The stack is not unwound.
Whether the stack is unwound before calling `std::terminate()` when a `noexcept` specification is violated (15.5.1)	

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Table 26-1. Implementation-Defined Behavior (continued)

ISO Standard	Implementation
	The stack is not unwound.
The numeric values of character literals in `#if` directives (16.1)	
	Interpreted in the same manner as they would on the target.
Whether a single-character character literal may have a negative value (16.1)	
	Yes
The manner of search for included source files (16.2)	
	Sequential, through a defined list of search paths. The search ends on the first match.
The nesting limit for `#include` directives (16.2)	
	XC32 imposes a limit of 200 levels to avoid runaway recursion.
The search locations for headers included using "" (16.2)	
	The `#include "file"` directive is used for header files defined by your project. XC32 searches for the file in the directory containing the current source file, then in the quote directories, and then in the system directories. You can prepend directories using a command-line option.
The search locations for headers included using <> (16.2)	

	The `#include <file>` directive is used for system header files packaged with XC32. You can prepend search directories using a command-line option. Directories are searched in the following order:
	`pic32m/include/c++/<gcc-ver>`
	`pic32m/include/c++/<gcc-ver>/pic32m`
	`pic32m/include/c++/<gcc-ver>/backward`
	`pic32m/include`
	`pic32m/include/musl`
	`lib/gcc/pic32m/<gcc-ver>/include`
	`pic32m/include/pic32m-libs`

The sequence of places searched for a header (16.2)	
	Quote form includes search the directory of the current file, then in the system directories. Angle-bracket form includes only search the system directories.
The behavior of a `#pragma` directive (16.6)	
	See Pragma Directives
The text equated to `__DATE__` when date of translation is not available (16.8)	
	Expands to `"??? ?? ????"`
The text equated to `__TIME__` when time of translation is not available (16.8)	
	Expands to `"??? ?? ????"`
Whether `__STDC_VERSION__` is a predefined macro and what it means (16.8)	
	This macro is a long integer constant that has the format *yyyymm*L, where *yyyy* is the year and *mm* is the month of the C Standard version with which the compiler is compatible. This shows the C Standard version to which the compiler conforms.
Whether `__STDC__` is a predefined macro and what it means (16.8)	
	In normal operation, this macro expands to the constant 1, to signify that this compiler conforms to ISO Standard C.
The set of headers for a freestanding implementation (17.6.1.3)	

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Table 26-1. Implementation-Defined Behavior (continued)

ISO Standard	Implementation

	Every header required by the standard except `<atomic>`, those being:
	`<ciso646>`
	`<cstddef>`
	`<cfloat>`
	`<limits>`
	`<climits>`
	`<cstdint>`
	`<cstdlib>`
	`<new>`
	`<typeinfo>`
	`<exception>`
	`<initializer_list>`
	`<cstdalign>`
	`<cstdarg>`
	`<cstdbool>`
	`<type_traits>`

Whether a name from the C standard library declared with external linkage has `extern "C"` or `extern "C++"` linkage (17.6.2.3)	
	`extern "C++"`
The exceptions thrown by standard library functions that do not have an exception specification (17.6.5.12)	
	There are no implementation-defined exception classes.
The `error_category` for errors originating outside the operating system (17.6.5.14)	
	None.
The type of `size_t` (18.2)	
	`unsigned int`
The form of the exit status returned to the host environment (18.5)	
	Host environments are not supported.
The return value of `bad_alloc::what` (18.6.2.1)	
	The name of the class.
The return value of `type_info::name()` (18.7.1)	
	The mangled type name.
The return value of `bad_cast::what` (18.7.2)	
	The name of the class.
The return value of `bad_typeid::what` (18.7.3)	
	The name of the class.
The result of `exception::what` (18.8.1)	
	The name of the class.
The return value of `bad_exception::what` (18.8.2)	
	The name of the class.
The use of a non-POF (non-“plain old function”) as signal handler (18.10)	
	Signals are not supported.
The exception type when the `shared_ptr` constructor fails (20.8.2.2.1)	
	`std::bad_alloc`
Whether placeholder types are `CopyAssignable` (20.9.9.1.4)	
	Yes.
Whether extended alignment is supported (20.10.7.6)	
	Yes.
Whether values are rounded or truncated to the required precision when converting between `time_t` values and `time_point` objects (20.12.7.1)	
	Values are truncated.
The type of `streamoff` (21.2.3.1)	

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Table 26-1. Implementation-Defined Behavior (continued)

ISO Standard	Implementation
	`long long`
The type of `streampos` (21.2.3.1)	
	Synonym for `fpos<mbstate_t>`
The return value of `char_traits<char16_t>::eof` (21.2.3.2)	
	`int_type(-1)`
The type of `u16streampos` (21.2.3.2)	
	Synonym for `fpos<mbstate_t>`
The return value of `char_traits<char32_t>::eof` (21.2.3.3)	
	`int_type(-1)`
The type of `u32streampos` (21.2.3.3)	
	Synonym for `fpos<mbstate_t>`
The type of `wstreampos` (21.2.3.4)	
	Synonym for `fpos<mbstate_t>`
Whether locale object is global or per-thread (22.3.1)	
	Locale object is global.
The effect on C locale of calling `locale::global` (22.3.1.5)	
	If the locale has a name, same as `setlocale()`.
The value of `ctype<char>::table_size` (22.4.1.3)	
	`SCHAR_MAX + 1`
The additional formats accepted for `time_get::do_get_date` (22.4.5.1.2)	
	None
Whether `time_get::do_get_year` accepts two-digit year numbers (22.4.5.1.2)	
	Two-digit year numbers are accepted.
The formatted character sequence generated by `time_put::do_put` in the C locale (22.4.5.3.2)	
	Same as `strftime()`
The type of `array::const_iterator` (23.3.2.1)	
	`const T*`
The type of `array::iterator` (23.3.2.1)	
	`T*`
The default number of buckets in `unordered_map` when this is not specified with the constructor (23.5.4.2)	
	0
The default number of buckets in `unordered_multimap` when this is not specified with the constructor (23.5.5.2)	
	0
The default number of buckets in `unordered_set` when this is not specified with the constructor (23.5.6.2)	
	0
The default number of buckets in `unordered_multiset` when this is not specified with the constructor (23.5.7.2)	
	0
The underlying source of random numbers for `random_shuffle` (25.3.12)	
	It uses `rand()` as the source of randomness.
The effect of calling `ios_base::sync_with_stdio` after any input or output operation on standard streams (27.5.3.4)	
	The synchronization referred to is only that between the standard C facilities and the standard C++ objects. User-declared streams are unaffected.
The argument values used to construct the `fail` object of `basic_ios::failure` thrown by `basic_ios` flags functions (27.5.5.4)	
	`const char&`
Whether sequence pointers are copied by `basic_stringbuf` move constructor (27.8.2.1)	

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Table 26-1. Implementation-Defined Behavior (continued)

ISO Standard	Implementation
	Sequence pointers are copied.
The effect of calling `basic_streambuf::setbuf` with non-zero arguments (27.8.2.4)	
	If no buffer has already been created and both arguments are non-zero, then the first argument is used as a buffer.
Whether sequence pointers are copied by `basic_filebuf` move constructor (27.9.1.2)	
	Sequence pointers are copied.
The effect of calling `basic_filebuf::setbuf` with non-zero arguments (27.9.1.5)	
	The first argument is used as a buffer.
The effect of calling `basic_filebuf::sync` when a get area exists (27.9.1.5)	
	No effect.
The type of `regex_constants::error_type` (28.5.3)	
	Unscoped enumeration types.
The values of various `ATOMIC_...LOCK_FREE` macros (29.4)	
	Not supported.
Whether `get_pointer_safety` returns `pointer_safety::relaxed` or `pointer_safety::preferred` if the implementation has relaxed pointer safety (29.4)	
	Relaxed pointer safety.
The presence and meaning of `native_handle_type` and `native_handle` (30.2.3)	
	Native handles are not supported.
The type of `ios_base::streamoff` (D.6)	
	`long long int`
The type of `ios_base::streampos` (D.6)	
	Typedef `fpos<mbstate_t>`

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27. Deprecated Features

The features described below are considered to be obsolete and have been replaced with more advanced functionality. Projects which depend on deprecated features will work properly with versions of the language tools cited. The use of a deprecated feature will result in a warning; programmers are encouraged to revise their projects in order to eliminate any dependency on deprecated features. Support for these features may be removed entirely in future versions of the language tools.

27.1. Variables in Specified Registers

The compiler allows you to put a few global variables into specified hardware registers.

Note: Using too many registers may impair the ability of the 32-bit compiler to compile. It is not recommended that registers be placed into fixed registers.

You can also specify the register in which an ordinary register variable should be allocate.

- Global register variables reserve registers throughout the program. This may be useful in programs such as programming language interpreters which have a couple of global variables that are accessed very often.
- Local register variables in specific registers do not reserve the registers. The compiler's data flow analysis is capable of determining where the specified registers contain live values, and where they are available for other uses. Stores into local register variables may be deleted when they appear to be unused. References to local register variables may be deleted, moved or simplified.

These local variables are sometimes convenient for use with the extended inline assembly (see Mixing C/C++ and Assembly Language), if you want to write one output of the assembler instruction directly into a particular register. (This will work provided the register you specify fits the constraints specified for that operand in the inline assembly statement).

27.2. Defining Global Register Variables

You can define a global register variable like this:

```
register int *foo asm ("t0");
```

Here `t0` is the name of the register which should be used. Choose a register that is normally saved and restored by function calls, so that library routines will not clobber it.

Defining a global register variable in a certain register reserves that register entirely for this use, at least within the current compilation. The register will not be allocated for any other purpose in the functions in the current compilation. The register will not be saved and restored by these functions. Stores into this register are never deleted even if they would appear to be dead, but references may be deleted, moved or simplified.

It is not safe to access the global register variables from signal handlers, or from more than one thread of control, because the system library routines may temporarily use the register for other things (unless you recompile them especially for the task at hand).

It is not safe for one function that uses a global register variable to call another such function `foo` by way of a third function `lose` that was compiled without knowledge of this variable (that is, in a source file in which the variable wasn't declared). This is because `lose` might save the register and put some other value there. For example, you can't expect a global register variable to be available in the comparison-function that you pass to `qsort`, since `qsort` might have put something else in that register. This problem can be avoided by recompiling `qsort` with the same global register variable definition.

If you want to recompile `qsort` or other source files that do not actually use your global register variable, so that they will not use that register for any other purpose, then it suffices to specify

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the compiler command-line option `-ffixed-reg`. You need not actually add a global register declaration to their source code.

A function that can alter the value of a global register variable cannot safely be called from a function compiled without this variable, because it could clobber the value the caller expects to find there on return. Therefore, the function that is the entry point into the part of the program that uses the global register variable must explicitly save and restore the value that belongs to its caller.

The library function `longjmp` will restore to each global register variable the value it had at the time of the `setjmp`.

All global register variable declarations must precede all function definitions. If such a declaration appears after function definitions, the register may be used for other purposes in the preceding functions.

Global register variables may not have initial values because an executable file has no means to supply initial contents for a register.

27.3. Specifying Registers for Local Variables

You can define a local register variable with a specified register like this:

```
register int *foo asm ("t0");
```

Here `t0` is the name of the register that should be used. Note that this is the same syntax used for defining global register variables, but for a local variable it would appear within a function.

Defining such a register variable does not reserve the register; it remains available for other uses in places where flow control determines the variable's value is not live. Using this feature may leave the compiler too few available registers to compile certain functions.

This option does not ensure that the compiler will generate code that has this variable in the register you specify at all times. You may not code an explicit reference to this register in an `asm` statement and assume it will always refer to this variable.

Assignments to local register variables may be deleted when they appear to be unused. References to local register variables may be deleted, moved or simplified.

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28. Built-in Functions

Built-in functions are coded in C source files syntactically like function calls, but are typically compiled into short assembly code sequences that directly implement the required function without calling a C function or library routine. These functions give the C programmer access to assembler operators or machine instructions that are currently only accessible using inline assembly, but are sufficiently useful that they are applicable to a broad range of applications.

There are no header files associated with built-in functions, as they are not true C functions. The `-f[no]builtin` option controls whether the built-in functions provided by the compiler are recognized in projects. The built-in function names all begin with the _ _builtin_ prefix, and hence do not belong to the compiler's namespace and not conflict with function or variable names in the programmer's namespace.

There are a number of reasons why providing built-in functions is preferable to requiring programmers to use inline assembly. They include the following:

1. Providing built-in functions for specific purposes simplifies coding.
2. Certain optimizations are disabled when inline assembly is used. This is not the case for built-in functions.
3. For machine instructions that use dedicated registers, coding inline assembly while avoiding register allocation errors can require considerable care. The built-in functions make this process simpler as you do not need to be concerned with the particular register requirements for each individual machine instruction.

28.1. __builtin_bcc0 Built-in Function

Description

Clear the non-zero bits present in the `clr` mask from the coprocessor 0 register specified by `rn` (register number) and `sel` (register bank).

Prototype

```
unsigned int __builtin_bcc0(rn, sel, clr);
```

Argument

```
rn : cp0 register number
sel : cp0 select (bank) number
clr : 32-bit mask to clear
```

Return Value

`unsigned int` : the original CP register value

Assembler Operator/Machine Instruction

```
mfc0 t, cs
nor d, s, t
and d, s, j
mtc0 s, cd
```

Error Messages

None.

28.2. __builtin_bsc0 Built-in Function

Description

Set the non-zero bits present in the `set` mask from the coprocessor 0 register specified by `rn` (register number) and `sel` (register bank).

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Prototype

```
unsigned int __builtin_bsc0(rn, sel, set);
```

Argument

```
rn : cp0 register number
sel : cp0 select (bank) number
set : 32-bit mask to set
```

Return Value

`unsigned int`: the original CP register value

Assembler Operator/ Machine Instruction

```
mfc0 t, cs
or d, s, t
mtc0 s, cd
```

Error Messages

None.

28.3. __builtin_bcsc0 Built-in Function

Description

Clear the non-zero bits present in the `clr` mask as well as set the non-zero bits present in the `set` mask from the coprocessor 0 register specified by `rn` (register number) and `sel` (register bank).

Prototype

```
unsigned int __builtin_bcsc0(rn, sel, clr, set);
```

Argument

```
rn : cp0 register number
sel : cp0 select (bank) number
clr : 32-bit mask to clear
set : 32-bit mask to set
```

Return Value

`unsigned int`: the original CP register value

Assembler Operator/ Machine Instruction

```
mfc0 t, cs
nor d, s, t
and d, s, j
or d, s, t
mtc0 s, cd
```

Error Messages

None.

28.4. __builtin_bswap16 Built-in Function

Returns its argument with the order of its bytes reversed. For example, an argument value of 0xaabb is returned as 0xbbaa. A byte here always means exactly 8 bits.

Prototype

```
uint16_t __builtin_bswap16 (uint16_t x)
```

Argument

`x`: the value whose bytes are to be swapped

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Return Value

The byte-swapped value

Error Messages

None.

28.5. __builtin_bswap32 Built-in Function

Returns its argument with the order of its bytes reversed. For example, an argument value of 0xaabbccdd is returned as 0xddccbbaa. A byte here always means exactly 8 bits.

Prototype

```
uint32_t __builtin_bswap32 (uint32_t x)
```

Argument

`x`: the value whose bytes are to be swapped

Return Value

The byte-swapped value

Error Messages

None.

28.6. __builtin_bswap64 Built-in Function

Returns its argument with the order of its bytes reversed. A byte here always means exactly 8 bits.

Prototype

```
uint64_t __builtin_bswap64 (uint64_t x)
```

Argument

`x`: the value whose bytes are to be swapped

Return Value

The byte-swapped value

Error Messages

None.

28.7. __builtin_clz Built-in Function

Description

Count leading (high-order) zero bits in `x`, considered to be a 32-bit word.

Prototype

```
unsigned int __builtin_clz(x);
```

Argument

```
x : 32-bit word to analyse
```

Return Value

```
unsigned int : number of leading zero bits
```

Assembler Operator/ Machine Instruction

```
clz d, s
```

Error Messages

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None.

28.8. __builtin_ctz Built-in Function

Description

Count trailing (low-order) zero bits in `x`, considered to be a 32-bit word.

Prototype

```
unsigned int __builtin_ctz(x);
```

Argument

```
x : 32-bit word to analyse
```

Return Value

```
unsigned int : number of trailing zero bits
```

Assembler Operator/ Machine Instruction

```
subu d, s, t
and d, s, t
clz d, s
li d, j
subu d, s, j
```

Error Messages

None.

28.9. __builtin_disable_interrupts Built-in Function

Description

This built-in returns the value of the Status register, then disables interrupts by clearing the Interrupt Enable (IE) bit in the Status register.

Prototype

```
void __builtin_disable_interrupts(void);
```

Argument

None.

Return Value

None.

Assembler Operator/Machine Instruction

```
di  $2
```

Error Messages

None.

28.10. __builtin_enable_interrupts Built-in Function

Description

This built-in returns the value of the Status register, then enables interrupts by setting the Interrupt Enable (IE) bit in the Status register.

Prototype

```
void __builtin_enable_interrupts(void);
```

Argument

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None.

Return Value

None.

Assembler Operator/Machine Instruction

```
ei  $2
```

Error Messages

None.

28.11. __builtin_get_isr_state Built-in Function

Remember: This built-in function inspects or manipulates the current CPU interrupt state.

Description

Get the current Interrupt Priority Level and Interrupt Enable bits.

Prototype

```
unsigned int __builtin_get_isr_state(void);
```

Argument

None.

Return Value

The current IPL and interrupt enable bits in a packed format. This value is to be used with the `__builtin_set_isr_state()` function.

Assembler Operator/ Machine Instruction

```
mfc0    $3, $12, 0
srl     $2,$3,10
ins     $2,$3,3,1
andi    $2,$2,0xf
sw      $2,0($fp)
```

Error Messages

None.

28.12. __builtin_has_attribute Built-in Function

The `__builtin_has_attribute` built-in function evaluates to an integer constant expression. This expression is true if the symbol or type referenced by the built-in function's first argument has been declared with the attribute referenced by its second argument; false otherwise. Neither argument is evaluated. The first argument is subject to the same restrictions as the argument to `typeof`, and when it does not reference a symbol, the type of this expression is considered. This built-in function cannot be used as the argument to `#if` or `#elif` preprocessor directives.

The attribute argument is an attribute name optionally followed by a comma-separated list of attribute arguments enclosed in parentheses. Both forms of attribute names—with and without double leading and trailing underscores—are recognized. If no arguments are specified with an attribute that expects one or more arguments, the built-in function considers only if its first argument has been declared with the attribute and ignores any attribute argument. When an incomplete set of attribute arguments have been specified, the built-in function returns true if all specified arguments match.

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For example, the first usage of the built-in function below evaluates to true because `x` is declared with the `aligned` attribute, but the second usage evaluates to false because `x` is declared `aligned (8)` and not `aligned (4)`.

```
attribute ((aligned (8))) int x;

 _Static_assert (__builtin_has_attribute (x, aligned), "aligned");
 _Static_assert (!__builtin_has_attribute (x, aligned (4)), "aligned (4)");
```

Due to a limitation, the `__builtin_has_attribute` built-in function always returns false when checking for the `mode` attribute, even if that attribute was used with the declaration of the type or variable referenced by the first argument. The function does not support checking of labels or C enumerators as the first argument.

Prototype

```
bool __builtin_has_attribute (type-or-expression, attribute)
```

Argument

`type-or-expression`: the symbol to check

`attribute`: the attribute to check against

Return Value

A true or false value

Error Messages

None.

28.13. __builtin_mfc0 Built-in Function

Description

Return the value in a coprocessor 0 register specified by `rn` (register number) and `sel` (register bank). The `sel` argument must be zero if the coprocessor 0 does not implement register banks other than 0.

Prototype

```
unsigned int __builtin_mfc0(rn, sel);
```

Argument

```
rn : cp0 register number
sel : cp0 select (bank) number
```

Return Value

```
unsigned int : the coprocessor register value
```

Assembler Operator/Machine Instruction

```
MFC0 rtemp, rd, sel
```

where `rtemp` is a temporary register allocated by the compiler, holding the value read from the coprocessor

Error Messages

None.

28.14. __builtin_mips_cache Built-in Function

Description

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Perform an operation on a cache line indicated by address. See the PIC32 Family Reference Manual for valid operation values.

Prototype

```
void __builtin_mips_cache(op, addr);
```

Argument

```
op : the cache operation
addr :
int32_t, const volatile void *
```

Return Value

None.

Assembler Operator/ Machine Instruction

```
cache op, addr
```

Error Message

None.

28.15. __builtin_mtc0 Built-in Function

Description

Moves the value `v` to the coprocessor 0 register specified by `rn` (register number) and `sel` (register bank).

Prototype

```
void __builtin_mtc0(rn, sel, v)
```

Argument

```
rn : cp0 register number
sel : cp0 select (bank) number
v : the value to write
```

Return Value

None

Assembler Operator/ Machine Instruction

```
MTC0 rtemp, rd, sel
```

where `rtemp` is a temporary register allocated by the compiler, preloaded with the value `v`.

Error Messages

None.

28.16. __builtin_mxc0 Built-in Function

Description

Write `val` to the coprocessor 0 register specified by `rn` (register number) and `sel` (register bank), returning the original value of the coprocessor register.

Prototype

```
unsigned int __builtin_mxc0(rn, sel, val);
```


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Argument

```
rn : cp0 register number
sel : cp0 select (bank) number
val : 32-bit value to move to the register
```

Return Value

`unsigned int : previous value in specified CP0 register`

Assembler Operator/ Machine Instruction

```
mfc0 t, cs
mtc0 s, cd
```

Error Messages

None.

28.17. void __builtin_nop(void)

Emit a no-operation instruction.

Prototype

`void __builtin_nop(void);`

Argument

None.

Return Value

None.

Assembler Operator/ Machine Instruction

`nop`

Error Messages

None.

28.18. __builtin_set_isr_state Built-in Function

Description

Set the Interrupt Priority Level and Interrupt Enable bits using a value obtained from `__builtin_get_isr_state()`.

Prototype

`void __builtin_set_isr_state(unsigned int);`

Argument

An unsigned integer value obtained from `__builtin_get_isr_state()`.

Return Value

None.

Assembler Operator/ Machine Instruction

```
di
ehb
mfc0   $2, $12, 0
ins    $2,$3,10,3
srl    $3,$3,3
ins    $2,$3,0,1
```


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```
mtc0   $2, $12, 0
ehb
```

Error Messages

None.

28.19. __builtin_software_breakpoint Built-in Function

Insert a software breakpoint.

Note that the `__conditional_software_breakpoint()` macro defined in `<assert.h>` provides a lightweight variant of `assert(exp)` that causes only a software breakpoint when the assertion fails rather than printing a message. This macro is disabled if, at the moment of including `<assert.h>`, a macro with the name `NDEBUG` has already been defined of if a macro with the name `__DEBUG` has not been defined. For example:

```
__conditional_software_breakpoint(myPtr!=NULL);
```

Prototype

```
void __builtin_software_breakpoint(void)
```

Argument

None.

Return Value

None.

Assembler Operator/ Machine Instruction

```
sdbbp 0
```

Error Messages

None.

28.20. __builtin_section_begin Built-in Function

Remember: This built-in function gets run-time information about section addresses and sizes.

Description

Return the beginning address of the quoted section name.

Prototype

```
unsigned long __builtin_section_begin(quoted-section-name);
```

Argument

`quoted-section-name` The name of the section.

Return Value

The address of the section.

Assembler Operator/ Machine Instruction

```
.startof.
```

Error Messages

An “undefined reference” error message will be displayed if the quoted section name does not exist in the link.

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28.21. __builtin_section_end Built-in Function

Remember: This built-in function gets run-time information about section addresses and sizes.

Description

Return the end address of the quoted section name + 1.

Prototype

```
unsigned long __builtin_section_end(quoted-section-name);
```

Argument

`quoted-section-name` The name of the section.

Return Value

The end address of the section + 1.

Assembler Operator/ Machine Instruction

`.endof.`

Error Messages

An “undefined reference” error message will be displayed if the quoted section name does not exist in the link.

28.22. __builtin_section_size Built-in Function

Remember: This built-in function gets run-time information about section addresses and sizes.

Description

Return the size in bytes of the named quoted section.

Prototype

```
unsigned long __builtin_section_size(quoted-section-name);
```

Argument

`quoted-section-name` The name of the section.

Return Value

The size in bytes of the named section.

Assembler Operator/ Machine Instruction

`.sizeof.`

Error Messages

An “undefined reference” error message will be displayed if the quoted section name does not exist in the link.

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29. Built-In DSP Functions

Many PIC32 MCUs support a DSP engine, including instructions that are designed to improve the performance of DSP and media applications. The DSPr2 engine provides instructions that operate on packed 8-bit/16-bit integer data, Q7, Q15 and Q31 fractional data.

The XC32 C compiler supports these DSP operations using both the generic vector extensions and a collection of built-in functions. Both kinds of support are enabled automatically when you select a DSP device with the `-mprocessor` option.

The SCOUNT and POS bits of the DSP control register are global. The WRDSP, EXTPDP, EXTPDPV and MTHLIP instructions modify the SCOUNT and POS bits. During optimization, the compiler will not delete these instructions and it will not delete calls to functions containing these instructions.

At present, the XC32 C compiler provides support for only operations on 32-bit vectors. The vector type associated with 8-bit integer data is usually called v4i8, the vector type associated with Q7 is usually called v4q7, the vector type associated with 16-bit integer data is usually called v2i16, and the vector type associated with Q15 is usually called v2q15. They can be defined in C as follows:

```
typedef signed char v4i8 __attribute__ ((vector_size(4)));
typedef signed char v4q7 __attribute__ ((vector_size(4)));
typedef short v2i16 __attribute__ ((vector_size(4)));
typedef short v2q15 __attribute__ ((vector_size(4)));
```

The v4i8, v4q7, v2i16 and v2q15 values are initialized in the same way as aggregates. For example:

```
v4i8 a = {1, 2, 3, 4};
v4i8 b;
b = (v4i8) {5, 6, 7, 8};

v2q15 c = {0x0fcb, 0x3a75};
v2q15 d;
d = (v2q15) {0.1234 * 0x1.0p15, 0.4567 * 0x1.0p15};
```

Notes:

1. The first value is the least significant and the last value is the most significant. The code above will set the lowest byte of a to 1.
2. Q7, Q15 and Q31 values must be initialized with their integer representation. As shown in this example, the integer representation of a Q7 value can be obtained by multiplying the fractional value by 0x1.0p7. The equivalent for Q15 values is to multiply by 0x1.0p15. The equivalent for Q31 values is to multiply by 0x1.0p31.

The table below lists the v4i8 and v2q15 operations for which hardware support exists. The a and b are v4i8 values, and c and d are v2q15 values.

C Code	Instruction
`a + b`	`addu.qb`
`c + d`	`addq.ph`
`a - b`	`subu.qb`
`c - d`	`subq.ph`

The table below lists the v2i16 operation for which hardware support exists. The e and `f` are v2i16 values.

C Code	Instruction
`e * f`	`mul.ph`

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It is easier to describe the DSP built-in functions if the types are defined beforehand.

```
typedef int q31;
typedef int i32;
typedef unsigned int ui32;
typedef long long a64;
```

The q31 and i32 operations are actually the same as `int`, but q31 is used to indicate a Q31 fractional value and i32 to indicate a 32-bit integer value. Similarly, a64 is the same as `long long`, but a64 is used to indicate values that will be placed in one of the four DSP accumulators ($ac0, $ac1, $ac2 or $ac3).

Also, some built-in functions prefer or require immediate numbers as parameters, because the corresponding DSP instructions accept both immediate numbers and register operands, or accept immediate numbers only. The immediate parameters are listed as follows.

```
imm0_3: 0 to 3.
imm0_7: 0 to 7.
imm0_15: 0 to 15.
imm0_31: 0 to 31.
imm0_63: 0 to 63.
imm0_255: 0 to 255.
imm_n32_31: -32 to 31.
imm_n512_511: -512 to 511.
```

The following built-in functions map directly to a particular DSP instruction. Please refer to the PIC32 DSP documentation for details on what each instruction does. In the table below, the function provides a way to generate the DSP instruction in your code. For example, in v2q15 `__builtin_mips_`**addq_ph** `(v2q15, v2q15)`, the **addq_ph** is the actual DSP instruction.

Table 29-1. Map Directly to DSP Instruction

v2q15 __builtin_mips_absq_s_ph (v2q15)
q31 __builtin_mips_absq_s_w (q31)
v2q15 __builtin_mips_addq_ph (v2q15, v2q15)
v2q15 __builtin_mips_addq_s_ph (v2q15, v2q15)
q31 __builtin_mips_addq_s_w (q31, q31)
i32 __builtin_mips_addsc (i32, i32)
v4i8 __builtin_mips_addu_qb (v4i8, v4i8)
v4i8 __builtin_mips_addu_s_qb (v4i8, v4i8)
i32 __builtin_mips_addwc (i32, i32)
i32 __builtin_mips_bitrev (i32)
i32 __builtin_mips_bposge32 (void)
void __builtin_mips_cmp_eq_ph (v2q15, v2q15)
void __builtin_mips_cmp_le_ph (v2q15, v2q15)
void __builtin_mips_cmp_lt_ph (v2q15, v2q15)
i32 __builtin_mips_cmpgu_eq_qb (v4i8, v4i8)
i32 __builtin_mips_cmpgu_le_qb (v4i8, v4i8)
i32 __builtin_mips_cmpgu_lt_qb (v4i8, v4i8)
void __builtin_mips_cmpu_eq_qb (v4i8, v4i8)
void __builtin_mips_cmpu_le_qb (v4i8, v4i8)
void __builtin_mips_cmpu_lt_qb (v4i8, v4i8)
a64 __builtin_mips_dpaq_s_w_ph (a64, v2q15, v2q15)
a64 __builtin_mips_dpaq_sa_l_w (a64, q31, q31)
a64 __builtin_mips_dpau_h_qbl (a64, v4i8, v4i8)
a64 __builtin_mips_dpau_h_qbr (a64, v4i8, v4i8)

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```
a64 __builtin_mips_dpsq_s_w_ph (a64, v2q15, v2q15)
a64 __builtin_mips_dpsq_sa_l_w (a64, q31, q31)
a64 __builtin_mips_dpsu_h_qbl (a64, v4i8, v4i8)
a64 __builtin_mips_dpsu_h_qbr (a64, v4i8, v4i8)
i32 __builtin_mips_extp (a64, i32)
i32 __builtin_mips_extp (a64, imm0_31)
i32 __builtin_mips_extpdp (a64, i32)
i32 __builtin_mips_extpdp (a64, imm0_31)
i32 __builtin_mips_extr_r_w (a64, i32)
i32 __builtin_mips_extr_r_w (a64, imm0_31)
i32 __builtin_mips_extr_rs_w (a64, i32)
i32 __builtin_mips_extr_rs_w (a64, imm0_31)
i32 __builtin_mips_extr_s_h (a64, i32)
i32 __builtin_mips_extr_s_h (a64, imm0_31)
i32 __builtin_mips_extr_w (a64, i32)
i32 __builtin_mips_extr_w (a64, imm0_31)
i32 __builtin_mips_insv (i32, i32)
i32 __builtin_mips_lbux (void *, i32)
i32 __builtin_mips_lhx (void *, i32)
i32 __builtin_mips_lwx (void *, i32)
a64 __builtin_mips_maq_s_w_phl (a64, v2q15, v2q15)
a64 __builtin_mips_maq_s_w_phr (a64, v2q15, v2q15)
a64 __builtin_mips_maq_sa_w_phl (a64, v2q15, v2q15)
a64 __builtin_mips_maq_sa_w_phr (a64, v2q15, v2q15)
i32 __builtin_mips_modsub (i32, i32)
a64 __builtin_mips_mthlip (a64, i32)
q31 __builtin_mips_muleq_s_w_phl (v2q15, v2q15)
q31 __builtin_mips_muleq_s_w_phr (v2q15, v2q15)
v2q15 __builtin_mips_muleu_s_ph_qbl (v4i8, v2q15)
v2q15 __builtin_mips_muleu_s_ph_qbr (v4i8, v2q15)
v2q15 __builtin_mips_mulq_rs_ph (v2q15, v2q15)
a64 __builtin_mips_mulsaq_s_w_ph (a64, v2q15, v2q15)
v2q15 __builtin_mips_packrl_ph (v2q15, v2q15)
v2q15 __builtin_mips_pick_ph (v2q15, v2q15)
v4i8 __builtin_mips_pick_qb (v4i8, v4i8)
q31 __builtin_mips_preceq_w_phl (v2q15)
q31 __builtin_mips_preceq_w_phr (v2q15)
v2q15 __builtin_mips_precequ_ph_qbl (v4i8)
v2q15 __builtin_mips_precequ_ph_qbla (v4i8)
v2q15 __builtin_mips_precequ_ph_qbr (v4i8)
v2q15 __builtin_mips_precequ_ph_qbra (v4i8)
v2q15 __builtin_mips_preceu_ph_qbl (v4i8)
v2q15 __builtin_mips_preceu_ph_qbla (v4i8)
v2q15 __builtin_mips_preceu_ph_qbr (v4i8)
v2q15 __builtin_mips_preceu_ph_qbra (v4i8)
v2q15 __builtin_mips_precrq_ph_w (q31, q31)
v4i8 __builtin_mips_precrq_qb_ph (v2q15, v2q15)
```


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```
v2q15 __builtin_mips_precrq_rs_ph_w (q31, q31)
v4i8 __builtin_mips_precrqu_s_qb_ph (v2q15, v2q15)
i32 __builtin_mips_raddu_w_qb (v4i8)
i32 __builtin_mips_rddsp (imm0_63)
v2q15 __builtin_mips_repl_ph (i32)
v2q15 __builtin_mips_repl_ph (imm_n512_511)
v4i8 __builtin_mips_repl_qb (i32)
v4i8 __builtin_mips_repl_qb (imm0_255)
a64 __builtin_mips_shilo (a64, i32)
a64 __builtin_mips_shilo (a64, imm_n32_31)
v2q15 __builtin_mips_shll_ph (v2q15, i32)
v2q15 __builtin_mips_shll_ph (v2q15, imm0_15)
v4i8 __builtin_mips_shll_qb (v4i8, i32)
v4i8 __builtin_mips_shll_qb (v4i8, imm0_7)
v2q15 __builtin_mips_shll_s_ph (v2q15, i32)
v2q15 __builtin_mips_shll_s_ph (v2q15, imm0_15)
q31 __builtin_mips_shll_s_w (q31, i32)
q31 __builtin_mips_shll_s_w (q31, imm0_31)
v2q15 __builtin_mips_shra_ph (v2q15, i32)
v2q15 __builtin_mips_shra_ph (v2q15, imm0_15)
v2q15 __builtin_mips_shra_r_ph (v2q15, i32)
v2q15 __builtin_mips_shra_r_ph (v2q15, imm0_15)
q31 __builtin_mips_shra_r_w (q31, i32)
q31 __builtin_mips_shra_r_w (q31, imm0_31)
v4i8 __builtin_mips_shrl_qb (v4i8, i32)
v4i8 __builtin_mips_shrl_qb (v4i8, imm0_7)
v2q15 __builtin_mips_subq_ph (v2q15, v2q15)
v2q15 __builtin_mips_subq_s_ph (v2q15, v2q15)
q31 __builtin_mips_subq_s_w (q31, q31)
v4i8 __builtin_mips_subu_qb (v4i8, v4i8)
v4i8 __builtin_mips_subu_s_qb (v4i8, v4i8)
void __builtin_mips_wrdsp (i32, imm0_63)
```

The following built-in functions map directly to a particular MIPS DSP REV 2 instruction. Please refer to the PIC32 DSP documentation for details on what each instruction does.

Table 29-2. Map Directly to MIPS DSP Instruction

```
v4q7 __builtin_mips_absq_s_qb (v4q7);
v2q15 __builtin_mips_addqh_ph (v2q15, v2q15);
v2q15 __builtin_mips_addqh_r_ph (v2q15, v2q15);
q31 __builtin_mips_addqh_r_w (q31, q31);
q31 __builtin_mips_addqh_w (q31, q31);
v2i16 __builtin_mips_addu_ph (v2i16, v2i16);
v2i16 __builtin_mips_addu_s_ph (v2i16, v2i16);
v4i8 __builtin_mips_adduh_qb (v4i8, v4i8);
v4i8 __builtin_mips_adduh_r_qb (v4i8, v4i8);
i32 __builtin_mips_append (i32, i32, imm0_31);
i32 __builtin_mips_balign (i32, i32, imm0_3);
```


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```
i32 __builtin_mips_cmpgdu_eq_qb (v4i8, v4i8);
i32 __builtin_mips_cmpgdu_le_qb (v4i8, v4i8);
i32 __builtin_mips_cmpgdu_lt_qb (v4i8, v4i8);
a64 __builtin_mips_dpa_w_ph (a64, v2i16, v2i16);
a64 __builtin_mips_dpaqx_s_w_ph (a64, v2q15, v2q15);
a64 __builtin_mips_dpaqx_sa_w_ph (a64, v2q15, v2q15);
a64 __builtin_mips_dpax_w_ph (a64, v2i16, v2i16);
a64 __builtin_mips_dps_w_ph (a64, v2i16, v2i16);
a64 __builtin_mips_dpsqx_s_w_ph (a64, v2q15, v2q15);
a64 __builtin_mips_dpsqx_sa_w_ph (a64, v2q15, v2q15);
a64 __builtin_mips_dpsx_w_ph (a64, v2i16, v2i16);
a64 __builtin_mips_madd (a64, i32, i32);
a64 __builtin_mips_maddu (a64, ui32, ui32);
a64 __builtin_mips_msub (a64, i32, i32);
a64 __builtin_mips_msubu (a64, ui32, ui32);
v2i16 __builtin_mips_mul_ph (v2i16, v2i16);
v2i16 __builtin_mips_mul_s_ph (v2i16, v2i16);
q31 __builtin_mips_mulq_rs_w (q31, q31);
v2q15 __builtin_mips_mulq_s_ph (v2q15, v2q15);
q31 __builtin_mips_mulq_s_w (q31, q31);
a64 __builtin_mips_mulsa_w_ph (a64, v2i16, v2i16);
a64 __builtin_mips_mult (i32, i32);
a64 __builtin_mips_multu (ui32, ui32);
v4i8 __builtin_mips_precr_qb_ph (v2i16, v2i16);
v2i16 __builtin_mips_precr_sra_ph_w (i32, i32, imm0_31);
v2i16 __builtin_mips_precr_sra_r_ph_w (i32, i32, imm0_31);
i32 __builtin_mips_prepend (i32, i32, imm0_31);
v4i8 __builtin_mips_shra_qb (v4i8, i32);
v4i8 __builtin_mips_shra_qb (v4i8, imm0_7);
v4i8 __builtin_mips_shra_r_qb (v4i8, i32);
v4i8 __builtin_mips_shra_r_qb (v4i8, imm0_7);
v2i16 __builtin_mips_shrl_ph (v2i16, i32);
v2i16 __builtin_mips_shrl_ph (v2i16, imm0_15);
v2q15 __builtin_mips_subqh_ph (v2q15, v2q15);
v2q15 __builtin_mips_subqh_r_ph (v2q15, v2q15);
q31 __builtin_mips_subqh_r_w (q31, q31);
q31 __builtin_mips_subqh_w (q31, q31);
v2i16 __builtin_mips_subu_ph (v2i16, v2i16);
v2i16 __builtin_mips_subu_s_ph (v2i16, v2i16);
v4i8 __builtin_mips_subuh_qb (v4i8, v4i8);
v4i8 __builtin_mips_subuh_r_qb (v4i8, v4i8);
```


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30. PIC32 DSP Library

30.1. Overview

The PIC32 DSP library consists of a set of functions that are applicable to many multimedia application areas. Most of the functions, like vector operations, filters, and transforms, are commonly used in many DSP and multimedia applications.

Some functions are designed to be used in specific applications such as video decoding or voice compression. It is beyond the scope of this manual to describe the operation of such applications.

Functions whose performance is considered critical are implemented in assembly and tuned where appropriate for a particular processor pipeline implementation and instruction set features. When a function is typically not considered to be performance critical, or the benefit from an assembly implementation is not significant, it is implemented in C. Often such functions perform initialization of data structures and are used only once during the lifetime of an application.

The following table lists all the functions currently available in the DSP Library, arranged by category, with the available implementation versions. All general purpose functions work with data in 16-bit fractional format, also known as Q15. Some of the functions also have a version that operates on 32-bit data in Q31 fractional format.

Table 30-1. General Purpose DSP Library Functions by Category

Category	Function Name	Description
Vector Math Functions	`mips_vec_abs16/32`	Compute the absolute value of each Q15/Q31 vector element.
	`mips_vec_add16/32`	Add the corresponding elements of two Q15/Q31 vectors.
	`mips_vec_addc16/32`	Add a constant to all elements of a vector.
	`mips_vec_dotp16/32`	Compute dot product of two Q15/Q31 vectors.
	`mips_vec_mul16/32`	Multiply the corresponding elements of two Q15/Q31 vectors. Can be used for applying windows.
	`mips_vec_mulc16/32`	Multiply all elements of a vector by a constant.
	`mips_vec_sub16/32`	Subtract the corresponding elements of two Q15/Q31 vectors.
	`mips_vec_sum_squares16/32`	Calculate the sum of squares of elements of a vector in Q15/Q31 format.
Filters	`mips_fir16`	Applies a block FIR filter to a Q15 vector.
	`mips_fir16_setup`	Prepare the filter coefficients for the mips_fir16 function.
	`mips_iir16`	Single-sample IIR filter.
	`mips_iir16_setup`	Prepare the filter coefficients for the mips_iir16 function.
	`mips_lms16`	Single-sample LMS filter
Transforms	`mips_fft16`	Compute the complex FFT of a vector containing Q15 complex samples, i.e., 16-bit fractional real and imaginary parts.
	`mips_fft16_setup` (deprecated)	Create a vector of twiddle factors used by the mips_fft16 function.
	`mips_fft32`	Compute the complex FFT of a vector containing Q31 complex samples, i.e., 32-bit fractional real and imaginary parts.
	`mips_fft32_setup` (deprecated)	Create a vector of twiddle factors used by the mips_fft32 function.
Video	`mips_h264_iqt`	Inverse quantization and transform for H.264 decoding.
	`mips_h264_iqt_setup`	Create inverse quantization matrix used by the mips_h264_iqt function.
	`mips_h264_mc_luma`	1/4-pixel motion compensation for luma pixels in H.264 video decoding.

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30.2. Fixed-Point Types

Input and output data for most functions in this library is represented in 16-bit fractional numbers, in Q15 format. This is the most commonly used data format for signal processing. Some function may use other data formats internally for increased precision of the intermediate results. The Q15 data type used by the DSP functions is specified as a signed 16-bit integer, typedefed as `int16` in the `<dsplib_def.h>` header files supplied with the library.

Note that within C code care must be taken not to confuse fixed-point values with integers. To the C compiler, objects used by these routines are integers, not fixed-point, and any arithmetic performed on those objects in C will be done as integers. Fixed-point values have been declared as integer types only because the standard C language does not include intrinsic support for fixed-point data types.

30.3. Saturation, Scaling, and Overflow

In the majority of DSP applications, overflow or underflow during computation is not desirable. It is best to design for appropriate scaling of the data path and avoid the possibility of overflow and underflow. However, such scaling can significantly limit the usable data range. Hence, many algorithm implementations relax the scaling and introduce saturation operations that clip the values that would otherwise overflow to the maximum or minimum limit of the data range.

Some of the general purpose DSP library module functions accumulate a series of values before producing the final result. Examples of these accumulations could include the vector dot product calculation, the FIR filter, the sum of squared values and even the FFT transform. All of these functions, with the exception of the FFT, include a parameter that controls the output scaling, i.e., additional amount of right shift applied when the result is converted to a Q15 value. The FFT results are automatically scaled down by $2^{log2(N)}$.

30.4. Array Alignment and Length Restrictions

For the sake of efficiency, most functions require that array pointer arguments are aligned on 4-byte boundaries. Arrays of the *int16* data type declared in C will be correctly aligned. Furthermore, there are often restrictions on the number of elements that a function can operate on. Typically the number of elements must be a multiple of a small integer (e.g., four or eight), and must be larger than, or equal to, a specified minimum. Note that to improve performance, the functions do not verify the validity of their input parameters. Supplying incorrect parameters may lead to unpredictable results.

30.5. Vector Math Functions

30.5.1. mips_vec_abs16

Description

Computes the absolute value of each element of *indata* and stores it to *outdata*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = abs(indata[N])

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_abs16
(
       int16 *outdata,
       int16 *indata,
       int N
);
```


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Argument

outdata: Output array of 16-bit fixed-point elements in Q15 format.

indata: Input array with 16-bit fixed-point elements in Q15 format.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.2. mips_vec_abs32

Description

Computes the absolute value of each element of *indata* and stores it to *outdata*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = abs(indata[N])

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_abs32
(
       int32 *outdata,
       int32 *indata,
       int N
);
```

Argument

outdata: Output array of 32-bit fixed-point elements in Q31 format.

indata: Input array with 32-bit fixed-point elements in Q31 format.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.3. mips_vec_add16

Description

Adds each element of *indata1* to the corresponding element of *indata2*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata1[n]+indata2[n]

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Include

dsplib_dsp.h

Prototype

```
void
mips_vec_add16
(
       int16 *outdata,
       int16 *indata1,
       int16 *indata2,
       int N
);
```

Argument

outdata: Output array of 16-bit fixed-point elements in Q15 format.

indata1: First input array with 16-bit fixed-point elements in Q15 format.

indata2: Second input array with 16-bit fixed-point elements in Q15 format.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata*, *indata1*, and *indata2* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.4. mips_vec_add32

Description

Adds each element of *indata1* to the corresponding element of *indata2*. The number of samples to be processed is given by the parameter N.

Mathematically,

outdata[n] = indata1[n]+indata2[n]

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_add32
(
       int32 *outdata,
       int32 *indata1,
       int32 *indata2,
       int N
);
```

Argument

outdata: Output array of 32-bit fixed-point elements in Q31 format.

indata1: First input array with 32-bit fixed-point elements in Q31 format.

indata2: Second input array with 32-bit fixed-point elements in Q31 format.

N: Number of samples.

Return Value

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None.

Remarks

- The pointers *outdata*, *indata1*, and *indata2* must be aligned on 4-byte boundaries.
- *N* must be larger than, or equal to, 4, and a multiple of 4.

30.5.5. mips_vec_addc16

Description

Adds the Q15 constant *c* to all elements of *indata*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata[n]+c

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_addc16
(
       int16 *outdata,
       int16 *indata,
       int16 c,
       int N
);
```

Argument

outdata: Output array of 16-bit fixed-point elements in Q15 format.

indata: Input array with 16-bit fixed-point elements in Q15 format.

c: Constant added to all elements of the vector.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.6. mips_vec_addc32

Description

Adds the Q31 constant *c* to all elements of *indata*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata[n]+c

Include

dsplib_dsp.h

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Prototype

```
void
mips_vec_addc32
(
       int32 *outdata,
       int32 *indata,
       int32 c,
       int N
);
```

Argument

outdata: Output array of 32-bit fixed-point elements in Q31 format.

indata: Input array with 32-bit fixed-point elements in Q31 format.

c: Constant added to all elements of the vector.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.7. mips_vec_dotp16

Description

Computes the dot product of the Q15 vectors *indata1* and *indata2*. The number of samples to be processed is given by the parameter *N*. The scale parameter specifies the amount of right shift applied to the final result.

Mathematically,

$$result = \frac{1}{2^{scale}} \sum_{n=0}^{N-1} indata1[n] \times indata2[n]$$

Include

dsplib_dsp.h

Prototype

```
int16
mips_vec_dotp16
(
       int16 *indata1,
       int16 *indata2,
       int N,
       int scale
);
```

Argument

indata1: First input array with 16-bit fixed point elements in Q15 format.

indata2: Second input array.

N: Number of samples.

scale: Scaling factor: divide the result by 2^{scale}.

Return Value

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Scaled result of the calculation in fractional Q15 format.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.8. mips_vec_dotp32

Description

Computes the dot product of the Q31 vectors *indata1* and *indata2*. The number of samples to be processed is given by the parameter *N*. The scale parameter specifies the amount of right shift applied to the final result.

Mathematically,

$$result = \frac{1}{2^{scale}} \sum_{n=0}^{N-1} indata1[n] \times indata2[n]$$

Include

dsplib_dsp.h

Prototype

```
int32
mips_vec_dotp32
(
       int32 *indata1,
       int32 *indata2,
       int N,
       int scale
);
```

Argument

indata1: First input array with 32-bit fixed point elements in Q31 format.

indata2: Second input array.

N: Number of samples.

scale: Scaling factor: divide the result by 2^{scale}.

Return Value

Scaled result of the calculation in fractional Q31 format.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.9. mips_vec_mul16

Description

Multiplies each Q15 element of *indata1* by the corresponding element of *indata2* and stores the results to *outdata*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata[n] x indata2[n]

Include

dsplib_dsp.h

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Prototype

```
void
mips_vec_mul16
(
       int16 *outdata,
       int16 *indata1,
       int16 *indata2,
       int N
);
```

Argument

outdata: Output array of 16-bit fixed-point elements in Q15 format.

indata1: First input array with 16-bit fixed-point elements in Q15 format.

indata2: Second input array.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata*, *indata1*, and *indata2* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.10. mips_vec_mul32

Description

Multiplies each Q31 element of *indata1* by the corresponding element of *indata2* and stores the results to outdata. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata1[n] x indata2[n]

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_mul32
(
       int32 *outdata,
       int32 *indata1,
       int32 *indata2,
       int N
);
```

Argument

outdata: Output array of 32-bit fixed-point elements in Q31 format.

indata1: First input array with 32-bit fixed-point elements in Q31 format.

indata2: Second input array.

N: Number of samples.

Return Value

None.

Remarks

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- The pointers *outdata*, *indata1*, and *indata2* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.11. mips_vec_mulc16

Description

Multiplies each Q15 element of *indata* by the Q15 constant *c* and stores the results to *outdata*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata1[n] x c

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_mulc16
(
       int16 *outdata,
       int16 *indata,
       int16 c,
       int N
);
```

Argument

outdata: Output array of 16-bit fixed-point elements in Q15 format.

indata: Input array with 16-bit fixed-point elements in Q15 format.

c: 16-bit fixed-point constant.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.12. mips_vec_mulc32

Description

Multiplies each Q31 element of *indata* by the Q31 constant *c* and stores the results to *outdata*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata1[n] x c

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_mulc32
(
       int32 *outdata,
       int32 *indata,
```


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```
        int32 c,
        int N
);
```

Argument

outdata: Output array of 32-bit fixed-point elements in Q31 format.

indata: Input array with 32-bit fixed-point elements in Q31 format.

c: 32-bit fixed-point constant.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata* and *indata* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.13. mips_vec_sub16

Description

Subtracts each element of *indata2* from the corresponding element of *indata1*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata1[n] – indata2[n]

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_sub16
(
        int16 *outdata,
        int16 *indata1,
        int16 *indata2,
        int N
);
```

Argument

outdata: Output array of 16-bit fixed-point elements in Q15 format.

indata1: First input array with 16-bit fixed-point elements in Q15 format.

indata2: Second input array with 16-bit fixed-point elements in Q15 format.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata*, *indata1*, and *indata2* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

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30.5.14. mips_vec_sub32

Description

Subtracts each element of *indata2* from the corresponding element of *indata1*. The number of samples to be processed is given by the parameter *N*.

Mathematically,

outdata[n] = indata1[n] – indata2[n]

Include

dsplib_dsp.h

Prototype

```
void
mips_vec_sub32
(
       int32 *outdata,
       int32 *indata1,
       int32 *indata2,
       int N
);
```

Argument

outdata: Output array of 32-bit fixed-point elements in Q31 format.

indata1: First input array with 32-bit fixed-point elements in Q31 format.

indata2: Second input array with 32-bit fixed-point elements in Q31 format.

N: Number of samples.

Return Value

None.

Remarks

- The pointers *outdata*, *indata1*, and *indata2* must be aligned on 4-byte boundaries.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.15. mips_vec_sum_squares16

Description

Computes the sum of squared values of all elements of *indata*. The number of samples to be processed is given by the parameter *N*. The scale parameter specifies the amount of right shift applied to the final result.

Mathematically,

$$result = \frac{1}{2^{scale}} \sum_{n=0}^{N-1} indata[n]^2$$

Include

dsplib_dsp.h

Prototype

```
int16
mips_vec_sum_squares16
(
       int16 *indata,
       int N,
```


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```
        int scale
);
```

Argument

indata: Input array with 16-bit fixed-point elements in Q15 format

N: Number of samples

scale: Scaling factor: divide the result by 2^{scale}.

Return Value

Scaled result of the calculation in fractional Q15 format.

Remarks

- The pointer *indata* must be aligned on a 4-byte boundary.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.5.16. mips_vec_sum_squares32

Description

Computes the sum of squared values of all elements of *indata*. The number of samples to be processed is given by the parameter *N*. The scale parameter specifies the amount of right shift applied to the final result.

Mathematically,

$$result = \frac{1}{2^{scale}} \sum_{n=0}^{N-1} indata[n]^2$$

Include

dsplib_dsp.h

Prototype

```
int32
mips_vec_sum_squares32
(
        int32 *indata,
        int N,
        int scale
);
```

Argument

indata: Input array with 32-bit fixed-point elements in Q31 format.

N: Number of samples.

scale: Scaling factor: divide the result by 2^{scale}.

Return Value

Scaled result of the calculation in fractional Q31 format.

Remarks

- The pointer *indata* must be aligned on a 4-byte boundary.
- *N* must be larger than or equal to 4 and a multiple of 4.

30.6. Filtering Functions

30.6.1. mips_fir16

Description

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Computes a finite impulse response (FIR) filter with coefficients specified in *coeffs2x* over the input data samples in *indata*. The function updates the *delayline*, which is used to initialize the filter the next time *mips_fir16()* is called. The number of samples to be processed is given by the parameter *N* and the number of filter coefficients is given by *K*. The scale parameter specifies the amount of right shift applied to the final result.

Mathematically,

$$output[n] = \frac{1}{2^{scale}} \sum_{k=0}^{K-1} indata[\, n-k \,] \times coeffs[k]$$

Include

dsplib_dsp.h

Prototype

```
void
mips_fir16
(
       int16 *outdata,
       int16 *indata,
       int16 *coeffs2x,
       int16 *delayline,
       int N,
       int K,
       int scale
);
```

Argument

outdata: Output array with 16-bit fixed-point elements in Q15 format.

indata: Input array with 16-bit fixed-point elements in Q15 format.

coeffs2x: Array of 2K 16-bit fixed-point coefficients prepared by *mips_fir16_setup()*.

delayline: Delay line array holding the last K input samples.

N: Number of samples.

K: Number of coefficients (filter taps).

scale: Scaling factor: divide the result by 2^{scale}.

Return Value

None.

Remarks

- The pointers *outdata*, *indata*, *coeffs2x*, and *delayline* must be aligned on a 4-byte boundary.
- *K* must be larger than or equal to 4 and a multiple of 4.

  Notes

  The *coeffs2x* array is twice the size of the original coefficient array, *coeffs*. The function *mips_fir16_setup()* takes the original coefficient array *coeffs* and rearranges the coefficients into the *coeffs2x* array to enable more efficient processing. All elements of the *delayline* array must be initialized to zero before the first call to *mips_fir16()*. Both *delayline* and *coeffs2x* have formats that are implementation-dependent and their contents should not be changed directly.

  Example

  ```
  int i;
  int K = 8;
  int N = 32;
  int16 coeffs[K];
  int16 coeffs2x[2*K];
  int16 delayline[K];
  ```


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```
int16 indata[N];
int16 outdata[N];
for (i = 0; i < K; i++)
   delayline[i] = 0;
// load coefficients into coeffs here
   ...
mips_fir16_setup(coeffs2x, coeffs, K);
while (true)
{
   // load input data into indata
      ...
   mips_fir16(outdata, indata, coeffs2x, delayline, N, K, 3);
   // do something with outdata
      ...
}
```

30.6.2. mips_fir16_setup

Description

Rearranges the coefficients from the input array, *coeffs*, into the output array *coeffs2x*, which is used by the *mips_fir16()* function. The number of coefficients to process is given by the parameter *K*.

Include

dsplib_dsp.h

Prototype

```
void
mips_fir16_setup
(
   int16 *coeffs2x,
   int16 *coeffs,
   int K
);
```

Argument

coeffs2x: Output array holding 2K coefficients rearranged for *mips_fir16()*.

coeffs: Input array holding K 16-bit fixed-point coefficients in Q15 format.

K: Number of coefficients.

Return Value

None.

Remarks

None.

Note

This function is implemented in C.

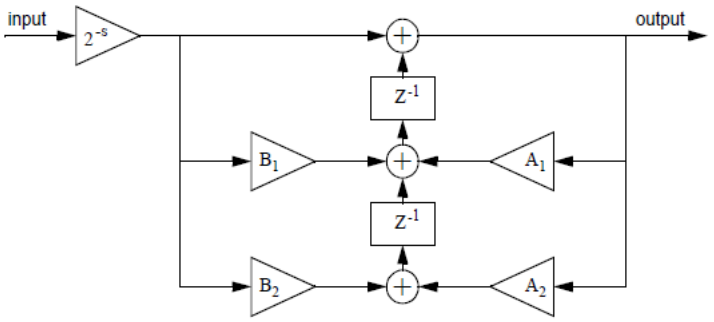
30.6.3. mips_iir16

Description

Computes a single-sample infinite impulse response (IIR) filter with coefficients specified in *coeffs*. The number of biquad sections composing the filter is given by the parameter *B*. The *scale* parameter specifies the amount of right shift applied to the input value of each biquad. Each biquad section is specified by four coefficients – A_1, A_2, B_1, and B_2 – and has two state variables stored inside *delayline*.°± The output of each biquad section becomes input to the next one. The output of the final section is returned as result of the *mips_iir16()* function.

The operations performed for each biquad section are illustrated below:

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Include

dsplib_dsp.h

Prototype

```
int16
mips_iir16
(
       int16 in,
       int16 *coeffs,
       int16 *delayline,
       int B,
       int scale
);
```

Argument

in: Input value in Q15 format.

coeffs: Array of 4B 16-bit fixed-point coefficients prepared by *mips_iir16_setup()*.

delayline: Delay line array holding 2B state 16-bit state variables.

B: Number of biquad sections.

scale: Scaling factor: divide the input to each biquad by 2^{scale}.

Return Value

IIR filter output value in fractional Q15 format.

Remarks

- The pointers *coeffs* and *delayline* must be aligned on a 4-byte boundary.
- *B* must be larger t**han or equal to 2 and a multiple of 2**.

Notes

The *coeffs* array contains four coefficients for each biquad. The coefficients are conveniently specified in an array of *biquad16* structures, which is converted to the appropriate internal representation by the *mips_iir16_setup()* function. All elements of the delayline array must be initialized to zero before the first call to *mips_iir16()*. Both *delayline* and *coeffs* have formats that are implementation-dependent and their contents should not be changed directly.

Example

```
int i;
int B = 4;

biquad16 bq[B];
int16 coeffs[4*B];
int16 delayline[2*B];
```


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```
int16 indata, outdata;

for (i = 0; i < 2*B; i++)
   delayline[i] = 0;

// load coefficients into bq here
...

mips_iir16_setup(coeffs, bq, B);

while (true)
{
   // get input data value into indata
      ...

   outdata = mips_iir16(indata, coeffs, delayline, B, 2);
   // do something with outdata
      ...
}
```

30.6.4. mips_iir16_setup

Description

Rearranges the coefficients from the input array, *bq*, into the output array *coeffs*, which is used by the *mips_iir16()* function. The number of biquad sections to process is given by the parameter *B*.

Include

dsplib_dsp.h

Prototype

```
void
mips_iir16_setup
(
   int16 *coeffs,
   biquad16 *bq,
   int B
);
```

Argument

coeffs: Output array holding 4B coefficients rearranged for mips_iir16().

bq: Input array holding Q15 coefficients for B biquad sections.

B: Number of biquad sections.

Return Value

None.

Remarks

None.

Notes

This function is implemented in C.

30.6.5. mips_lms16

Description

Computes a Least Mean Squares (LMS) adaptive filter and updates its coefficients. The new coefficients are computed using the *error* between the last filter output and the reference signal *ref*. The function takes one input sample *in* and computes one output sample. The parameter *mu* controls the adaptation rate of the filter.

Include

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dsplib_dsp.h

Prototype

```
int16
mips_lms16
(
        int16 in,
        int16 ref,
        int16 *coeffs,
        int16 *delayline,
        int16 *error,
        int16 K,
        int mu
);
```

Argument

in: Input value in Q15 format.

ref: Desired (reference) value in Q15 format.

coeffs: Input/output array of 16-bit fixed-point coefficients.

delayline: Delay line array holding the last *K* input samples.

error: Input/output value indicating the difference between the filter output and the reference value.

K: Number of coefficients (filter taps).

mu: Adaptation rate in Q15 format.

Return Value

LMS filter output value in Q15 format.

Remarks

- The pointers *coeffs* and *delayline* must be aligned on a 4-byte boundary.
- *K* must be larger than or equal to 4 and a multiple of 2.

Notes

The order of the elements of the *coeffs* and *delayline* arrays is implementation dependent. The *delayline* array must be initialized to zero before the first call to *mips_lms16()*.

30.7. Frequency Domain Transform Functions

30.7.1. mips_fft16

Description

Computes the complex fast Fourier transform (FFT) of the input sequence *din*. The number of samples to be processed is specified by the parameter *log2N: N = 2^{log2N}*. The *fftc* array holds complex coefficients needed by the FFT algorithm. The *scratch* hold intermediate data; its contents are destroyed on each call to *mips_fft16()*.

Mathematically,

$$output[n] = \frac{1}{2^{\log 2N}} \sum_{k=0}^{N-1} din[n] \times e^{-j\frac{2\pi kn}{N}}$$

Include

dsplib_dsp.h

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Prototype

```
void
mips_fft16
(
       int16c *dout,
       int16c *din,
       int16c *fftc,
       int16c *scratch,
       int log2N
);
```

Argument

dout: Output array with 16-bit complex fixed-point elements in Q15 format.

din: Input array with 16-bit complex fixed-point elements in Q15 format.

fftc: Input array with 16-bit complex fixed-point twiddle factors in Q15 format.

scratch: Intermediate results array holding 16-bit complex fixed-point data.

log2N: Logarithm base 2 of the number of samples: $N = 2^{log2N}$.

Return Value

None.

Remarks

- The pointers *dout*, *din*, *fftc*, and *scratch* must be aligned on 4-byte boundaries.
- *log2N* must be larger than or equal to 3.

Notes

The *scratch* array must be large enough to hold N 16-bit complex data samples having 16-bit real part and 16-bit imaginary part.

Copying *fftc* to RAM prior to calling this function can be used to improve performance.

Example

```
#include “fftc.h” // pre-computed coefficients
int log2N = 6; // log2(64) = 6
int N = 1 << log2N; // N = 2^6 = 64
int16c din[N];
int16c dout[N];
int16c scratch[N];
#define fftc fft16c64 // from fftc.h, for N = 64
while (true)
{
  // load complex input data into din
  ...
  mips_fft16(dout, din, fftc, scratch, log2N);
  // do something with dout
  ...
}
```

30.7.2. mips_fft16_setup – Function Deprecated

Description

Calculates the twiddle factors need to compute an FFT of size *N*. The twiddle factors are used by the *mips_fft16()* function. The number of samples to be processed is specified by the parameter *log2N: N = 2^{log2N}*.

Include

dsplib_dsp.h

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Prototype

```
void
mips_fft16_setup
(
       int16c *twiddles,
       int log2N
);
```

Argument

twiddles: Output array containing N 16-bit complex twiddle factors.

log2N: Logarithm base 2 of the number of samples: N = 2^{log2N}.

Return Value

None.

Remarks

This function requires floating-point support.

Notes

This function is implemented in C.

30.7.3. mips_fft32

Description

Computes the complex Fast Fourier Transform (FFT) of the input sequence *din*. The number of samples to be processed is specified by the parameter *log2N: N = 2^{log2N}*. The *fftc* array holds complex coefficients needed by the FFT algorithm. The *scratch* hold intermediate data; its contents are destroyed on each call to *mips_fft32()*.

Mathematically,

$$output[n] = \frac{1}{2^{\log 2N}} \sum_{k=0}^{N-1} din[n] \times e^{-j\frac{2\pi kn}{N}}$$

Include

dsplib_dsp.h

Prototype

```
void
mips_fft32
(
       int32c *dout,
       int32c *din,
       int32c *fftc,
       int132 *scratch,
       int log2N
);
```

Argument

dout: Output array with 32-bit complex fixed-point elements in Q31 format.

din: Input array with 32-bit complex fixed-point elements in Q31 format.

fftc: Input array with 32-bit complex fixed-point twiddle factors in Q31 format.

scratch: Intermediate results array holding 32-bit complex fixed-point data.

log2N: Logarithm base 2 of the number of samples: N = 2^{log2N}.

Return Value

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None.

Remarks

- The pointers *dout*, *din*, *fftc*, and *scratch* must be aligned on 4-byte boundaries.
- *log2N* must be larger than or equal to 3.

Notes

The *scratch* array must be large enough to hold N 32-bit complex data samples having 32-bit real part and 32-bit imaginary part.

Copying *fftc* to RAM prior to calling this function can be used to improve performance.

Example

```
#include “fftc.h” // pre-computed coefficients
int log2N = 6; // log2(64) = 6
int N = 1 << log2N; // N = 2^6 = 64
int32c din[N];
int32c dout[N];
int32c scratch[N];
#define fftc fft32c64 // from fftc.h, for N = 64
while (true)
{
  // load complex input data into din
  ...
  mips_fft32(dout, din, fftc, scratch, log2N);
  // do something with dout
  ...
}
```

30.7.4. mips_fft32_setup – Function Deprecated

Description

Calculates the twiddle factors need to compute an FFT of size *N*. The twiddle factors are used by the *mips_fft32()* function. The number of samples to be processed is specified by the parameter *log2N: N* = 2^{log2N}.

Include

dsplib_dsp.h

Prototype

```
void
mips_fft32_setup
(
       int32c *twiddles,
       int log2N
);
```

Argument

twiddles: Output array containing N 32-bit complex twiddle factors.

log2N: Logarithm base 2 of the number of samples: N = 2^{log2N}.

Return Value

None.

Remarks

This function requires floating-point support.

Notes

This function is implemented in C.

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30.8. Video Processing Functions

30.8.1. mips_h264_iqt

Description

Combined inverse quantization and inverse transform function. The input DCT coefficients are inverse quantized by multiplying them with corresponding elements of the inverse quantization matrix. The results are transformed by a 4x4¦-element integer inverse DCT as specified in the H.264 video compression standard.

Include

dsplib_video.h

Prototype

```
void
mips_h264_iqt
(
       uint8 b[4][4],
       int16 c[4][4],
       int16 iq[4][4]
);
```

Argument

b: Output 4x4-pixel array in 8-bit unsigned integer format.

c: Input 4x4-element array of DCT coefficients in signed 16-bit integer format.

iq: Inverse quantization matrix in signed 16-bit integer format.

Return Value

None.

Remarks

The pointers *b*, *c*, and *iq* must be aligned on 4-byte boundaries.

Notes

The *mips_iqt_setup()* function can be used to initialize the *iq* array.

Example:

```
uint8 b[4][4]
int16 dct_data[4][4];
int16 iq_matrix[4][4];

// quantization parameter
int QP = 28;

// initialize the inverse quantization matrix
mips_h264_iqt_setup(iq_matrix, mips_h264_iq_coeffs, QP);

...

// load DCT data into dct_data
   ...

mips_h264_iqt(b, dct_data, iq_matrix);
```

30.8.2. mips_h264_iqt_setup

Description

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Computes the inverse quantization matrix used by the *mips_iqt()* function. The default inverse quantization coefficient array as specified by the H.264 video compression standard is provided as *mips_h264_iq_coeffs* and can be used in place of the q parameter.

Include

dsplib_video.h

Prototype

```
void
mips_h264_iqt_setup
(
       int16 iq[4][4],
       int16 q[6][4][4],
       int16 qp
);
```

Argument

iq: Output 4x4-element inverse quantization matrix in signed 16-bit integer format.

q: Input 6x4x4-element inverse quantization coefficient array in signed 16-bit integer format.

qp: Quantization parameter.

Return Value

None.

Remarks

None.

Notes

This function is implemented in C.

30.8.3. mips_h264_mc_luma

Description

This function computes 1/4-pixel motion compensation for luma blocks as specified by the H.264 video compression standard. The function performs all necessary interpolations depending on the fractional offset of the desired block as specified by the *dx* and *dy* input parameters. Note, however, that there is no special handling of cases that cross the picture edge. It is expected that the image will be enlarged by four pixels in each direction and the pixels along the edges of the image will be replicated to the expanded borders.

Include

dsplib_video.h

Prototype

```
void
mips_h264_mc_luma
(
       uint8 b[4][4],
       uint8 *src,
       int ystride,
       int dx,
       int dy
);
```

Argument

b: Output 4x4-pixel array in 8-bit unsigned integer format.

src: Pointer to the top-left pixel of the source image block.

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ystride: Vertical stride, i.e., distance in bytes between corresponding pixels on adjacent rows.

dx, *dy*: Fractional pixel offsets multiplied by four, e.g., *dx = 1* specifies a 1/4-pixel offset.

Return Value

None.

Remarks:

The offsets *dx* and *dy* must have values between 0 and 3 inclusive.

Example

```
uint8 b[4][4];
uint8 luma[HEIGHT][WIDTH];

int ystride = WIDTH;

...

// obtain 1/4-pixel coordinates of desired block
int x4 = ...;
int y4 = ...;

// compute the integer and fractional parts
int x = x4 >> 2;
int y = y4 >> 2;
int dx4 = x4 & 0x03;
int dy4 = y4 & 0x03;

mips_h264_mc_luma(b, &luma[y][x], ystride, dx4, dy4);
```

30.8.4. MIPS Technologies Inc.'s DSP Library Notices:

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31. PIC32 Debug-Support Library

31.1. Overview

This library supports both the Application Input/Output debugging feature and the PIC32 Starter Kit Debug I/O feature.

31.1.1. Application Input/Output with printf() and scanf()

Many PIC32 devices support the APPIN/APPOUT debugging feature. This PIC32 feature allows the PIC32 application to write text or data to an MPLAB IDE window, invoked from the Tools menu, without halting the target device. Similarly, you may use the display window to send text or data back to the target PIC32 device. This feature requires an MPLAB REAL ICE emulator or MPLAB ICD 4 debugger.

31.1.2. Starter Kit Debug Print Mechanism with DBPRINTF() and DBSCANF()

A similar target input/output feature is available for the PIC32 Starter Kit (DM320001) featuring the PIC32MX360F512L MCU and the PIC32 USB Starter Board (DM320003) featuring the PIC32MX460F512L MCU.

The print output functionality is routed to the Output window on the MPLAB PIC32MX tab of the interface window.

For input using the Starter Kit, MPLAB IDE uses a TargetIN window. To send text to the target, type your text into the *Enter Information to be Sent to Target* box and click **Send**.

31.2. Configuring Debug Input/Output for the Target And Tool

The debug-support library, for both the APPIN/APPOUT mechanism and the Starter Kit mechanism, works by providing alternate I/O helper functions: `_mon_write ()`, `_mon_putc ()`, and `_mon_getc()` . These alternate functions use the APPIN/APPOUT or Starter Kit mechanism as requested in the project. These debug-support function implementations override the default helper I/O function implementations.

You can choose which implementation to use by defining a preprocessor symbol. To choose the APPIN/APPOUT implementation, pass the `-mappio-debug` option to `pic32-gcc.exe`. To choose the PIC32 Starter Kit implementation, pass `-DPIC32_STARTER_KIT` to the compiler shell. Also use `#include <p32xxxx.h>` to include the generic header file in your source code.

With one of the above options passed to the compiler and the `sys/appio.h` include file added to your source code, the debugging-support library provides alternate I/O helper functions to the linker. These alternate I/O helper functions redirect `stdin` and `stdout` to the appropriate debugging mechanism. Standard I/O functions now use the selected mechanism.

31.3. PIC32 Debugging Support Header

The `<sys/appio.h>` header file contains conditional-compilation directives that cause the compiler to pull in the correct aliased functions. In addition, it provides macros that simplify enabling and disabling the debugging feature.

31.3.1. DBINIT()

Description

Selects the appropriate mechanism (APPIN/APPOUT or Starter Kit) and initializes buffering as appropriate. When the `-mappio-debug` option is passed to the compiler, the `init` function initializes the debug library for APPIN/APPOUT. When the `-DPIC32_STARTER_KIT` option is passed to the compiler, the `init` function initializes the debug library for the PIC32 Starter Kit.

The APPIN/APPOUT mechanism disables `stdin`/`stdout` buffering while the PIC32 Starter Kit mechanism uses default line buffering.

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Include

```
<sys/appio.h>
```

Remarks

Behaves as `((void)0)` when APPIO debugging or Starter Kit I/O debugging is not enabled.

31.3.2. DBPRINTF()

Description

Calls `printf()` but is enabled only with the `-mappio-debug` or `-DPIC32_STARTER_KIT` option. When one of these options is not specified on the compiler command line, `DBPRINTF()` behaves as `((void)0)` and `printf` is not called.

Include

```
<sys/appio.h>
```

Remarks

Behaves as `((void)0)` when APPIO debugging or Starter Kit I/O debugging is not enabled via the `-mappio-debug` or `-DPIC32_STARTER_KIT` option. Use this macro to insert messages that should print only when debugging.

31.3.3. DBSCANF()

Description

Calls `scanf()`. Available for only the APPIN/APPOUT mechanism, not for the PIC32 Starter Kit mechanism.

Include

```
<sys/appio.h>
```

Remarks

Behaves as `((void)0)` when APPIN/APPOUT debugging is not enabled via the `-mappio-debug` or `-DPIC32_STARTER_KIT` option. Use this macro to read formatted input that should read only when debugging. PIC32 Starter Kit users should consider `DBGETS` instead.

31.3.4. DBGETC(canblock)

Description

Get a single `char` from the input mechanism.

Include

```
<sys/appio.h>
```

Remarks

Behaves as `((void)0)` when APPIN/APPOUT debugging or Starter Kit I/O debugging is not enabled via the `-mappio-debug` or `-DPIC32_STARTER_KIT` option.

31.3.5. DBGETWORD(int canblock)

Description

Read a 32-bit word from the APPIN mechanism. Available only for the APPIN/APPOUT mechanism, not for the PIC32 Starter Kit mechanism.

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Include

```
<sys/appio.h>
```

Remarks

Behaves as `((void)0)` when APPIN/APPOUT debugging is not enabled via the `-mappio-debug` or `-DPIC32_STARTER_KIT` option.

31.3.6. DBPUTC(char c)

Description

Writes a single `char` to the output mechanism

Include

```
<sys/appio.h>
```

Remarks

Behaves as `((void)0)` when APPIN/APPOUT debugging or Starter Kit I/O debugging is not enabled via the `-mappio-debug` or `-DPIC32_STARTER_KIT` option.

31.3.7. DBPUTWORD(int w)

Description

Writes a 32-bit integer word to the APPOUT mechanism. Available only for the APPIN/APPOUT mechanism, not for the PIC32 Starter Kit mechanism.

Include

`<sys/appio.h>`

Remarks

Behaves as `((void)0)` when APPIN/APPOUT is not enabled via the `-mappio-debug` or `-DPIC32_STARTER_KIT` option.

Example Code

```
#include <p32xxxx.h>

int main (void)

{

    int num;

    char buf[256] ={0};

    DBINIT();


    while(1)

    {

      DBPRINTF ("Hello there!\n");

      DBPRINTF ("Enter a string\n");

#if defined(__APPIO_DEBUG)

      DBSCANF ("%s", &buf[0]);

#elif defined(PIC32_STARTER_KIT)

      DBGETS  (&buf[0],128);
```


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```
#endif
      DBPRINTF ("Entered \"%s\"\n\n", &buf[0]);


      printf ("Prints to UART2 by default or APPOUT when enabled\n");
    }
  return 0;
}
```


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32. DSP Wrapper Functions

32.1. Overview

The PIC32 DSP wrapper functions assist programmers who are porting existing 16-bit application software using dsPIC® DSP library functions to PIC32. The wrapper functions internally call the DSP library functions provided by MIPS Technologies. The wrapper functions are available for some of the functions supported by dsPIC DSP library.

Note: The DSP libraries from MIPS Technologies support a variety of signal processing functions that have applicability in speech compression, echo cancellation, noise cancellation, channel equalization, audio decoding, and many other DSP and media applications. It is always advisable for the new users to use MIPS Technologies DSP libraries.

32.2. PIC32 DSP Wrapper Functions List

These functions are supported by the DSP wrapper functions for PIC32 MCUs:

- VectorAdd16
- VectorAdd32
- VectorDotProduct16
- VectorDotProduct32
- VectorMultiply16
- VectorMultiply32
- VectorScale16
- VectorScale32
- VectorSubtract16
- VectorSubtract32
- VectorPower16
- VectorPower32
- FIR
- FFTComplex16
- TwidFactorInit16
- FFTComplex32
- TwidFactorInit32

32.3. Differences Between Wrapper Functions and dsPIC® DSP Library

The PIC32 DSP wrapper function names, input parameters and return parameters use the sames as their counterparts in the dsPIC DSP library; however, these are some functional differences:

The number of coefficients in `filter` (`filter->numCoeffs`) must be larger than or equal to 4 and multiple of 4.

Table 32-1. Differences in Wrapper Functions

PIC32 DSP Wrapper Function Name	Differences with Corresponding Function of dsPIC® DSP Library	General Comments Regarding PIC32 DSP Library

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`FIR (int numSamps, short int* dstSamps, short int* srcSamps, FIRStruct* filter)`	Some of the parameters of the structure `FIRStruct` are not necessary for PIC32 library function. Hence, it is not necessary to initialize these parameters before the FIR function is called. These parameters are namely: `filter->coeffsEnd`, `filter -> coeffsPage`, `filter->delay End`, `filter->delay`	Number of coefficients in filter (`filter->numCoeffs`) must be larger than or equal to 4 and multiple of 4.
`TwidFactorInit16 (int log2N, fractcomplex16* twidFactors, int conjFlag)` `TwidFactorInit32 (int log2N, fractcomplex32* twidFactors, int conjFlag)`	There is a provision in the `TwidFactorInit` function of dsPIC library, either to generate or not generate a complex conjugates of twiddles. It is controlled by flag `conjFlag`. There is no such facility in the PIC32 DSP library. Both `TwidFactorInit16` and `TwidFactorInit32` in PIC32 do not generate a complex conjugate of twiddles. However, the parameter is kept in the function prototype of `TwidFactorInit` of PIC32 to make it compatible with dsPIC.	

Notes:

1. PIC32 supports both 16-bit and 32-bit vector math operations.
2. The current version of PIC32 DSP wrapper functions does not support floating-point calculations.
3. For all the vector math operations, the number of samples must be larger than or equal to 4 or multiple of 4.
4. log2N must be larger than or equal to 3 for function `FFTComplex16` and `FFTComplex32`.
5. All the source and destination pointers used for math operations must be aligned on 4-byte boundaries.
6. The include file for these DSP wrapper functions is `<mchp_dsp_wrapper.h>`.

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33. Document Revision History

Revision A (August 2018)

- Initial revision of the document.

Revision B (April 2020)

- The document was re-formatted throughout, including paragraph numbering and minor editing changes.
- Added new topic How Do I Stop My Project's Checksum From Changing? to the How To's section.
- Corrected description of option `-fenforce-eh-specs` in Table 4-7.
- Revised Command-line Driver section extensively.
- Updated Example 9-6 and Example 9-7 in Using an Application-Defined Memory Region.
- Added examples for `keep` and `noload` in the Function Attributes and Specifiers.
- Adding more information to Jump to NMI Handler (_nmi_handler) if an NMI Occurred.

Revision C (May 2023)

- Updated the stated size and information relating to the `double` type, which is now 64 bits wide.
- Corrected examples of using the `__pack` specifier.
- Updated information on the compiler option controls available in the MPLAB X IDE.
- Provided dedicated sections on all compiler options in addition to a summary table.
- Added new section on the compiler's code coverage feature.
- Added a new section on the stack and the stack guidance feature.
- Added `-f[no-]common` option description, which controls the placement of global variables defined without an initializer.
- Added `-Warray-bounds` option description, which can warn on out-of-bounds array indices and pointer offsets.
- Added `-Wmultistatement-macros` option description, which warns on unsafe macro expansion.
- Added `-Wsizeof-pointer-div` option description, which warns on suspicious divisions involving pointers.
- Indicated that the `-foptimize-register-move` option no longer has any effect.
- Added information on the `iar` argument to the `-mext` option.
- Added information on the `used` variable attribute.
- Added information on the `externally_visible` function attribute and variable attribute.
- Expanded information on the `naked` function attribute.
- Updated and expanded the sections relating to variables in program memory, reflecting changes in the compiler.
- Expanded information on fixed-point types and arithmetic.
- Expanded information on interrupt context switching.
- Updated information on the runtime startup code, including information on the data initialization template.
- Added information on smart IO library features.
- Expanded information on optimizations performed.
- Added section on preprocessor arithmetic.

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- Added information on the `default_function_attributes`, `default_variable_attributes`, `message`, `GCC optimize`, `pack`, and `weak` pragmas.
- Removed reference to the `__PIC__` and `__pic__` position independent code macros, which are no longer supported.
- Indicated in the default linker script information that selecting an alternate DFP will affect the script used.
- Added information on `__builtin_mfc0` and `__builtin_mtc0` built-in functions.
- Corrected information relating to the return value for the `__builtin_bcc0`, `__builtin_bsc0`, and `__builtin_bcsc0` built-in functions.

Revision D (September 2023)

- Merged the MIPS-related library content in the *32-Bit Language Tools Libraries* document into this guide.
- Updated references to the C++ standard to reflect that the ISO/IEC 14882:2014 C++ program language is now supported.
- Renamed references to the MPLAB XC16 compiler to be MPLAB XC-DSC to reflect the change in product name.
- Defined the compiler's implementation-defined behavior for the C++14 standard in a new section.
- Clarified information in the runtime startup section.
- Updated Common C Interface chapter to reflect recent changes in MPLAB XC compilers.
- Removed reference to MPLAB XC8 in the *Embedded Compiler Compatibility Mode* chapter, as this compiler no longer supports this mode.

Revision E (June 2024)

- Added new How To explaining how the stack usage for each function in a module can be displayed
- Updated compiler options used with the **Linktime Optimizations** setting in **XC32 Global options** tab of the MPLAB X IDE **Project Properties**
- Added option present in the **xc32-ar (Library Archive)** tab of the MPLAB X IDE **Project Properties**
- Added a diagram indicating the internal compiler applications
- Updated information relating to runtime startup files
- Added the following option descriptions to the guide:

`-mmalloc-variant`	`-mips16e`	`--version`
`-mlibc-variant`	`-std`	`-Wformat-smart-io`
`-dA`	`-fdiagnostics-show-caret`	`-fframe-base-loclist`
`-mno-info-linker`	`-ffat-lto-objects`	`-finline-small-functions`
`-flto-partition`	`-fpeel-loops`	`-ftracer`
`-fuse-linker-plugin`	`-T`	

- Corrected typo in the name of what should have been the `--dint-compression` option and specified this with the `-Wl,` prefix, since it is a linker option
- Updated the Dynamic Memory Allocation section to include the new allocation schemes
- Updated several items in the Common C Interface section to improve readability and include the XC-DSC compiler
- Expanded the description of the `__builtin_disable_interrupts` and `__builtin_enable_interrupts` Built-in Functions

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Revision F (June 2025)

- Modified compiler command-line examples to now use the `-mdfp` option
- Update dreferenced compiler installation paths from `pic32mx` to `pic32m`
- Updated the paths where the runtime startup code files can be found after extraction from the shipped archive file
- Indicated that improved object file compatibility might mean that some Microchip-specific features may not work with third party tools_p
- Added more information to the `-mdfp` option regarding the use of DFPs
- Indicated in the descriptions of the `-o` and `-save-temps` options that they additionally control the name and location of aux and dump files
- Added new options: `-Warray-compare`, `-Warray-parameter`, `-Wenum-int-mismatch`, `-Wmismatched-dealloc`, `-Wmismatched-new-delete`, `-Wself-move`, `-Wsizeof-array-div`, `-Wvla-parameter`, `-Wzero-length-bounds`, `-Wabsolute-value`, `-Waddress-of-packed-member`, `-Wbidi-chars`, `-Wc++11-extensions`, `-Wc++14-extensions`, `-Wc++17-extensions`, `-Wc++20-extensions`, `-Wc++23-extensions`, `-Wctad-maybe-unsupported`, `-Wdangling-reference`, `-Wdeprecated-enum-enum-conversion`, `-Wdeprecated-enum-float-conversion`, `-Wmissing-requires`, `-Wrange-loop-construct`, `-Wstring-compare`, `-Wstringop-overread`, `-Wvexing-parse`, and `-Wxor-used-as-pow`
- Adjusted the default setting for the feature controlled by `-fcommon`, which has recently changed in the compiler
- Removed the section for `-aux-info`, as this option is not fully supported
- Corrected information in the `-D` and `-U` preprocessor macro option sections relating to when this option is processed
- Corrected the name give to sections used to hold objects or functions that use the `address` attribute
- Added description of the `-msemihost` option
- Added description of the `-finline` option
- Added description of the `-ftree-vrp` option
- Added description of the `-nostdlib++` option
- Clarified that objects and library archives built with LTO enabled are platform dependent
- Corrected typo in `-fcall-used-`*`reg`* option description
- Removed floating-point macro definitions that are now documented in the *Microchip Unified Standard Library Reference Guide*
- Removed information on the `default_function_attributes` and `default_variable_attributes`, which had been incorrectly added
- Indicated that section names associated with persistent objects can vary if other attributes are used with the object
- Indicated that section names associated with absolute objects and function have arbitrary names
- Added description of new `__has_builtin` operator
- Added description of new `access` attribute
- Added description of new `__builtin_has_attribute` built-in function
- Added descriptions for new `__builtin_bswap16`, `__builtin_bswap32`, and `__builtin_bswap64` built-in functions
- Provided more examples of function attributes

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- Clarified that care must be taken when using inline assembly code that defines labels
- Included `xc32-objdump` command to generate an assembly listing in the *How Do I Know What Code the Compiler Is Producing?* How To
- Clarified the difference between Free and PRO compilers in the *What's the Difference Between a Free and PRO Compiler?* How To.

Revision G (December 2025)

- Added information relating to the new Picolibc library, an alternative to MUSL, selectable using the `--mchp-stdlibc` option
- Updated the `-mreserve` option to more accurately describe its use with XC32 compilers
- Added a section for the `copy` variable and function attributes, which have been recently added to the compiler
- Added description of the `uninitialized` and variable attribute
- Added sections for the `alias` function and variable attributes
- Added sections for the `-fzero-call-used-regs` and `-ftrivial-auto-var-init` options, which are new to the compiler
- Added descriptions of the `-Wextra` option and expanded the description of the `-Werror` option
- Added descriptions of the `-Wtrivial-auto-var-init`, `-Wuninitialized`, and `-Wno-analyzer-use-of-uninitialized-value` warning options
- Added information relating to the new word-oriented data initialization feature and associated `--mchp-dinit` option
- Added descriptions of graphical controls for the compiler options available when using the MPLAB Extensions for VS Code
- Removed ye olde ASCII table

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