

IBM XL C/C++ for Linux, V13.1



# Optimization and Programming Guide

*Version 13.1*



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**Note**

Before using this information and the product it supports, read the information in “Notices” on page 127.

**First edition**

This edition applies to IBM XL C/C++ for Linux, V13.1 (Program 5765-J08; 5725-C73) and to all subsequent releases and modifications until otherwise indicated in new editions. Make sure you are using the correct edition for the level of the product.

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## About this information

This guide discusses advanced topics related to the use of the IBM® XL C/C++ for Linux, V13.1 compiler, with a particular focus on program portability and optimization. The guide provides both reference information and practical tips for getting the most out of the compiler's capabilities, through recommended programming practices and compilation procedures.

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## Who should read this information

This document is addressed to programmers building complex applications, who already have experience compiling with XL C/C++, and would like to take further advantage of the compiler's capabilities for program optimization and tuning, support for advanced programming language features, and add-on tools and utilities.

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## How to use this information

This document uses a "task-oriented" approach to present the topics, by concentrating on a specific programming or compilation problem in each section. Each topic contains extensive cross-references to the relevant sections of the reference guides in the IBM XL C/C++ for Linux, V13.1 documentation set, which provide detailed descriptions of compiler options and pragmas, and specific language extensions.

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## How this information is organized

This guide includes these topics:

- Chapter 1, "Using 32-bit and 64-bit modes," on page 1 discusses common problems that arise when porting existing 32-bit applications to 64-bit mode, and provides recommendations for avoiding these problems.
- Chapter 2, "Using XL C/C++ with Fortran," on page 5 discusses considerations for calling Fortran code from XL C/C++ programs.
- Chapter 3, "Aligning data," on page 11 discusses the different compiler options available for controlling the alignment of data in aggregates, such as structures and classes, on all platforms.
- Chapter 4, "Handling floating-point operations," on page 17 discusses options available for controlling the way floating-point operations are handled by the compiler.
- Chapter 5, "Using C++ constructors," on page 21 discusses delegating constructors that can concentrate common initializations in one constructor.
- Chapter 6, "Using C++ templates," on page 23 discusses the different options for compiling programs that include C++ templates.
- Chapter 7, "Constructing a library," on page 31 discusses how to compile and link static and shared libraries, and how to specify the initialization order of static objects in C++ programs.
- Chapter 8, "Optimizing your applications," on page 39 discusses the various options provided by the compiler for optimizing your programs, and provides recommendations for use of the different options.

- Chapter 9, “Debugging optimized code,” on page 71 discusses the potential usability problems of the optimized programs and the options that can be used to debug the optimized code.
- Chapter 10, “Coding your application to improve performance,” on page 77 discusses recommended programming practices and coding techniques for enhancing program performance and compatibility with the compiler's optimization capabilities.
- Chapter 11, “Using the high performance libraries,” on page 103 discusses two performance libraries that are shipped with XL C/C++: the Mathematical Acceleration Subsystem (MASS), which contains tuned versions of standard math library functions; and the Basic Linear Algebra Subprograms (BLAS), which contains basic functions for matrix multiplication.
- Chapter 12, “Parallelizing your programs,” on page 119 provides an overview of the different options offered by the XL C/C++ for creating multi-threaded programs, including OpenMP language constructs.

## Conventions

### Typographical conventions

The following table shows the typographical conventions used in the IBM XL C/C++ for Linux, V13.1 information.











Table 1. *Typographical conventions*

Typeface	Indicates	Example
<b>bold</b>	Lowercase commands, executable names, compiler options, and directives.	The compiler provides basic invocation commands, <code>xlc</code> and <code>xlc</code> ( <code>xlc++</code> ), along with several other compiler invocation commands to support various C/C++ language levels and compilation environments.
<i>italics</i>	Parameters or variables whose actual names or values are to be supplied by the user. Italics are also used to introduce new terms.	Make sure that you update the <i>size</i> parameter if you return more than the <i>size</i> requested.
<u>underlining</u>	The default setting of a parameter of a compiler option or directive.	<code>nomaf</code>   <u><code>maf</code></u>
monospace	Programming keywords and library functions, compiler builtins, examples of program code, command strings, or user-defined names.	To compile and optimize <code>myprogram.c</code> , enter: <code>xlc myprogram.c -O3</code> .

### Qualifying elements (icons)

Most features described in this information apply to both C and C++ languages. In descriptions of language elements where a feature is exclusive to one language, or where functionality differs between languages, this information uses icons to delineate segments of text as follows:

Table 2. Qualifying elements


Qualifier/Icon	Meaning
C only, or C only begins   C only ends	The text describes a feature that is supported in the C language only; or describes behavior that is specific to the C language.
C++ only, or C++ only begins   C++ only ends	The text describes a feature that is supported in the C++ language only; or describes behavior that is specific to the C++ language.
IBM extension, or IBM extension begins   IBM extension ends	The text describes a feature that is an IBM extension to the standard language specifications.
C11, or C11 begins   C11 ends	The text describes a feature that is introduced into standard C as part of C11.
C++11, or C++11 begins   C++11 ends	The text describes a feature that is introduced into standard C++ as part of C++11.


## Syntax diagrams


Throughout this information, diagrams illustrate XL C/C++ syntax. This section will help you to interpret and use those diagrams.



- Read the syntax diagrams from left to right, from top to bottom, following the path of the line.

The  symbol indicates the beginning of a command, directive, or statement.

The  symbol indicates that the command, directive, or statement syntax is continued on the next line.

The  symbol indicates that a command, directive, or statement is continued from the previous line.

The  symbol indicates the end of a command, directive, or statement.

Fragments, which are diagrams of syntactical units other than complete commands, directives, or statements, start with the  symbol and end with the  symbol.

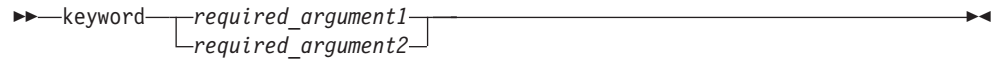
- Required items are shown on the horizontal line (the main path):



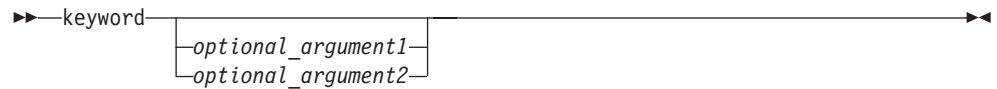
- Optional items are shown below the main path:



- If you can choose from two or more items, they are shown vertically, in a stack. If you *must* choose one of the items, one item of the stack is shown on the main path.



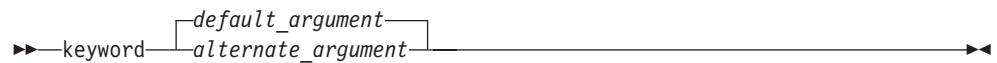
If choosing one of the items is optional, the entire stack is shown below the main path.



- An arrow returning to the left above the main line (a repeat arrow) indicates that you can make more than one choice from the stacked items or repeat an item. The separator character, if it is other than a blank, is also indicated:



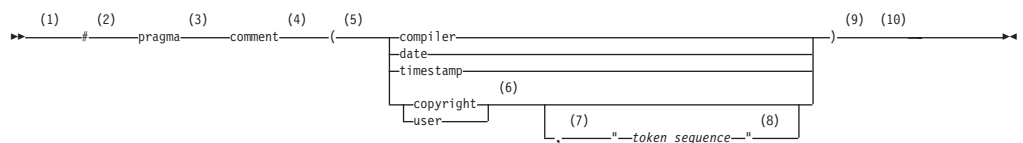
- The item that is the default is shown above the main path.



- Keywords are shown in nonitalic letters and should be entered exactly as shown.
- Variables are shown in italicized lowercase letters. They represent user-supplied names or values.
- If punctuation marks, parentheses, arithmetic operators, or other such symbols are shown, you must enter them as part of the syntax.

### Sample syntax diagram

The following syntax diagram example shows the syntax for the **#pragma comment** directive.



### Notes:

- 1 This is the start of the syntax diagram.

- 2 The symbol # must appear first.
- 3 The keyword pragma must appear following the # symbol.
- 4 The name of the pragma comment must appear following the keyword pragma.
- 5 An opening parenthesis must be present.
- 6 The comment type must be entered only as one of the types indicated: compiler, date, timestamp, copyright, or user.
- 7 A comma must appear between the comment type copyright or user, and an optional character string.
- 8 A character string must follow the comma. The character string must be enclosed in double quotation marks.
- 9 A closing parenthesis is required.
- 10 This is the end of the syntax diagram.

The following examples of the **#pragma comment** directive are syntactically correct according to the diagram shown above:

```
#pragma comment(date)
#pragma comment(user)
#pragma comment(copyright,"This text will appear in the module")
```

## Examples in this information

The examples in this information, except where otherwise noted, are coded in a simple style that does not try to conserve storage, check for errors, achieve fast performance, or demonstrate all possible methods to achieve a specific result.

The examples for installation information are labelled as either *Example* or *Basic example*. *Basic examples* are intended to document a procedure as it would be performed during a basic, or default, installation; these need little or no modification.

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## Related information

The following sections provide related information for XL C/C++:

### IBM XL C/C++ information

XL C/C++ provides product information in the following formats:

- README files

README files contain late-breaking information, including changes and corrections to the product information. README files are located by default in the XL C/C++ directory and in the root directory of the installation CD.

- Installable man pages

Man pages are provided for the compiler invocations and all command-line utilities provided with the product. Instructions for installing and accessing the man pages are provided in the *IBM XL C/C++ for Linux, V13.1 Installation Guide*.

- Information center

The fully searchable HTML-based documentation is viewable on the web at [http://www.ibm.com/support/knowledgecenter/SSXVZZ\\_13.1.0/com.ibm.compilers.linux.doc/welcome.html](http://www.ibm.com/support/knowledgecenter/SSXVZZ_13.1.0/com.ibm.compilers.linux.doc/welcome.html).

- PDF documents

PDF documents are located by default in the /opt/ibm/xlC/13.1.0/doc/LANG/pdf/ directory, where *LANG* is one of en\_US, zh\_CN, or ja\_JP. The PDF files are also available on the web at <http://www.ibm.com/support/docview.wss?uid=swg27036675>.

The following files comprise the full set of XL C/C++ product information:

*Table 3. XL C/C++ PDF files*

Document title	PDF file name	Description
<i>IBM XL C/C++ for Linux, V13.1 Installation Guide, SC27-4248-00</i>	install.pdf	Contains information for installing XL C/C++ and configuring your environment for basic compilation and program execution.
<i>Getting Started with IBM XL C/C++ for Linux, V13.1, SC27-4247-00</i>	getstart.pdf	Contains an introduction to the XL C/C++ product, with information on setting up and configuring your environment, compiling and linking programs, and troubleshooting compilation errors.
<i>IBM XL C/C++ for Linux, V13.1 Compiler Reference, SC27-4249-00</i>	compiler.pdf	Contains information about the various compiler options, pragmas, macros, environment variables, and built-in functions, including those used for parallel processing.
<i>IBM XL C/C++ for Linux, V13.1 Language Reference, SC27-4250-00</i>	langref.pdf	Contains information about the C and C++ programming languages, as supported by IBM, including language extensions for portability and conformance to nonproprietary standards.
<i>IBM XL C/C++ for Linux, V13.1 Optimization and Programming Guide, SC27-4251-00</i>	proguide.pdf	Contains information on advanced programming topics, such as application porting, interlanguage calls with Fortran code, library development, application optimization and parallelization, and the XL C/C++ high-performance libraries.

To read a PDF file, use Adobe Reader. If you do not have Adobe Reader, you can download it (subject to license terms) from the Adobe website at <http://www.adobe.com>.

More information related to XL C/C++ including IBM Redbooks® publications, white papers, tutorials, documentation errata, and other articles, is available on the web at:

<http://www.ibm.com/support/docview.wss?uid=swg27036675>

**Note:** Documentation errata is reflected only in the English version of the information center.

For more information about boosting performance, productivity, and portability, see the C/C++ café at <http://www.ibm.com/software/rational/cafe/community/ccpp>.

## Standards and specifications

XL C/C++ is designed to support the following standards and specifications. You can refer to these standards for precise definitions of some of the features found in this information.

- *Information Technology - Programming languages - C, ISO/IEC 9899:1990*, also known as C89.

- *Information Technology - Programming languages - C, ISO/IEC 9899:1999*, also known as C99.
- *Information Technology - Programming languages - C, ISO/IEC 9899:2011*, also known as C11. (Partial support)
- *Information Technology - Programming languages - C++, ISO/IEC 14882:1998*, also known as C++98.
- *Information Technology - Programming languages - C++, ISO/IEC 14882:2003*, also known as *Standard C++*.
- *Information Technology - Programming languages - C++, ISO/IEC 14882:2011*, also known as C++11. (Partial support)
- *Information Technology - Programming languages - Extensions for the programming language C to support new character data types, ISO/IEC DTR 19769*. This draft technical report has been accepted by the C standards committee, and is available at <http://www.open-std.org/JTC1/SC22/WG14/www/docs/n1040.pdf>
- *Draft Technical Report on C++ Library Extensions, ISO/IEC DTR 19768*. This draft technical report has been submitted to the C++ standards committee, and is available at <http://www.open-std.org/JTC1/SC22/WG21/docs/papers/2005/n1836.pdf>.
- *AltiVec Technology Programming Interface Manual*, Motorola Inc. This specification for vector data types, to support vector processing technology, is available at [http://www.freescale.com/files/32bit/doc/ref\\_manual/ALTIVECPIM.pdf](http://www.freescale.com/files/32bit/doc/ref_manual/ALTIVECPIM.pdf).
- *ANSI/IEEE Standard for Binary Floating-Point Arithmetic, ANSI/IEEE Std 754-1985*.
- *OpenMP Application Program Interface Version 4.0 (Partial support)*, available at <http://www.openmp.org>

## Other IBM information

- *ESSL for AIX® V5.1/ESSL for Linux on POWER® V5.1 Guide and Reference* available at the Engineering and Scientific Subroutine Library (ESSL) and Parallel ESSL web page.

## Other information

- *Using the GNU Compiler Collection* available at <http://gcc.gnu.org/onlinedocs>

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## Technical support

Additional technical support is available from the XL C/C++ Support page at [http://www.ibm.com/support/entry/portal/overview/software/rational/xl\\_c~c++\\_for\\_linux](http://www.ibm.com/support/entry/portal/overview/software/rational/xl_c~c++_for_linux). This page provides a portal with search capabilities to a large selection of Technotes and other support information.

If you cannot find what you need, you can send email to [compinfo@ca.ibm.com](mailto:compinfo@ca.ibm.com).

For the latest information about XL C/C++, visit the product information site at <http://www.ibm.com/software/products/us/en/xlcpp-linux/>.

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## How to send your comments

Your feedback is important in helping to provide accurate and high-quality information. If you have any comments about this information or any other XL C/C++ information, send your comments by email to [compinfo@ca.ibm.com](mailto:compinfo@ca.ibm.com).

Be sure to include the name of the manual, the part number of the manual, the version of XL C/C++, and, if applicable, the specific location of the text you are commenting on (for example, a page number or table number).

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## Chapter 1. Using 32-bit and 64-bit modes

You can use the XL C/C++ compiler to develop either 32-bit or 64-bit applications. To do so, specify **-q32** (the default) or **-q64**, respectively, during compilation.

However, porting existing applications from 32-bit to 64-bit mode can lead to a number of problems, mostly related to the differences in C/C++ long and pointer data type sizes and alignment between the two modes. The following table summarizes these differences.

*Table 4. Size and alignment of data types in 32-bit and 64-bit modes*

Data type	32-bit mode		64-bit mode	
	Size	Alignment	Size	Alignment
long, signed long, unsigned long	4 bytes	4-byte boundaries	8 bytes	8-byte boundaries
pointer	4 bytes	4-byte boundaries	8 bytes	8-byte boundaries
size_t (defined in the header file <stddef>)	4 bytes	4-byte boundaries	8 bytes	8-byte boundaries
ptrdiff_t (defined in the header file <stddef>)	4 bytes	4-byte boundaries	8 bytes	8-byte boundaries

The following sections discuss some of the common pitfalls implied by these differences, as well as recommended programming practices to help you avoid most of these issues:

- “Assigning long values” on page 2
- “Assigning pointers” on page 3
- “Aligning aggregate data” on page 4
- “Calling Fortran code” on page 4

When compiling in 32-bit or 64-bit mode, you can use the **-qwarn64** option to help diagnose some issues related to porting applications. In either mode, the compiler immediately issues a warning if undesirable results, such as truncation or data loss, will occur when the program is executed.

For suggestions on improving performance in 64-bit mode, see “Optimize operations in 64-bit mode”.

### Related information in the XL C/C++ Compiler Reference



-q32, -q64



-qwarn64



Compile-time and link-time environment variables

---

## Assigning long values

The limits of long type integers defined in the `limits.h` standard library header file are different in 32-bit and 64-bit modes, as shown in the following table.

Table 5. Constant limits of long integers in 32-bit and 64-bit modes

Symbolic constant	Mode	Value	Hexadecimal	Decimal
LONG_MIN (smallest signed long)	32-bit	$-(2^{31})$	0x80000000L	-2,147,483,648
	64-bit	$-(2^{63})$	0x8000000000000000L	-9,223,372,036,854,775,808
LONG_MAX (largest signed long)	32-bit	$2^{31}-1$	0x7FFFFFFFL	+2,147,483,647
	64-bit	$2^{63}-1$	0x7FFFFFFFFFFFFFFFL	+9,223,372,036,854,775,807
ULONG_MAX (largest unsigned long)	32-bit	$2^{32}-1$	0xFFFFFFFFUL	+4,294,967,295
	64-bit	$2^{64}-1$	0xFFFFFFFFFFFFFFFFUL	+18,446,744,073,709,551,615

Implications of these differences are:

- Assigning a long value to a double variable can cause loss of accuracy.
- Assigning constant values to long variables can lead to unexpected results. This issue is explored in more detail in “Assigning constant values to long variables.”
- Bit-shifting long values will produce different results, as described in “Bit-shifting long values” on page 3.
- Using `int` and `long` types interchangeably in expressions will lead to implicit conversion through promotions, demotions, assignments, and argument passing, and can result in truncation of significant digits, sign shifting, or unexpected results, without warning. These operations can impact performance.

In situations where a long value can overflow when assigned to other variables or passed to functions, you must:

- Avoid implicit type conversion by using explicit type casting to change types.
- Ensure that all functions that accept or return long types are properly prototyped.
- Ensure that long type parameters can be accepted by the functions to which they are being passed.

## Assigning constant values to long variables

Although type identification of constants follows explicit rules in C and C++, many programs use hexadecimal or unsuffixed constants as “typeless” variables and rely on a two's complement representation to truncate values that exceed the limits permitted on a 32-bit system. As these large values are likely to be extended into a 64-bit long type in 64-bit mode, unexpected results can occur, generally at boundary areas such as:

- `constant > UINT_MAX`
- `constant < INT_MIN`
- `constant > INT_MAX`

Some examples of unexpected boundary side effects are listed in the following table.

Table 6. Unexpected boundary results of constants assigned to long types

Constant assigned to long	Equivalent value	32-bit mode	64-bit mode
-2,147,483,649	INT_MIN-1	+2,147,483,647	-2,147,483,649
+2,147,483,648	INT_MAX+1	-2,147,483,648	+2,147,483,648
+4,294,967,726	UINT_MAX+1	0	+4,294,967,296
0xFFFFFFFF	UINT_MAX	-1	+4,294,967,295
0x100000000	UINT_MAX+1	0	+4,294,967,296
0xFFFFFFFFFFFFFFFF	ULONG_MAX	-1	-1

Unsuffixes constants can lead to type ambiguities that can affect other parts of your program, such as when the results of `sizeof` operations are assigned to variables. For example, in 32-bit mode, the compiler types a number like 4294967295 (`UINT_MAX`) as an unsigned long and `sizeof` returns 4 bytes. In 64-bit mode, this same number becomes a signed long and `sizeof` returns 8 bytes. Similar problems occur when passing constants directly to functions.

You can avoid these problems by using the suffixes `L` (for long constants), `UL` (for unsigned long constants), `LL` (for long long constants), or `ULL` (for unsigned long long constants) to explicitly type all constants that have the potential of affecting assignment or expression evaluation in other parts of your program. In the example cited in the preceding paragraph, suffixing the number as 4294967295U forces the compiler to always recognize the constant as an unsigned int in 32-bit or 64-bit mode. These suffixes can also be applied to hexadecimal constants.

## Bit-shifting long values

Left-bit-shifting long values produces different results in 32-bit and 64-bit modes. The examples in Table 7 show the effects of performing a bit-shift on long constants, using the following code segment:

```
long l=valueL<<1;
```

Table 7. Results of bit-shifting long values

Initial value	Symbolic constant	Value after bit shift by one bit	
		32-bit mode	64-bit mode
0x7FFFFFFFL	INT_MAX	0xFFFFFFFFE	0x00000000FFFFFFFFE
0x80000000L	INT_MIN	0x00000000	0x0000000100000000
0xFFFFFFFFL	UINT_MAX	0xFFFFFFFFE	0x00000001FFFFFFFFE

In 32-bit mode, 0xFFFFFFFFE is negative. In 64 bit mode, 0x00000000FFFFFFFFE and 0x00000001FFFFFFFFE are both positive.

## Assigning pointers

In 64-bit mode, pointers and `int` types are no longer the same size. The implications of this are:

- Exchanging pointers and `int` types causes segmentation faults.
- Passing pointers to a function expecting an `int` type results in truncation.
- Functions that return a pointer, but are not explicitly prototyped as such, return an `int` instead and truncate the resulting pointer, as illustrated in the following example.

To avoid these types of problems:

- Prototype any functions that return a pointer, where possible by using the appropriate header file.
- Be sure that the type of parameter you are passing in a function (pointer or int) call matches the type expected by the function being called.
- For applications that treat pointers as an integer type, use type long or unsigned long in either 32-bit or 64-bit mode.
- Use the **-qwarn64** option to get warning messages in the listing file about potential problems.

---

## Aligning aggregate data

Normally, structures are aligned according to the most strictly aligned member in both 32-bit and 64-bit modes. However, since long types and pointers change size and alignment in 64-bit, the alignment of a structure's strictest member can change, resulting in changes to the alignment of the structure itself.

Structures that contain pointers or long types cannot be shared between 32-bit and 64-bit applications. Unions that attempt to share long and int types, or overlay pointers onto int types can change the alignment. In general, you need to check all but the simplest structures for alignment and size dependencies.

Any aggregate data written to a file in one mode cannot be correctly read in the other mode. Data exchanged with other languages has similar problems.

For detailed information on aligning data structures, including structures that contain bit fields, see Chapter 3, "Aligning data," on page 11.

---

## Calling Fortran code

A significant number of applications use C, C++, and Fortran together, by calling each other or sharing files. It is currently easier to modify data sizes and types on the C and C++ sides than on the Fortran side of such applications. The following table lists C and C++ types and the equivalent Fortran types in the different modes.

*Table 8. Equivalent C/C++ and Fortran data types*

C/C++ type	Fortran type	
	32-bit	64-bit
signed int	INTEGER	INTEGER
signed long	INTEGER	INTEGER*8
unsigned long	LOGICAL	LOGICAL*8
pointer	INTEGER	INTEGER*8
		integer POINTER (8 bytes)

### Related information:

Chapter 2, "Using XL C/C++ with Fortran," on page 5

---

## Chapter 2. Using XL C/C++ with Fortran

With XL C/C++, you can call functions written in Fortran from your C and C++ programs. This section discusses some programming considerations for calling Fortran code in the following areas:

- "Identifiers" on page 4
- "Corresponding data types" on page 6
- "Character and aggregate data" on page 7
- "Function calls and parameter passing" on page 8
- "Pointers to functions" on page 8
- "Sample program: C/C++ calling Fortran" on page 8 provides an example of a C program which calls a Fortran subroutine.

For more information about language interoperability, see "BIND (Fortran 2003)" and "Interoperability of procedures" in the *XL Fortran Language Reference*.

**Related information:**

"Calling Fortran code" on page 4

---

### Identifiers

C++ functions callable from Fortran should be declared with extern "C" to avoid name mangling. For details, see the appropriate section about options and conventions for mixing Fortran with C/C++ code in the Fortran optimization and programming guide.

You need to follow these recommendations when writing C and C++ code to call functions written in Fortran:

- Avoid using uppercase letters in identifiers. Although XL Fortran folds external identifiers to lowercase by default, the Fortran compiler can be set to distinguish external names by case.
- Avoid using long identifier names. The maximum number of significant characters in XL Fortran identifiers is 250<sup>1</sup>.

**Note:**

1. The Fortran 90 and 95 language standards require identifiers to be no more than 31 characters; the Fortran 2003 and 2008 standards require identifiers to be no more than 63 characters.

## Corresponding data types

The following table shows the correspondence between the data types available in C/C++ and Fortran. Several data types in C have no equivalent representation in Fortran. Do not use them when programming for interlanguage calls.


Table 9. Correspondence of data types among C, C++ and Fortran


C and C++ data types	Fortran data types	
	Types	Types with kind type parameters from the ISO_C_BINDING module
bool (C++) _Bool (C)	LOGICAL(1)	LOGICAL(C_BOOL)
char	CHARACTER	CHARACTER(C_CHAR)
signed char	INTEGER*1	INTEGER(C_SIGNED_CHAR)
unsigned char	LOGICAL*1	N/A
signed short int	INTEGER*2	INTEGER(C_SHORT)
unsigned short int	LOGICAL*2	N/A
int	INTEGER*4	INTEGER(C_INT)
unsigned int	LOGICAL*4	N/A
signed long int	INTEGER*4 (with -q32) INTEGER*8 (with -q64)	INTEGER(C_LONG)
unsigned long int	LOGICAL*4 (with -q32) INTEGER*8 (with -q64)	N/A
signed long long int	INTEGER*8	INTEGER(C_LONG_LONG)
unsigned long long int	LOGICAL*8	N/A
size_t	INTEGER*4 (with -q32) INTEGER*8 (with -q64)	INTEGER(C_SIZE_T)
intptr_t	INTEGER*4 (with -q32) INTEGER*8 (with -q64)	INTEGER(C_INTPTR_T)
intmax_t	INTEGER*8	INTEGER(C_INTMAX_T)
int8_t	INTEGER*1	INTEGER(C_INT8_T)
int16_t	INTEGER*2	INTEGER(C_INT16_T)
int32_t	INTEGER*4	INTEGER(C_INT32_T)
int64_t	INTEGER*8	INTEGER(C_INT64_T)
int_least8_t	INTEGER*1	INTEGER(C_INT_LEAST8_T)
int_least16_t	INTEGER*2	INTEGER(C_INT_LEAST16_T)
int_least32_t	INTEGER*4	INTEGER(C_INT_LEAST32_T)
int_least64_t	INTEGER*8	INTEGER(C_INT_LEAST64_T)
int_fast8_t	INTEGER or INTEGER*4	INTEGER(C_INT_FAST8_T)
int_fast16_t	INTEGER*4	INTEGER(C_INT_FAST16_T)

Table 9. Correspondence of data types among C, C++ and Fortran (continued)

C and C++ data types	Fortran data types	
	Types	Types with kind type parameters from the ISO_C_BINDING module
int_fast32_t	INTEGER*4	INTEGER(C_INT_FAST32_T)
int_fast64_t	INTEGER*8	INTEGER(C_INT_FAST64_T)
float	REAL or REAL*4	REAL(C_FLOAT)
double	REAL*8 or DOUBLE PRECISION	REAL(C_DOUBLE)
long double	REAL*8 or DOUBLE PRECISION	REAL(C_LONG_DOUBLE )
float _Complex	COMPLEX*8 or COMPLEX(4)	COMPLEX(C_FLOAT_COMPLEX)
double _Complex	COMPLEX*16 or COMPLEX(8)	COMPLEX(C_DOUBLE_COMPLEX)
long double _Complex	COMPLEX*32 or COMPLEX(16)	COMPLEX(C_LONG_DOUBLE_COMPLEX)
structure or union	derived type	N/A
enumeration	INTEGER*4	N/A
char[n]	CHARACTER*n	N/A
array pointer to type, or type []	Dimensioned variable (transposed)	N/A
pointer to function	Functional parameter	N/A
structure (with -qalign=packed)	Sequence derived type	N/A

#### Related information in the XL C/C++ Compiler Reference

 -qldbl128, -qlongdouble

 -qalign

## Character and aggregate data

Most numeric data types have counterparts across C/C++ and Fortran. However, character and aggregate data types require special treatment:

- C character strings are delimited by a '\0' character. In Fortran, all character variables and expressions have a length that is determined at compile time. Whenever Fortran passes a string argument to another routine, it appends a hidden argument that provides the length of the string argument. This length argument must be explicitly declared in C. The C code should not assume a null terminator; the supplied or declared length should always be used.
- An n-element C/C++ array is indexed with 0...n-1, whereas an n-element Fortran array is typically indexed with 1...n. In addition, Fortran supports user-specified bounds while C/C++ does not.
- C stores array elements in row-major order (array elements in the same row occupy adjacent memory locations). Fortran stores array elements in ascending storage units in column-major order (array elements in the same column occupy

adjacent memory locations). Table 10 shows how a two-dimensional array declared by `A[3][2]` in C and by `A(3,2)` in Fortran, is stored:

Table 10. Storage of a two-dimensional array

Storage unit	C and C++ element name	Fortran element name
Lowest	<code>A[0][0]</code>	<code>A(1,1)</code>
	<code>A[0][1]</code>	<code>A(2,1)</code>
	<code>A[1][0]</code>	<code>A(3,1)</code>
	<code>A[1][1]</code>	<code>A(1,2)</code>
	<code>A[2][0]</code>	<code>A(2,2)</code>
Highest	<code>A[2][1]</code>	<code>A(3,2)</code>

- In general, for a multidimensional array, if you list the elements of the array in the order they are laid out in memory, a row-major array will be such that the rightmost index varies fastest, while a column-major array will be such that the leftmost index varies fastest.

---

## Function calls and parameter passing

Functions must be prototyped equivalently in both C/C++ and Fortran.

In C, by default, all function arguments are passed by value, and the called function receives a copy of the value passed to it. In Fortran, by default, arguments are passed by reference, and the called function receives the address of the value passed to it. You can use the Fortran `%VAL` built-in function or the `VALUE` attribute to pass by value. Refer to the *XL Fortran Language Reference* for more information.

For call-by-reference (as in Fortran), the address of the parameter is passed in a register. When passing parameters by reference, if you write C or C++ functions that call a program written in Fortran, all arguments must be pointers, or scalars with the address operator.

For more information about interlanguage calls to functions or routines, see "Interlanguage calls" in the *XL Fortran Optimization and Programming Guide*.

---

## Pointers to functions

A function pointer is a data type whose value is a function address. In Fortran, a dummy argument that appears in an `EXTERNAL` statement is a function pointer. Starting from the Fortran 2003 standard, Fortran variables of type `C_FUNPTR` is interoperable with function pointers. Function pointers are supported in contexts such as the target of a call statement or an actual argument of such a statement.

---

## Sample program: C/C++ calling Fortran

The following example illustrates how program units written in different languages can be combined to create a single program. It also demonstrates parameter passing between C/C++ and Fortran subroutines with different data types as arguments. The example includes the following source files:

- The main program source file: `example.c`
- The Fortran add function source file: `add.f`

### Main program source file: example.c

```
#include <stdio.h>
extern double add(int *, double [], int *, double []);

double ar1[4]={1.0, 2.0, 3.0, 4.0};
double ar2[4]={5.0, 6.0, 7.0, 8.0};

main()
{
    int x, y;
    double z;

    x = 3;
    y = 3;

    z = add(&x, ar1, &y, ar2); /* Call Fortran add routine */
    /* Note: Fortran indexes arrays 1..n */
    /* C indexes arrays 0..(n-1) */

    printf("The sum of %1.0f and %1.0f is %2.0f \n",
        ar1[x-1], ar2[y-1], z);
}
```

### Fortran add function source file: add.h

```
REAL*8 FUNCTION ADD (A, B, C, D)
REAL*8 B,D
INTEGER*4 A,C
DIMENSION B(4), D(4)
ADD = B(A) + D(C)
RETURN
END
```

Compile the main program and Fortran add function source files as follows:

```
xlc -c example.c
xlf -c add.f
```

Link the object files from compile step to create executable add:

```
xlc -o add example.o add.o
```

Execute binary:

```
./add
```

The output is as follows:

The sum of 3 and 7 is 10



---

## Chapter 3. Aligning data

XL C/C++ provides many mechanisms for specifying data alignment at the levels of individual variables, members of aggregates, entire aggregates, and entire compilation units. If you are porting applications between different platforms, or between 32-bit and 64-bit modes, you need to take into account the differences between alignment settings available in the different environments, to prevent possible data corruption and deterioration in performance. In particular, vector types have special alignment requirements which, if not followed, can produce incorrect results. For more information, see the *AltiVec Technology Programming Interface Manual*.

XL C/C++ provides alignment modes and alignment modifiers for specifying data alignment. Using alignment modes, you can set alignment defaults for all data types for a compilation unit (or subsection of a compilation unit), by specifying a predefined suboption.

Using alignment modifiers, you can set the alignment for specific variables or data types within a compilation unit, by specifying the exact number of bytes that should be used for the alignment.

“Using alignment modes” discusses the default alignment modes for all data types on the different platforms and addressing models; the suboptions and pragmas you can use to change or override the defaults; and rules for the alignment modes for simple variables, aggregates, and bit fields.

“Using alignment modifiers” on page 15 discusses the different specifiers, pragmas, and attributes you can use in your source code to override the alignment mode currently in effect, for specific variable declarations. It also provides the rules governing the precedence of alignment modes and modifiers during compilation.

**Related information in the XL C/C++ Compiler Reference**



-qaltivec

**Related external information**



AltiVec Technology Programming Interface Manual, available at [http://www.freescale.com/files/32bit/doc/ref\\_manual/ALTIVECPIM.pdf](http://www.freescale.com/files/32bit/doc/ref_manual/ALTIVECPIM.pdf)

---

### Using alignment modes

Each data type supported by XL C/C++ is aligned along byte boundaries according to platform-specific default alignment modes. On Linux, the default alignment mode is **linuxppc**.

You can change the default alignment mode, by using any of the following mechanisms:

- Set the alignment mode for all variables in a single file or multiple files during compilation

To use this approach, you specify the **-qalign** compiler option during compilation, with the **linuxppc** (default) or **bit\_packed** suboption.

- Set the alignment mode for all variables in a section of source code

To use this approach, you specify the **#pragma align** or **#pragma options align** directives in the source files, with the **linuxppc** (default), **bit\_packed**, or **reset** suboption. Each directive changes the alignment mode in effect for all variables that follow the directive until another directive is encountered, or until the end of the compilation unit.

Each of the valid alignment modes is defined in Table 11, which provides the alignment value, in bytes, for scalar variables, for all data types. Where there are differences between 32-bit and 64-bit modes, these are indicated. Also, where there are differences between the first (scalar) member of an aggregate and subsequent members of the aggregate, these are indicated.

Table 11. Alignment settings (values given in bytes)

Data type	Storage	Alignment setting	
		linuxppc	bit_packed
_Bool (C), bool (C++)	1	1	1
char, signed char, unsigned char	1	1	1
wchar_t (32-bit mode)	2	2	1
wchar_t (64-bit mode)	4	4	1
int, unsigned int	4	4	1
short int, unsigned short int	2	2	1
long int, unsigned long int (32-bit mode)	4	4	1
long int, unsigned long int (64-bit mode)	8	8	1
long long	8	8	1
float	4	4	1
double	8	8	1
long double	8	8	1
long double with <b>-qldbl128</b>	16	16	1
pointer (32-bit mode)	4	4	1
pointer (64-bit mode)	8	8	1
vector types	16	16	1

If you generate data with an application on one platform and read the data with an application on another platform, it is recommended that you use the **bit\_packed** mode, which results in equivalent data alignment on all platforms.

**Notes:**

- Vectors in a bit-packed structure may not be correctly aligned unless you take extra action to ensure their alignment.
- Vectors might suffer from alignment issues if they are accessed via heap-allocated storage or through pointer arithmetic. For example, `double __align(16) my_array[1000]` is 16-byte aligned while `my_array[1]` is not. How `my_array[i]` is aligned is determined by the value of `i`.

“Alignment of aggregates” on page 13 discusses the rules for the alignment of entire aggregates and provide examples of aggregate layouts. “Alignment of bit-fields” on page 13 discusses additional rules and considerations for the use and alignment of bit fields, and provides an example of bit-packed alignment.

**Related information in the XL C/C++ Compiler Reference**



-qalign





-qldbl128, -qlongdouble




#pragma options

## Alignment of aggregates

The data contained in Table 11 on page 12 (in “Using alignment modes” on page 11) apply to scalar variables, and variables that are members of aggregates such as structures, unions, and classes. The following rules apply to aggregate variables, namely structures, unions or classes, as a whole (in the absence of any modifiers):




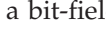
- For all alignment modes, the size of an aggregate is the smallest multiple of its alignment value that can encompass all of the members of the aggregate.
-  Empty aggregates are assigned a size of 0 bytes. As a result, two distinct variables might have the same address.
-  Empty aggregates are assigned a size of 1 byte. Note that static data members do not participate in the alignment or size of an aggregate; therefore a structure or class containing only a single static data member has a size of 1 byte.
- For all alignment modes, the alignment of an aggregate is equal to the largest alignment value of any of its members. With the exception of packed alignment modes, members whose natural alignment is smaller than that of their aggregate's alignment are padded with empty bytes.
- Aligned aggregates can be nested, and the alignment rules applicable to each nested aggregate are determined by the alignment mode that is in effect when a nested aggregate is declared.



### Notes:


-  The C++ compiler might generate extra fields for classes that contain base classes or virtual functions. Objects of these types might not conform to the usual mappings for aggregates.
- The alignment of an aggregate must be the same in all compilation units. For example, if the declaration of an aggregate is in a header file and you include that header file into two distinct compilations units, choose the same alignment mode for both compilations units.

For rules on the alignment of aggregates containing bit fields, see “Alignment of bit-fields.”

## Alignment of bit-fields

You can declare a bit-field as a `_Bool` (C),  `bool` (C++), `char`, signed `char`, unsigned `char`, `short`, unsigned `short` , `int`, unsigned `int`, `long`, unsigned `long`,  `long long`, or unsigned `long long`  data type. The alignment of a bit-field depends on its base type and the compilation mode (32-bit or 64-bit).

 The length of a bit-field cannot exceed the length of its base type. In extended mode, you can use the `sizeof` operator on a bit-field. The `sizeof` operator on a bit-field returns the size of the base type. 

 The length of a bit-field can exceed the length of its base type, but the remaining bits are used to pad the field, and do not actually store any value.



However, alignment rules for aggregates containing bit-fields are different depending on the alignment mode in effect. These rules are described below.

### Rules for Linux PowerPC® alignment

- Bit-fields are allocated from a bit-field container. The size of this container is determined by the declared type of the bit-field. For example, a char bit-field uses an 8-bit container, an int bit-field uses 32 bits, and so on. The container must be large enough to contain the bit-field, as the bit-field will not be split across containers.
- Containers are aligned in the aggregate as if they start on a natural boundary for that type of container. Bit-fields are not necessarily allocated at the start of the container.
- If a zero-length bit-field is the first member of an aggregate, it has no effect on the alignment of the aggregate and is overlapped by the next data member. If a zero-length bit-field is a non-first member of the aggregate, it pads to the next alignment boundary determined by its base declared type but does not affect the alignment of the aggregate.
- Unnamed bit-fields do not affect the alignment of the aggregate.

### Rules for bit-packed alignment

- Bit-fields have an alignment of 1 byte, and are packed with no default padding between bit-fields.
- A zero-length bit-field causes the next member to start at the next byte boundary. If the zero-length bit-field is already at a byte boundary, the next member starts at this boundary. A non-bit-field member that follows a bit-field is aligned on the next byte boundary.

### Example of bit-packed alignment

```
#pragma options align=bit_packed
struct {
    int a : 8;
    int b : 10;
    int c : 12;
    int d : 4;
    int e : 3;
    int : 0;
    int f : 1;
    char g;
} A;
```

```
pragma options align=reset
```

The size of A is 7 bytes. The alignment of A is 1 byte. The layout of A is:

Member name	Byte offset	Bit offset
a	0	0
b	1	0
c	2	2
d	3	6
e	4	2
f	5	0
g	6	0

---

## Using alignment modifiers

XL C/C++ also provides alignment modifiers, with which you can exercise even finer-grained control over alignment, at the level of declaration or definition of individual variables or aggregate members. Available modifiers are:

### **#pragma pack(...)**

#### **Valid application:**

The entire aggregate (as a whole) immediately following the directive.

**Effect:** Sets the maximum alignment of the members of the aggregate to which it applies, to a specific number of bytes. Also allows a bit-field to cross a container boundary. Used to reduce the effective alignment of the selected aggregate.

#### **Valid values:**

When **-qpack\_semantic=ibm** is in effect (the default for XL C/C++), **1, 2, 4, 8, 16, nopack, pop**, and empty parentheses. The use of empty parentheses has the same functionality as **nopack**. When **-qpack\_semantic=gnu** is in effect (the default when using **gxl**c and **gxl**c++ utilities), **[push,]1, [push,]2, [push,]4, [push,]8, [push,]16, pop**, and empty parentheses.

### **\_\_attribute\_\_((aligned(n)))**

#### **Valid application:**

As a variable attribute, it applies to a single aggregate (as a whole), namely a structure, union, or class; or to an individual member of an aggregate.<sup>1</sup>

As a type attribute, it applies to all aggregates declared of that type. If it is applied to a typedef declaration, it applies to all instances of that type.<sup>2</sup>

#### **Effect:**

Sets the minimum alignment of the specified variable (or variables), to a specific number of bytes. Typically used to increase the effective alignment of the selected variables.

#### **Valid values:**

*n* must be a positive power of 2, or NIL. NIL can be specified as either **\_\_attribute\_\_((aligned()))** or **\_\_attribute\_\_((aligned))**; this is the same as specifying the maximum system alignment (16 bytes on all UNIX platforms).

### **\_\_attribute\_\_((packed))**

#### **Valid application:**

As a variable attribute, it applies to simple variables, or individual members of an aggregate, namely a structure or class<sup>1</sup>. As a type attribute, it applies to all members of all aggregates declared of that type.

**Effect:** Sets the maximum alignment of the selected variable, or variables, to which it applies, to the smallest possible alignment value, namely one byte for a variable and one bit for a bit field.

### **\_\_align(n)**

**Effect:** Sets the minimum alignment of the variable or aggregate to which it applies to a specific number of bytes; also might effectively increase the amount of storage occupied by the variable. Used to increase the effective alignment of the selected variables.

**Valid application:**

Applies to simple static (or global) variables or to aggregates as a whole, rather than to individual members of aggregates, unless these are also aggregates.

**Valid values:**

$n$  must be a positive power of 2. XL C/C++ also allows you to specify a value greater than the system maximum.

**Notes:**

1. In a comma-separated list of variables in a declaration, if the modifier is placed at the beginning of the declaration, it applies to all the variables in the declaration. Otherwise, it applies only to the variable immediately preceding it.
2. Depending on the placement of the modifier in the declaration of a struct, it can apply to the definition of the type, and hence applies to all instances of that type; or it can apply to only a single instance of the type. For details, see *Type Attributes* in the *XL C/C++ Language Reference*.

**Related information in the *XL C/C++ Compiler Reference***

#pragma pack



-qpack\_semantic

**Related information in the *XL C/C++ Language Reference***

The aligned type attribute (IBM extension)



The packed type attribute (IBM extension)



The \_\_align type qualifier (IBM extension)



Type attributes (IBM extension)



The aligned variable attribute (IBM extension)



The packed variable attribute (IBM extension)

---

## Chapter 4. Handling floating-point operations

The following sections provide reference information, portability considerations, and suggested procedures for using compiler options to manage floating-point operations:

- “Floating-point formats”
- “Handling multiply-add operations”
- “Compiling for strict IEEE conformance” on page 18
- “Handling floating-point constant folding and rounding” on page 18
- “Handling floating-point exceptions” on page 20

---

### Floating-point formats

XL C/C++ supports the following binary floating-point formats:

- 32-bit single precision, with an approximate absolute normalized range of 0 and  $10^{-38}$  to  $10^{+38}$  and precision of about 7 decimal digits
- 64-bit double precision, with an approximate absolute normalized range of 0 and  $10^{-308}$  to  $10^{+308}$  and precision of about 16 decimal digits
- 128-bit extended precision, with slightly greater range than double-precision values, and with a precision of about 32 decimal digits

Note that the long double type may represent either double-precision or extended-precision values, depending on the setting of the **-qldbl128** compiler option. The default is 128 bits. For compatibility with older compilations, you can use **-qnoldbl128** if you need long double to be 64 bits.

**Related information in the XL C/C++ Compiler Reference**



**-qldbl128**, **-qlongdouble**

---

### Handling multiply-add operations

By default, the compiler generates a single non-IEEE 754 compatible multiply-add instruction for binary floating-point expressions such as  $a+b*c$ , partly because one instruction is faster than two. Because no rounding occurs between the multiply and add operations, this may also produce a more precise result. However, the increased precision might lead to different results from those obtained in other environments, and may cause  $x*y-x*y$  to produce a nonzero result. To avoid these issues, you can suppress the generation of multiply-add instructions by using the **-qfloat=nomaf** option.

**Related information in the XL C/C++ Compiler Reference**



**-qfloat**

---

## Compiling for strict IEEE conformance

By default, XL C/C++ follows most, but not all of the rules in the IEEE standard. If you compile with the **-qnostrict** option, which is enabled by default at optimization level **-O3** or higher, some IEEE floating-point rules are violated in ways that can improve performance but might affect program correctness. To avoid this issue, and to compile for strict compliance with the IEEE standard, use the following options:

- Use the **-qfloat=nomaf** compiler option.
- If the program changes the rounding mode at run time, use the **-qfloat=rrm** option.
- If the data or program code contains signaling NaN values (NaNs), use any of the following groups of options. (A signaling NaN is different from a quiet NaN; you must explicitly code it into the program or data or create it by using the **-qinitauto** compiler option.)
  - The **-qfloat=nans** and **-qstrict=nans** options
  - The **-qfloat=nans** and **-qstrict** options
- If you compile with **-O3**, **-O4**, or **-O5**, include the option **-qstrict** after it. You can also use the suboptions of **-qstrict** to refine the level of control for the transformations performed by the optimizers.

### Related information:

“Advanced optimization” on page 42

**Related information in the XL C/C++ Compiler Reference**



**-qfloat**



**-qstrict**



**-qinitauto**

---

## Handling floating-point constant folding and rounding

By default, the compiler replaces most operations involving constant operands with their result at compile time. This process is known as constant folding. Additional folding opportunities might occur with optimization or with the **-qnostrict** option. The result of a floating-point operation folded at compile time normally produces the same result as that obtained at execution time, except in the following cases:


- The compile-time rounding mode is different from the execution-time rounding mode. By default, both are round-to-nearest; however, if your program changes the execution-time rounding mode, to avoid differing results, do either of the following operations:
  - Change the compile-time rounding mode to match the execution-time mode, by compiling with the appropriate **-y** option. For more information and an example, see “Matching compile-time and runtime rounding modes” on page 19.
  - Suppress folding, by compiling with the **-qfloat=nofold** option.
- Expressions like  $a+b*c$  are partially or fully evaluated at compile time. The results might be different from those produced at execution time, because  $b*c$  might be rounded before being added to  $a$ , while the runtime multiply-add instruction does not use any intermediate rounding. To avoid differing results, do either of the following operations:

- Suppress the use of multiply-add instructions, by compiling with the **-qfloat=nomaf** option.
- Suppress folding, by compiling with the **-qfloat=nofold** option.
- An operation produces an infinite, NaN, or underflow to zero result. Compile-time folding prevents execution-time detection of an exception, even if you compile with the **-qflttrap** option. To avoid missing these exceptions, suppress folding with the **-qfloat=nofold** option.


**Related information:**

“Handling floating-point exceptions” on page 20

**Related information in the XL C/C++ Compiler Reference**

 **-qfloat**

 **-qstrict**

 **-qflttrap**

## Matching compile-time and runtime rounding modes

The default rounding mode used at compile time and run time is round-to-nearest, ties to even. If your program changes the rounding mode at run time, the results of a floating-point calculation might be slightly different from those that are obtained at compile time. The following example illustrates this:

```
#include <float.h>
#include <fenv.h>
#include <stdio.h>

int main ( )
{
    volatile double one = 1.f, three = 3.f; /* volatiles are not folded */
    double one_third;

    one_third = 1. / 3.; /* folded */
    printf ("1/3 with compile-time rounding = %.17f\n", one_third);

    fesetround (FE_TOWARDZERO);
    one_third = one / three; /* not folded */

    printf ("1/3 with execution-time rounding to zero = %.17f\n", one_third);

    fesetround (FE_TONEAREST);
    one_third = one / three; /* not folded */

    printf ("1/3 with execution-time rounding to nearest = %.17f\n", one_third);

    fesetround (FE_UPWARD);
    one_third = one / three; /* not folded */

    printf ("1/3 with execution-time rounding to +infinity = %.17f\n", one_third);

    fesetround (FE_DOWNWARD);
    one_third = one / three; /* not folded */

    printf ("1/3 with execution-time rounding to -infinity = %.17f\n", one_third);

    return 0;
}
```

When compiled with the default options, this code produces the following results:

```
1/3 with compile-time rounding = 0.3333333333333331
1/3 with execution-time rounding to zero = 0.3333333333333331
1/3 with execution-time rounding to nearest = 0.3333333333333331
1/3 with execution-time rounding to +infinity = 0.3333333333333337
1/3 with execution-time rounding to -infinity = 0.3333333333333331
```

Because the fourth computation changes the rounding mode to round-to-infinity, the results are slightly different from the first computation, which is performed at compile time, using round-to-nearest. If you do not use the **-qfloat=nofold** option to suppress all compile-time folding of floating-point computations, it is recommended that you use the **-y** compiler option with the appropriate suboption to match compile-time and runtime rounding modes. In the previous example, compiling with **-yp** (round-to-infinity) produces the following result for the first computation:

```
1/3 with compile-time rounding = 0.3333333333333337
```

In general, if the rounding mode is changed to +infinity or -infinity, it is recommended that you also use the **-qfloat=rrm** option.

**Related information in the XL C/C++ Compiler Reference**



**-qfloat**



**-y**

---

## Handling floating-point exceptions

By default, invalid operations such as division by zero, division by infinity, overflow, and underflow are ignored at run time. However, you can use the **-qflttrap** option or call C or operating system functions to detect these types of exceptions.

In addition, you can add suitable support code to your program to make program execution continue after an exception occurs, and to modify the results of operations causing exceptions.

Because, however, floating-point computations involving constants are usually folded at compile time, the potential exceptions that would be produced at runtime may not occur. To ensure that the **-qflttrap** option traps all runtime floating-point exceptions, consider using the **-qfloat=nofold** option to suppress all compile-time folding.

**Related information in the XL C/C++ Compiler Reference**



**-qfloat**



**-qflttrap**

---

## Chapter 5. Using C++ constructors

### C++11

Before C++11, common initialization in multiple constructors of the same class could not be concentrated in one place in a robust, maintainable manner. A basic approach can solve this problem:

#### Using delegating constructors:

With the delegating constructors feature, you can concentrate common initializations in one constructor, which can make the program more readable and maintainable. Delegating constructors help reduce the code size and collective size of the object files. For more information, see “Using delegating constructors (C++11).”

### C++11

**Related information in the XL C/C++ Compiler Reference**

 -qlanglvl

---

## Using delegating constructors (C++11)

**Note:** IBM supports selected features of C++11, known as C++0x before its ratification. IBM will continue to develop and implement the features of this standard. The implementation of the language level is based on IBM's interpretation of the standard. Until IBM's implementation of all the C++11 features is complete, including the support of a new C++11 standard library, the implementation may change from release to release. IBM makes no attempt to maintain compatibility, in source, binary, or listings and other compiler interfaces, with earlier releases of IBM's implementation of the new C++11 features.

Syntactically, *delegating constructors* and *target constructors* present the same interface as other constructors, see “Delegating constructors (C++11)” in the *XL C/C++ Language Reference*.

Consider the following points when you use the delegating constructors feature:

- Call the target constructor implementation in such a way that virtual bases, direct nonvirtual bases, and class members are initialized by the target constructor as appropriate.
- The feature has minimal impact on compile time and run time performance. However, use of default arguments with an existing constructor is recommended in place of a delegating constructor where possible. Without inlining and interprocedural analysis, run time performance may degrade because of function call overhead and increased opacity.

**Related information in the XL C/C++ Compiler Reference**

 -qlanglvl

**Related information in the XL C/C++ Language Reference**

 Delegating constructors (C++11)



---

## Chapter 6. Using C++ templates

In C++, you can use a template to declare a set of related:

- Classes (including structures)
- Functions
- Static data members of template classes

### Reducing redundant template instantiations

Within an application, you can instantiate the same template multiple times with the same arguments or with different arguments. If you use the same arguments for template instantiation in different compilation units, the repeated instantiations are redundant. These redundant instantiations increase compilation time, increase the size of the executable, and deliver no benefit.

There are several basic approaches to the problem of redundant instantiations:

#### Handling redundancy during linking

The size increase of the final executable might be small enough that it does not justify changing the way you compile your program or modify the source file. Most linkers have some form of garbage collection functionality. If you use `-qtplinst=always` or `-qtplinst=auto` without using `-qtemplateregistry` or `-qtempinc`, no compile time management of redundant instantiations is done.

#### Controlling implicit instantiation in the source code

**Concentrating implicit instantiations of a specialization:** Organize your source code so that object files contain fewer instances of each required instantiation and fewer unused instantiations. This is the least usable approach, because you must know where each template is defined, which instantiations are used, and where to declare an explicit instantiation for each instantiation.

**C++11** **Using explicit instantiation declarations:** With the explicit instantiation declarations feature, you can suppress the implicit instantiation of a template specialization or its members. This helps reduce the collective size of the object files. It might also reduce the size of the final executable if the suppressed symbol definitions are meant to be found in a shared library, or if the system linker is unable to always remove additional definitions of a symbol. For more information, see “Using explicit instantiation declarations (C++11)” on page 28 **C++11**.

**Note:** If you want to control implicit instantiation in the source code, or use explicit instantiation declarations, you can use the `-qtplinst=none` or `-qtplinst=noinlines` option to prevent accidental implicit instantiations from occurring.

#### Having the compiler store instantiation information in a registry

Use the `-qtemplateregistry` compiler option. Information about each template instantiation is stored in a template registry. If the compiler is asked to instantiate the same template again with the same arguments, it points to the instantiation in the first object file instead. This approach is described in “Using the `-qtemplateregistry` compiler option” on page 26.

### Having the compiler store instantiations in a template include directory



Use the **-qtempinc** compiler option. If the template definition and implementation files have the required structure, each template instantiation is stored in a template include directory. If the compiler is asked to instantiate the same template again with the same arguments, it uses the stored version instead. The source file created in the template include directory is compiled during the link step recursively until all instantiations are done. This approach is described in “Using the -qtempinc compiler option.”

**Note:** Use this approach for legacy codes only.

#### Notes:

- The **-qtempinc** and **-qtemplateregistry** compiler options are mutually exclusive.
- **-qtemplateregistry** is a better approach than **-qtempinc** for the following reasons:
  - **-qtemplateregistry** provides better benefits than **-qtempinc**.
  - **-qtemplateregistry** does not require modifications to the header files.

The compiler generates code for an implicit instantiation unless one of the following conditions is true:

- You use either **-qtmplinst=none** or **-qtmplinst=noinlines**.
- You use **-qtmplinst=auto**, which is the default suboption of **-qtmplinst** with **-qnotemplateregistry**.
- You use **-qtmplinst=auto** with **-qtempinc** and the template source that is organized to use **-qtempinc**.
-  C++11 An explicit instantiation declaration for that instantiation is in the current translation unit. 

**Related information in the XL C/C++ Compiler Reference**



**-qtempinc** (C++ only)



**-qtemplateregistry** (C++ only)



**-qtmplinst** (C++ only)



**-qlanglvl**

---

## Using the -qtempinc compiler option

To use **-qtempinc**, you must structure your application as follows:

- Declare your class templates and function templates in template declaration files, with a **.h** extension.
- For each template declaration, create a template definition file. This file must have the same file name as the template declaration file and an extension of **.c** or **.t**, or the name must be specified in a **#pragma implementation** directive. For a class template, the implementation file defines the member functions and static data members. For a function template, the implementation file defines the function.
- In your source program, specify an **#include** directive for each template declaration file.
- Optionally, to ensure that your code is applicable for both **-qtempinc** and **-qnotempinc** compilations, in each template declaration file, conditionally

include the corresponding template implementation file if the `__TEMPINC__` macro is *not* defined. (This macro is automatically defined when you use the **-qtempinc** compilation option.) This produces the following results:

- Whenever you compile with **-qnotempinc**, the template implementation file is included.
- Whenever you compile with **-qtempinc**, the compiler does not include the template implementation file. Instead, the compiler looks for a file with the same name as the template implementation file and extension `.c` the first time it needs a particular instantiation. If the compiler subsequently needs the same instantiation, it uses the copy stored in the template include directory.

**Note:**

- Use the **-qtempinc** option for legacy applications only.
- Use **-qtemplateregistry** that provides more benefits than **-qtempinc**, and does not require modifications to your source files. For details, see "**-qtemplateregistry** (C++ only)" in the *XL C/C++ Compiler Reference*.

**Related information in the XL C/C++ Compiler Reference**



**-qtempinc** (C++ only)



**-qtemplateregistry** (C++ only)



**-qtmplinst** (C++ only)



**#pragma implementation** (C++ only)

## Example of using **-qtempinc**

The following example shows how the compiler manages implicit instantiation of a template when the template declaration and definition are in separate files. This example includes the following source files:

- The template declaration file: `a.h`
- The corresponding template implementation file: `a.t`
- The main program source file: `a.cpp`

### Template declaration file: `a.h`

```
struct IC {
    virtual void myfunc() = 0;
};

template <class T> struct C : public IC{
    virtual void myfunc();
};

#ifdef __TEMPINC__
#include "a.t"
#else
#pragma implementation("a.t")
#endif
```

### Template implementation file : `a.t`

This file contains the template definition of `myfunc` function, which is called from the main program.

```
template <class T> void C<T>::myfunc() {}
```

## Main program file: a.cpp

This file creates an object that requires an implicit instantiation.

```
#include "a.h"

int main() {
    IC* pIC = new C<int>();
    pIC->myfunc();
}
```

You can use the following command to compile the main program a.cpp:

```
xlc -qtempinc a.cpp
```

### Notes:

- If **-qnotempinc** is specified, the template implementation file is included; otherwise, if **-qtempinc** is specified, the `#pragma implementation` directive instructs the compiler path to the template implementation file.
- Compiler searches for a.c as the template implementation file by default, if the `#pragma implementation` directive is not specified.

## Regenerating the template instantiation file

The compiler builds a template instantiation file in the TEMPINC directory corresponding to each template implementation file. With each compilation, the compiler can add information to the file but it never removes information from the file.

As you develop your program, you might remove template function references or reorganize your program so that the template instantiation files become obsolete. You can periodically delete the TEMPINC destination and recompile your program.

## Using -qtempinc with shared libraries

In a traditional application development environment, different applications can share both source files and compiled files. When you use templates, applications can share source files but cannot share compiled files.

If you use **-qtempinc**:

- Each application must have its own TEMPINC destination.
- You must compile all of the source files for the application, even if some of the files have already been compiled for another application.

---

## Using the -qtemplateregistry compiler option

The template registry uses a "first-come first-served" algorithm:

- When a compiler performs an implicit instantiation for the first time, it is instantiated in the compilation unit in which it occurs.
- When another compilation unit performs the same implicit instantiation, it is not instantiated. Thus, only one copy is generated for the entire program.

The instantiation information is stored in a template registry file. You must use the same template registry file for the entire program. Two programs cannot share a template registry file.

The default file name for the template registry file is `templateregistry`, but you can specify any other valid file name to override this default. When cleaning your program build environment before starting a fresh or scratch build, you must delete the registry file along with the old object files.

You can perform multiple compilations in parallel using the same template registry file with minimal impact on compile time.

When you recompile your program, the information in the template registry file is also used to determine whether a recompilation of a source file might introduce link errors because of missing template instantiations. If the following conditions are true, the compiler will schedule the recompilation of one or more source files when you recompile a source file:

- The source file instantiated a template that other source files instantiated.
- The source file was chosen by the template registry to actually instantiate the template.
- The source file no longer instantiates the template.

When the preceding conditions are all true, the compiler chooses another source file to instantiate the template in. That file is scheduled for recompilation during the link step. If you happen to recompile a source file that is scheduled to be recompiled during the link step, the scheduled recompilation is cancelled.

You can use **-qnotemplaterecompile** to disable the scheduled recompilation during the link step. For details, see "`-qtemplatercompile (C++ only)`" in the *XL C/C++ Compiler Reference*.

**Related information in the XL C/C++ Compiler Reference**



`-qtempinc` (C++ only)



`-qtemplatercompile` (C++ only)



`-qtemplateregistry` (C++ only)

## Recompiling related compilation units

If two compilation units, A and B, reference the same instantiation, the **-qtemplateregistry** compiler option has the following effect:

- If you compile A first, the object file for A contains the code for the instantiation.
- When you later compile B, the object file for B does not contain the code for the instantiation because object A already does.
- If you later change A so that it no longer references this instantiation, the reference in object B would produce an unresolved symbol error. When you recompile A, the compiler detects this problem and handles it as follows:
  - If the **-qtemplatercompile** compiler option is in effect, the compiler automatically recompiles B during the link step, using the same compiler options that were specified for A. (Note, however, that if you use separate compilation and linkage steps, you need to include the compilation options in the link step to ensure the correct compilation of B.)
  - If the **-qnotemplatercompile** compiler option is in effect, the compiler issues a warning and you must manually recompile B.

**Related information in the XL C/C++ Compiler Reference**



`-qtemplateregistry` (C++ only)

 -qtemplaterecompile (C++ only)

## Switching from -qtempinc to -qtemplateregistry

Because the **-qtemplateregistry** compiler option does not impose any restrictions on the file structure of your application, it has less administrative overhead than **-qtempinc**. You can make the switch as follows:

- If your application compiles successfully with both **-qtempinc** and **-qnotempinc**, you do not need to make any changes.
- If your application compiles successfully with **-qtempinc** but not with **-qnotempinc**, you must change it so that it will compile successfully with **-qnotempinc**. In each template definition file, conditionally include the corresponding template implementation file if the `__TEMPINC__` macro is not defined. This is illustrated in “Example of using -qtempinc” on page 25.




---

## Using explicit instantiation declarations (C++11)

**Note:** IBM supports selected features of C++11, known as C++0x before its ratification. IBM will continue to develop and implement the features of this standard. The implementation of the language level is based on IBM's interpretation of the standard. Until IBM's implementation of all the C++11 features is complete, including the support of a new C++11 standard library, the implementation may change from release to release. IBM makes no attempt to maintain compatibility, in source, binary, or listings and other compiler interfaces, with earlier releases of IBM's implementation of the new C++11 features.

Syntactically, an *explicit instantiation declaration* is an *explicit instantiation definition* preceded by the extern keyword, see “Explicit instantiation (C++ only)” in the *XL C/C++ Language Reference*.

Consider the following points when you use the explicit instantiation declarations feature:

-  An explicit instantiation declaration of a class template specialization does not cause implicit instantiation of said specialization. 
-  In a translation unit, if a user-defined inline function is subject to an explicit instantiation declaration and not subject to an explicit instantiation definition, no out-of-line copy of the function is generated in that translation unit no matter whether the compiler option **-qkeepinlines** is specified or not.

**Note:** This rule does not limit the behavior for functions that are implicitly generated by the compiler. Implicitly declared special members such as the default constructor, copy constructor, destructor and copy assignment operator are inline and the compiler might instantiate them. In particular, out-of-line copies might be generated.



- A degradation of the amount of inlining achieved on functions that are not inline and are subject to explicit instantiation declarations might occur.
- When a non-pure virtual member function is subject to an explicit instantiation declaration, either directly or through its class, the virtual member function must be subject to an explicit instantiation definition somewhere in the entire program. Otherwise, an unresolved symbol error might result at link time.
- When implicit instantiation of a class template specialization is allowed, the user program must be written as if the implicit instantiation of all virtual member

functions of that class specialization occurs. Otherwise, an unresolved symbol error for a virtual member function might result at link time.

- When implicit instantiation of a class template specialization is allowed and the specialization is subject to an explicit instantiation declaration, the class template specialization must be subject to an explicit instantiation definition somewhere in the user program. Otherwise, an unresolved symbol error might result at link time.

**Related information in the *XL C/C++ Compiler Reference***



-qtempinc (C++ only)



#pragma implementation (C++ only)



-qlanglvl

**Related information in the *XL C/C++ Language Reference***



Explicit instantiation (C++ only)



---

## Chapter 7. Constructing a library

You can include static and shared libraries in your C and C++ applications.

“Compiling and linking a library” describes how to compile your source files into object files for inclusion in a library, how to link a library into the main program, and how to link one library into another.

“Initializing static objects in libraries (C++)” on page 32 describes how to use priorities to control the order of initialization of objects across multiple files in a C++ application.

---

### Compiling and linking a library

This section describes how to compile your source files into object files for inclusion in a library, how to link a library into the main program, and how to link one library into another.

#### Related information:

Dynamic and static linking

### Compiling a static library

To compile a static library:

1. Compile each source file into an object file, with no linking. For example:  

```
xlc -c test.c example.c
```
2. Use the `ar` command to add the generated object files to an archive library file. For example:  

```
ar -rv libex.a test.o example.o
```

### Compiling a shared library

To compile a shared library:

1. Compile your source files into an object file, with no linking. Note that in the case of compiling a shared library, the **-qp** compiler option is also used. For example:  

```
xlc -qp -c foo.c
```
2. Use the **-qmkshrobj** compiler option to create a shared object from the generated object files. For example:  

```
xlc -qmkshrobj -o libfoo.so foo.o
```

**Related information in the XL C/C++ Compiler Reference**

 **-qp**

 **-qmkshrobj**

### Linking a library to an application

You can use the same command string to link a static or shared library to your main program. For example:

```
xlc -o myprogram main.c -Ldirectory [-Rdirectory] -ltest
```

where *directory* is the path to the directory containing the library `libtest.a`.

By using the **-l** option, you instruct the linker to search in the directory specified via the **-L** option (and, for a shared library, the **-R** option) for `libtest.so`; if it is not found, the linker searches for `libtest.a`. For additional linkage options, including options that modify the default behavior, see the operating system `ld` documentation .

**Related information in the XL C/C++ Compiler Reference**




 **-l**  
 **-L**  
 **-R**

## Linking a shared library to another shared library

Just as you link modules into an application, you can create dependencies between shared libraries by linking them together. For example:

```
xlc -qmkshrobj -o mylib.so myfile.o -ldirectory -Rdirectory -ltest
```

**Related information in the XL C/C++ Compiler Reference**

 **-qmkshrobj**  
 **-R**  
 **-L**

---

## Initializing static objects in libraries (C++)

The C++ language definition specifies that, before the `main` function in a C++ program is executed, all non-local objects with constructors, from all the files included in the program must be properly constructed. Although the language definition specifies the order of initialization for these objects within a file (which follows the order in which they are declared), it does not specify the order of initialization for these objects across files and libraries. You might want to specify the initialization order of static objects declared in various files and libraries in your program.

To specify an initialization order for objects, you assign relative priority numbers to objects. The mechanisms by which you can specify priorities for entire files or objects within files are discussed in “Assigning priorities to objects.” The mechanisms by which you can control the initialization order of objects across modules are discussed in “Order of object initialization across libraries” on page 34.

**Related information:**

“Assigning priorities to objects”

“Order of object initialization across libraries” on page 34

## Assigning priorities to objects

You can assign a priority number to objects and files within a single library, and the objects will be initialized at run time according to the order of priority. However, because of the differences in the way modules are loaded and objects initialized on the different platforms, the levels at which you can assign priorities vary among the different platforms, as follows:

**Set the priority level for an entire file**

To use this approach, you specify the **-qpriority** compiler option during

compilation. By default, all objects within a single file are assigned the same priority level, and are initialized in the order in which they are declared, and terminated in reverse declaration order.

#### Set the priority level for objects within a file

To use this approach, you include **#pragma priority** directives in the source files. Each **#pragma priority** directive sets the priority level for all objects that follow it, until another pragma directive is specified. Within a file, the first **#pragma priority** directive must have a higher priority number than the number specified in the **-qpriority** option (if it is used), and subsequent **#pragma priority** directives must have increasing numbers. While the relative priority of objects within a single file will remain the order in which they are declared, the pragma directives will affect the order in which objects are initialized across files. The objects are initialized according to their priority, and terminated in reverse priority order.

#### Set the priority level for individual objects

To use this approach, you use `init_priority` variable attributes in the source files. The `init_priority` attribute takes precedence over **#pragma priority** directives, and can be applied to objects in any declaration order. On Linux, the objects are initialized according to their priority and terminated in reverse priority across compilation units.

### Using priority numbers

Priority numbers can range from 101 to 65535. The smallest priority number that you can specify, 101, is initialized first. The largest priority number, 65535, is initialized last. If you do not specify a priority level, the default priority is 65535.

The examples below show how to specify the priority of objects within a single file, and across two files. “Order of object initialization across libraries” on page 34 provides detailed information on the order of initialization of objects.

#### Example of object initialization within a file

The following example shows how to specify the priority for several objects within a source file.

```
...
#pragma priority(2000) //Following objects constructed with priority 2000
...

static Base a ;

House b ;
...
#pragma priority(3000) //Following objects constructed with priority 3000
...

Barn c ;
...
#pragma priority(2500) // Error - priority number must be larger
                      // than preceding number (3000)
...
#pragma priority(4000) //Following objects constructed with priority 4000
...

Garage d ;
...
```

## Example of object initialization across multiple files

The following example describes the initialization order for objects in two files, `farm.C` and `zoo.C`. Both files are contained in the same shared module, and use the `-qpriority` compiler option and `#pragma priority` directives.

<code>farm.C -qpriority=1000</code>	<code>zoo.C -qpriority=2000</code>
<code>...</code>	<code>...</code>
<code>Dog a ;</code>	<code>Bear m ;</code>
<code>Dog b ;</code>	<code>...</code>
<code>...</code>	<code>#pragma priority(5000)</code>
<code>#pragma priority(6000)</code>	<code>...</code>
<code>Cat c ;</code>	<code>Zebra n ;</code>
<code>Cow d ;</code>	<code>Snake s ;</code>
<code>...</code>	<code>...</code>
<code>#pragma priority(7000)</code>	<code>#pragma priority(8000)</code>
<code>Mouse e ;</code>	<code>Frog f ;</code>
<code>...</code>	<code>...</code>

At run time, the objects in these files are initialized in the following order:

Sequence	Object	Priority value	Comment
1	Dog a	1000	Takes option priority (1000).
2	Dog b	1000	Follows with the same priority.
3	Bear m	2000	Takes option priority (2000).
4	Zebra n	5000	Takes pragma priority (5000).
5	Snake s	5000	Follows with same priority.
6	Cat c	6000	Next priority number.
7	Cow d	6000	Follows with same priority.
8	Mouse e	7000	Next priority number.
9	Frog f	8000	Next priority number (initialized last).

### Related information in the *XL C/C++ Compiler Reference*



`-qpriority` / `#pragma priority` (C++ only)



`-qmkshrobj`

### Related information in the *XL C/C++ Language Reference*



The `init_priority` variable attribute

## Order of object initialization across libraries

Each static library and shared library is loaded and initialized at runtime in reverse link order, once all of its dependencies have been loaded and initialized. Link order is the order in which each library was listed on the command line during linking into the main application. For example, if library A calls library B, library B is loaded before library A.

As each module is loaded, objects are initialized in order of priority, according to the rules outlined in “Assigning priorities to objects” on page 32. If objects do not have priorities assigned, or have the same priorities, object files are initialized in reverse link order — where link order is the order in which the files were given on

the command line during linking into the library — and the objects within the files are initialized according to their declaration order. Objects are terminated in reverse order of their construction.

## Example of object initialization across libraries

In this example, the following modules are used:

- `main.out`, the executable containing the main function
- `libS1` and `libS2`, two shared libraries
- `libS3` and `libS4`, two shared libraries that are dependencies of `libS1`
- `libS5` and `libS6`, two shared libraries that are dependencies of `libS2`

The source files are compiled into object files with the following command strings:

```
x1C -qpriority=101 -c fileA.C -o fileA.o
x1C -qpriority=150 -c fileB.C -o fileB.o
x1C -c fileC.C -o fileC.o
x1C -c fileD.C -o fileD.o
x1C -c fileE.C -o fileE.o
x1C -c fileF.C -o fileF.o
x1C -qpriority=300 -c fileG.C -o fileG.o
x1C -qpriority=200 -c fileH.C -o fileH.o
x1C -qpriority=500 -c fileI.C -o fileI.o
x1C -c fileJ.C -o fileJ.o
x1C -c fileK.C -o fileK.o
x1C -qpriority=600 -c fileL.C -o fileL.o
```

The dependent libraries are created with the following command strings:

```
x1C -qmkshrobj -o libS3.so fileE.o fileF.o
x1C -qmkshrobj -o libS4.so fileG.o fileH.o
x1C -qmkshrobj -o libS5.so fileI.o fileJ.o
x1C -qmkshrobj -o libS6.so fileK.o fileL.o
```

The dependent libraries are linked with their parent libraries using the following command strings:

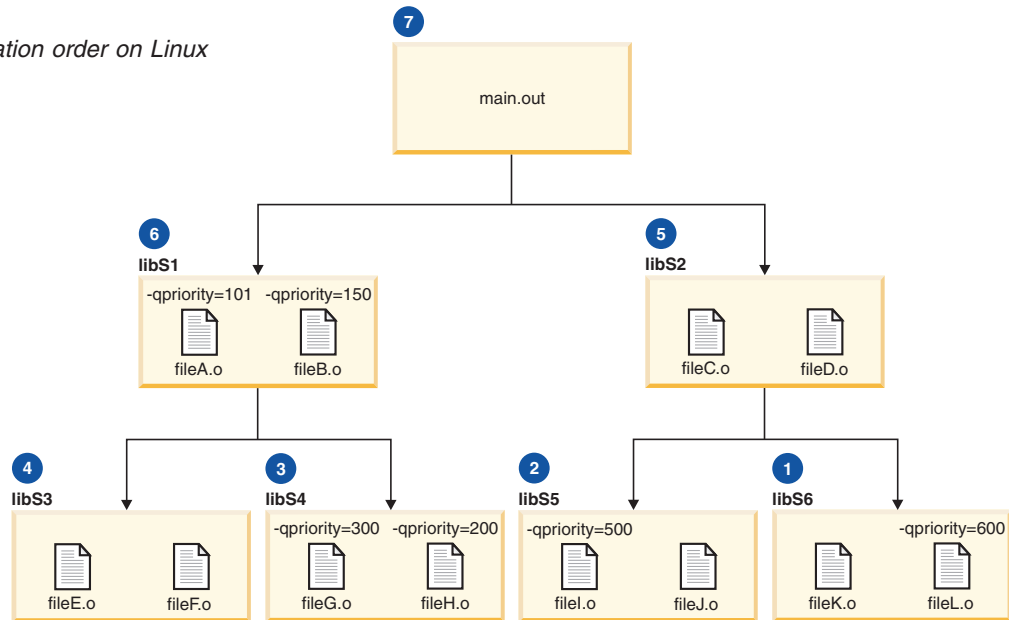
```
x1C -qmkshrobj -o libS1.so fileA.o fileB.o -L. -R. -lS3 -lS4
x1C -qmkshrobj -o libS2.so fileC.o fileD.o -L. -R. -lS5 -lS6
```

The parent libraries are linked with the main program with the following command string:

```
x1C main.C -o main.out -L. -R. -lS1 -lS2
```

The following diagram shows the initialization order of the shared libraries.

Figure 1. Object initialization order on Linux



Objects are initialized as follows:

Sequence	Object	Priority value	Comment
1	libS6	n/a	libS2 was entered last on the command line when linked with main, and so is initialized before libS1. However, libS5 and libS6 are dependencies of libS2, so they are initialized first. Since it was entered last on the command line when linked to create libS2, libS6 is initialized first. The objects in this library are initialized according to their priority.
2	fileL	600	The objects in fileL are initialized next (lowest priority number in this module).
3	fileK	65535	The objects in fileK are initialized next (next priority number in this module (default priority of 65535)).
4	libS5	n/a	libS5 was entered before libS6 on the command line when linked with libS2, so it is initialized next. The objects in this library are initialized according to their priority.
5	fileI	500	The objects in fileI are initialized next (lowest priority number in this module).
6	fileJ	65535	The objects in fileJ are initialized next (next priority number in this module (default priority of 65535)).
7	libS4	n/a	libS4 is a dependency of libS1 and was entered last on the command line when linked to create libS1, so it is initialized next. The objects in this library are initialized according to their priority.
8	fileH	200	The objects in fileH are initialized next (lowest priority number in this module).
9	fileG	300	The objects in fileG are initialized next (next priority number in this module).

Sequence	Object	Priority value	Comment
10	libS3	n/a	libS3 is a dependency of libS1 and was entered first on the command line during the linking with libS1, so it is initialized next. The objects in this library are initialized according to their priority.
11	fileF	65535	Both fileF and fileE are assigned a default priority of 65535. However, because fileF was listed last on the command line when the object files were linked into libS3, fileF is initialized first.
12	fileE	65535	Initialized next.
13	libS2	n/a	libS2 is initialized next. The objects in this library are initialized according to their priority.
14	fileD	65535	Both fileD and fileC are assigned a default priority of 65535. However, because fileD was listed last on the command line when the object files were linked into libS2, fileD is initialized first.
15	fileC	65535	Initialized next.
16	libS1		libS1 is initialized next. The objects in this library are initialized according to their priority.
17	fileA	101	The objects in fileA are initialized next (lowest priority number in this module).
18	fileB	150	The objects in fileB are initialized next (next priority number in this module).
19	main.out	n/a	Initialized last. The objects in main.out are initialized according to their priority.

#### Related information in the *XL C/C++ Compiler Reference*



-qmkshrobj



-W



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## Chapter 8. Optimizing your applications

The XL compilers enable development of high performance 32-bit and 64-bit applications by offering a comprehensive set of performance enhancing techniques that exploit the multilayered PowerPC architecture. These performance advantages depend on good programming techniques, thorough testing and debugging, followed by optimization, and tuning.

---

### Distinguishing between optimization and tuning

You can use optimization and tuning separately or in combination to increase the performance of your application. Understanding the difference between them is the first step in understanding how the different levels, settings, and techniques can increase performance.

#### Optimization

Optimization is a compiler driven process that searches for opportunities to restructure your source code and give your application better overall performance at run time, without significantly impacting development time. The XL compiler optimization suite, which you control using compiler options and directives, performs best on well-written source code that has already been through a thorough debugging and testing process. These optimization transformations can:

- Reduce the number of instructions your application executes to perform critical operations.
- Restructure your object code to make optimal use of the PowerPC architecture.
- Improve memory subsystem usage.
- Exploit the ability of the architecture to handle large amounts of shared memory parallelization.

Each basic optimization technique can result in a performance benefit, although not all optimizations can benefit all applications. Consult the “Steps in the optimization process” on page 40 for an overview of the common sequence of steps you can use to increase the performance of your application.

#### Tuning

While optimization applies general transformations designed to improve the performance of any application in any supported environment, tuning offers you opportunities to adjust specific characteristics or target execution environments of your application to improve its performance. Even at low optimization levels, tuning for your application and target architecture can have a positive impact on performance. With proper tuning the compiler can:

- Select more efficient machine instructions.
- Generate instruction sequences that are more relevant to your application.
- Select from more focussed optimizations to improve your code.

For instructions, see “Tuning for your system architecture” on page 46.

---

## Steps in the optimization process

As you begin the optimization process, consider that not all optimization techniques suit all applications. Trade-offs sometimes occur between an increase in compile time, a reduction in debugging capability, and the improvements that optimization can provide.

Learning about, and experimenting with different optimization techniques can help you strike the right balance for your XL compiler applications while achieving the best possible performance. Also, though it is unnecessary to hand-optimize your code, compiler-friendly programming can be extremely beneficial to the optimization process. Unusual constructs can obscure the characteristics of your application and make performance optimization difficult. Use the steps in this section as a guide for optimizing your application.

1. The Basic optimization step begins your optimization processes at levels 0 and 2.
2. The Advanced optimization step exposes your application to more intense optimizations at levels 3, 4 and 5.
3. The Using high-order loop analysis and transformations step can help you limit loop execution time.
4. The Using interprocedural analysis step can optimize your entire application at once.
5. The Using profile-directed feedback step focuses optimizations on specific characteristics of your application.
6. The Debugging optimized code step can help you identify issues and problems that can occur with optimized code.

---

## Basic optimization

The XL compiler supports several levels of optimization, with each option level building on the levels below through increasingly aggressive transformations, and consequently using more machine resources.

Ensure that your application compiles and executes properly at low optimization levels before trying more aggressive optimizations. This topic discusses two optimizations levels, listed with complementary options in the *Basic optimizations* table. The table also includes a column for compiler options that can have a performance benefit at that optimization level for some applications.

Table 12. Basic optimizations

Optimization level	Additional options implied by default	Complementary options	Other options with possible benefits
-O0	None	-qarch	None
-O2	-qmaxmem=8192	-qarch -qtune	-qmaxmem=-1 -qhot=level=0

### Optimizing at level 0

#### Benefits at level 0

- Minimal performance improvement, with minimal impact on machine resources.
- Exposes some source code problems, helping in the debugging process.

Begin your optimization process at **-O0** which the compiler already specifies by default. This level performs basic analytical optimization by removing obviously redundant code, and can result in better compile time. It also ensures your code is algorithmically correct so you can move forward to more complex optimizations. **-O0** also includes some redundant instruction elimination and constant folding. The option **-qfloat=nofold** can be used to suppress folding floating-point operations. Optimizing at this level accurately preserves all debugging information and can expose problems in existing code, such as uninitialized variables and bad casting.

Additionally, specifying **-qarch** at this level targets your application for a particular machine and can significantly improve performance by ensuring your application takes advantage of all applicable architectural benefits.

**Note:** For SMP programs, you need to add an additional option **-qsmp=noopt**.

For more information on tuning, see “Tuning for your system architecture” on page 46.

## Optimizing at level 2

### Benefits at level 2

- Eliminates redundant code
- Basic loop optimization
- Can structure code to take advantage of **-qarch** and **-qtune** settings

After successfully compiling, executing, and debugging your application using **-O0**, recompiling at **-O2** opens your application to a set of comprehensive low-level transformations that apply to subprogram or compilation unit scopes and can include some inlining. Optimizations at **-O2** are a relative balance between increasing performance while limiting the impact on compilation time and system resources. You can increase the memory available to some of the optimizations in the **-O2** portfolio by providing a larger value for the **-qmaxmem** option. Specifying **-qmaxmem=-1** allows the optimizer to use memory as needed without checking for limits but does not change the transformations the optimizer applies to your application at **-O2**.

In C, compile with **-qlibansi** unless your application defines functions with names identical to those of library functions. If you encounter problems with **-O2**, consider using **-qalias=noansi** rather than turning off optimization.

Also, ensure that pointers in your C code follow these type restrictions:

- Generic pointers can be `char*` or `void*`
- Mark all shared variables and pointers to shared variables `volatile`

### Starting to tune at O2

Choosing the right hardware architecture target or family of targets becomes even more important at **-O2** and higher. By targeting the proper hardware, the optimizer can make the best use of the hardware facilities available. If you choose a family of hardware targets, the **-qtune** option can direct the compiler to emit code consistent with the architecture choice, but executes optimally on the chosen tuning hardware target. With this option, you can compile for a general set of targets but have the code run best on a particular target.

See the “Tuning for your system architecture” on page 46 section for details on the **-qarch** and **-qtune** options.

The **-O2** option can perform a number of additional optimizations, including:

- Common subexpression elimination: Eliminates redundant instructions.
- Constant propagation: Evaluates constant expressions at compile-time.
- Dead code elimination: Eliminates instructions that a particular control flow does not reach, or that generate an unused result.
- Dead store elimination: Eliminates unnecessary variable assignments.
- Graph coloring register allocation: Globally assigns user variables to registers.
- Value numbering: Simplifies algebraic expressions, by eliminating redundant computations.
- Instruction scheduling for the target machine.
- Loop unrolling and software pipelining.
- Moving loop-invariant code out of loops.
- Simplifying control flow.
- Strength reduction and effective use of addressing modes.
- Widening, which merges adjacent load/stores and other operations.
- Pointer aliasing improvements to enhance other optimizations.

Even with **-O2** optimizations, some useful information about your source code is made available to the debugger if you specify **-g**. Using a higher **-g** level increases the information provided to the debugger, but reduces the optimization that can be done. Conversely, higher optimization levels can transform code to an extent to which debugging information is no longer accurate. Use that information with discretion.

---

## Advanced optimization

Higher optimization levels can have a tremendous impact on performance, but some trade-offs can occur in terms of code size, compile time, resource requirements, and numeric or algorithmic precision.

After applying “Basic optimization” on page 40 and successfully compiling and executing your application, you can apply more powerful optimization tools. The XL compiler optimization portfolio includes many options for directing advanced optimization, and the transformations your application undergoes are largely under your control. The discussion of each optimization level in Table 13 includes information on not only the performance benefits, and the possible trade-offs as well, but information on how you can help guide the optimizer to find the best solutions for your application.

*Table 13. Advanced optimizations*

Optimization Level	Additional options implied	Complementary options	Options with possible benefits
<b>-O3</b>	<b>-qnostrict</b> <b>-qmaxmem=-1</b> <b>-qhot=level=0</b>	<b>-qarch</b> <b>-qtune</b>	<b>-qpdf</b>

Table 13. Advanced optimizations (continued)

Optimization Level	Additional options implied	Complementary options	Options with possible benefits
<b>-O4</b>	<b>-qnostrict</b> <b>-qmaxmem=-1</b> <b>-qhot</b> <b>-qipa</b> <b>-qarch=auto</b> <b>-qtune=auto</b> <b>-qcache=auto</b>	<b>-qarch</b> <b>-qtune</b> <b>-qcache</b>	<b>-qpdf</b> <b>-qsmp=auto</b>
<b>-O5</b>	All of <b>-O4</b> <b>-qipa=level=2</b>	<b>-qarch</b> <b>-qtune</b> <b>-qcache</b>	<b>-qpdf</b> <b>-qsmp=auto</b>

When you compile programs with any of the following sets of options:

- **-qhot -qignerrno -qnostrict**
- **-qhot -O3**
- **-O4**
- **-O5**

the compiler automatically attempts to vectorize calls to system math functions by calling the equivalent vector functions in the Mathematical Acceleration Subsystem libraries (MASS), with the exceptions of functions `vdnint`, `vdint`, `vcosin`, `vscosin`, `vqdr`, `vsqdr`, `vrqdr`, `vsrqdr`, `vpopcnt4`, and `vpopcnt8`. If the compiler cannot vectorize, it automatically tries to call the equivalent MASS scalar functions. For automatic vectorization or scalarization, the compiler uses versions of the MASS functions contained in the system library `libxlopt.a`.

In addition to any of the preceding sets of options, when the **-qipa** option is in effect, if the compiler cannot vectorize, it tries to inline the MASS scalar functions before deciding to call them.

## Optimizing at level 3

### Benefits at level 3

- In-depth memory access analysis
- Better loop scheduling
- High-order loop analysis and transformations (**-qhot=level=0**)
- Inlining of small procedures within a compilation unit by default
- Eliminating implicit compile-time memory usage limits

Specifying **-O3** initiates more intense low-level transformations that remove many of the limitations present at **-O2**. For instance, the optimizer no longer checks for memory limits, by defaulting to **-qmaxmem=-1**. Additionally, optimizations encompass larger program regions and attempt more in-depth analysis. While not all applications contain opportunities for the optimizer to provide a measurable increase in performance, most applications can benefit from this type of analysis.

### Potential trade-offs at level 3

With the in-depth analysis of **-O3** comes a trade-off in terms of compilation time and memory resources. Also, since **-O3** implies **-qnostrict**, the optimizer can alter

certain floating-point semantics in your application to gain execution speed. This typically involves precision trade-offs as follows:

- Reordering of floating-point computations.
- Reordering or elimination of possible exceptions, such as division by zero or overflow.
- Using alternative calculations that might give slightly less precise results or not handle infinities or NaNs in the same way.

You can still gain most of the **-O3** benefits while preserving precise floating-point semantics by specifying **-qstrict**. Compiling with **-qstrict** is necessary if you require the same absolute precision in floating-point computational accuracy as you get with **-O0**, **-O2**, or **-qnoopt** results. The option **-qstrict=ieee** also ensures adherence to all IEEE semantics for floating-point operations. If your application is sensitive to floating-point exceptions or the order of evaluation for floating-point arithmetic, compiling with **-qstrict**, **-qstrict=exceptions**, or **-qstrict=order** helps to ensure accurate results. You should also consider the impact of the **-qstrict=precision** suboption group on floating-point computational accuracy. The precision suboption group includes the individual suboptions: **subnormals**, **operationprecision**, **association**, **reductionorder**, and **library** (described in the **-qstrict** option in the *XL C/C++ Compiler Reference*).

Without **-qstrict**, the difference in computation for any one source-level operation is very small in comparison to “Basic optimization” on page 40. Although a small difference can be compounded if the operation is in a loop structure where the difference becomes additive, most applications are not sensitive to the changes that can occur in floating-point semantics.

See “-O -qoptimize” in the *XL C/C++ Compiler Reference* for information on the **-O** level syntax.

## An intermediate step: adding **-qhot** suboptions at level 3

At **-O3**, the optimization includes minimal **-qhot** loop transformations at **level=0** to increase performance. You can further increase your performance benefit by increasing the level and therefore the aggressiveness of **-qhot**. Try specifying **-qhot** without any suboptions, or **-qhot=level=1**.

For more information on **-qhot**, see “Using high-order loop analysis and transformations” on page 48.

Conversely, if the application does not use loops processing arrays (which **-qhot** improves), you can improve compile speed significantly, usually with minimal performance loss by using **-qnohot** after **-O3**.

## Optimizing at level 4

### Benefits at level 4

- Propagation of global and argument values between compilation units
- Inlining code from one compilation unit to another
- Reorganization or elimination of global data structures
- An increase in the precision of aliasing analysis

Optimizing at **-O4** builds on **-O3** by triggering **-qipa=level=1** which performs interprocedural analysis (IPA), optimizing your entire application as a unit. This option is particularly pertinent to applications that contain a large number of frequently used routines.

To make full use of IPA optimizations, you must specify **-O4** on the compilation and link steps of your application build as interprocedural analysis occurs in stages at both compile and link time.

## Potential trade-offs at level 4

In addition to the trade-offs already mentioned for **-O3**, specifying **-qipa** can significantly increase compilation time, especially at the link step.

### The IPA process

1. At compile time optimizations occur on a file-by-file basis, as well as preparation for the link stage. IPA writes analysis information directly into the object files the compiler produces.
2. At the link stage, IPA reads the information from the object files and analyzes the entire application.
3. This analysis guides the optimizer on how to rewrite and restructure your application and apply appropriate **-O3** level optimizations.

The “Using interprocedural analysis” on page 51 section contains more information on IPA including details on IPA suboptions.

Beyond **-qipa**, **-O4** enables other optimization options:

- **-qhot**

Enables more aggressive HOT transformations to optimize loop constructs and array language.

- **-qarch=auto** and **-qtune=auto**

Optimizes your application to execute on a hardware architecture identical to your build machine. If the architecture of your build machine is incompatible with your application's execution environment, you must specify a different **-qarch** suboption after the **-O4** option. This overrides **-qarch=auto**.

- **-qcache=auto**

Optimizes your cache configuration for execution on specific hardware architecture. The **auto** suboption assumes that the cache configuration of your build machine is identical to the configuration of your execution architecture. Specifying a cache configuration can increase program performance, particularly loop operations by blocking them to process only the amount of data that can fit into the data cache at a time.

If you want to execute your application on a different machine, specify correct cache values.

## Optimizing at level 5

### Benefits at level 5

- Most aggressive optimizations available
- Makes full use of loop optimizations and IPA

As the highest optimization level, **-O5** includes all **-O4** optimizations and deepens whole program analysis by increasing the **-qipa** level to 2. Compiling with **-O5** also increases how aggressively the optimizer pursues aliasing improvements.

Additionally, if your application contains a mix of C/C++ and Fortran code that you compile using the XL compilers, you can increase performance by compiling and linking your code with the **-O5** option.

## Potential trade-offs at level 5

Compiling at **-O5** requires more compile time and machine resources than any other optimization levels, particularly if you include **-O5** on the IPA link step. Compile at **-O5** as the final phase in your optimization process after successfully compiling and executing your application at **-O4**.

---

## Tuning for your system architecture

You can instruct the compiler to generate code for optimal execution on a given microprocessor or architecture family. By selecting appropriate target machine options, you can optimize to suit the broadest possible selection of target processors, a range of processors within a given family of processor architectures, or a specific processor.


The following table lists the optimization options that affect individual aspects of the target machine. Using a predefined optimization level sets default values for these individual options.

*Table 14. Target machine options*

Option	Behavior
<b>-q32</b>	Generates code for a 32-bit (4 byte integer / 4 byte long / 4 byte pointer) addressing model (32-bit execution mode). This is the default setting.
<b>-q64</b>	Generates code for a 64-bit (4 byte integer / 8 byte long / 8 byte pointer) addressing model (64-bit execution mode).
<b>-qarch</b>	Selects a family of processor architectures for which instruction code should be generated. This option restricts the instruction set generated to a subset of that for the PowerPC architecture. The default on all Linux distributions is <code>-qarch=ppc64grsq</code> . Using <code>-O4</code> or <code>-O5</code> sets the default to <code>-qarch=auto</code> . See “Getting the most out of target machine options” on page 47 below for more information on this option.
<b>-qtune</b>	Biases optimization toward execution on a given microprocessor, without implying anything about the instruction set architecture to use as a target. See “Getting the most out of target machine options” on page 47 below for more information on this option.
<b>-qcache</b>	Defines a specific cache or memory geometry. The defaults are determined through the setting of <code>-qtune</code> . See “Getting the most out of target machine options” on page 47 below for more information on this option.

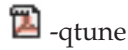
For a complete listing of valid hardware-related suboptions and combinations of suboptions, see *Acceptable -qarch/-qtune combinations* in the **-qtune** section of the *XL C/C++ Compiler Reference* and see *Specifying Compiler Options for Architecture-Specific* in the *XL C/C++ Compiler Reference*.

### Related information in the XL C/C++ Compiler Reference

 `-q32`, `-q64`

 `-qarch`

 `-qipa`



-qtune



-qcache



Specifying compiler options for architecture-specific, 32-bit or 64-bit compilation

## Getting the most out of target machine options

### Using -qarch options

You use the **-qarch** compiler option to generate instructions that are optimized for a specific machine architecture. For example, if you want to generate an object code that contains instructions optimized for POWER8™, you use **-qarch=pwr8**. If your application runs on the same machine on which you are compiling it, you can use the **-qarch=auto** option, which automatically detects the specific architecture of the compiling machine, and generates code to take advantage of instructions available only on that machine (or on a system that supports the equivalent processor architecture). Otherwise, use the **-qarch** option to specify the smallest possible family of the machines that can run your code reasonably well.

If you want to run your application on a system architecture that provides specific feature supports, you must specify a corresponding **-qarch** suboption to generate the object code for your system architecture. For example, if you want to deploy your application on a POWER7®, POWER7+™, or POWER8 machine and to fully exploit VMX vector processing and large-page support, you must specify **-qarch=pwr7** for POWER7 or POWER7+ and **-qarch=pwr8** for POWER8 on your compiling machine. Specifying **-qarch=auto** or **-qarch** does not give you the support you want. However, if you deploy your application on both POWER7 and POWER8, you must make sure that **-qarch** is set to the lowest common architecture. This way your application will only contain instructions that are common to all processors the application is deployed on. In this example, the lowest common architecture is POWER7, so you must use **-qarch=pwr7**. For details about **-qarch** and its suboptions, see **-qarch** in the *XL C/C++ Compiler Reference*. For details about the corresponding system architectures each **-qarch** suboption supports, see the Features support in processor architectures table in **-qarch**.

### Using -qtune options

You use the **-qtune** compiler option to control the scheduling of instructions that are optimized for your machine architecture. If you specify a particular architecture with **-qarch**, **-qtune** automatically selects the suboption that generates instruction sequences with the best performance for that architecture. If you specify a group of architectures with **-qarch**, compiling with **-qtune=auto** generates code that runs on all of the architectures in the specified group, but the instruction sequences are those with the best performance on the architecture of the compiling machine.

Try to specify with **-qtune** the particular architecture that the compiler should target for best performance but still allow execution of the produced object file on all architectures specified in the **-qarch** option. For information on the valid combinations of **-qarch** and **-qtune**, see *Acceptable -qarch/-qtune combinations* in the **-qtune** section of the *XL C/C++ Compiler Reference*.

If you need to create a single binary file that runs on a range of PowerPC hardware, consider using the **-qtune=balanced** option. With this option in effect, optimization decisions made by the compiler are not targeted to a specific version

of hardware. Instead, tuning decisions try to include features that are generally helpful across a broad range of hardware and avoid those optimizations that might be harmful on some hardware.

**Note:** You must verify the performance of code compiled with the **-qtune=balanced** option before distributing it.

The difference between **-qtune=balanced** and other **-qtune** suboptions including **-qtune=auto** is that, with other suboptions, the compiler generates instructions that are optimized for that specified versions of hardware architecture and might not perform well on others. With the **-qtune=balanced** option, the compiler generates instructions that perform reasonably well across a range of Power<sup>®</sup> hardware. For details, see **-qtune** in the *XL C/C++ Compiler Reference*.

## Using -qcache options

Before using the **-qcache** option, use the **-qlistopt** option to generate a listing of the current settings and verify if they are satisfactory. If you decide to specify your own **-qcache** suboptions, use **-qhot** or **-qsmp** along with it. For the full set of suboptions, option syntax, and guidelines for use, see **-qcache** in the *XL C/C++ Compiler Reference*.

**Related information in the *XL C/C++ Compiler Reference***



**-qhot**



**-qsmp**



**-qcache**



**-qlistopt**



**-qarch**



**-qtune**

---

## Using high-order loop analysis and transformations

High-order transformations are optimizations that specifically improve the performance of loops through techniques such as interchange, fusion, and unrolling.

The goals of these loop optimizations include:

- Reducing the costs of memory access through the effective use of caches and address translation look-aside buffers.
- Overlapping computation and memory access through effective utilization of the data prefetching capabilities provided by the hardware.
- Improving the utilization of microprocessor resources through reordering and balancing the usage of instructions with complementary resource requirements.
- Generating SIMD vector instructions.
- Generating calls to vector math library functions.

To enable high-order loop analysis and transformations, you use the **-qhot** option, which implies an optimization level of **-O2**. The following table lists the suboptions available for **-qhot**.

Table 15. *-qhot suboptions*

Suboption	Behavior
level=0	Instructs the compiler to perform a subset of high-order transformations that enhance performance by improving data locality. This suboption implies <b>-qhot=novector</b> and <b>-qhot=noarraypad</b> . This level is automatically enabled if you compile with <b>-O3</b> .
level=1	This is the default suboption if you specify <b>-qhot</b> with no suboptions. This level is also automatically enabled if you compile with <b>-O4</b> or <b>-O5</b> . This is equivalent to specifying <b>-qhot=vector</b> .
level=2	When used with <b>-qsmp</b> , instructs the compiler to perform the transformations of <b>-qhot=level=1</b> plus some additional transformation on nested loops. The resulting loop analysis and transformations can lead to more cache reuse and loop parallelization.
vector	When specified with <b>-qnostrict</b> and <b>-qignerrno</b> , or <b>-O3</b> or a higher optimization level, instructs the compiler to transform some loops to use the optimized versions of various math functions contained in the MASS libraries, rather than use the system versions. The optimized versions make different trade-offs with respect to accuracy and exception-handling versus performance. This suboption is enabled by default if you specify <b>-qhot</b> with no suboptions. Also, specifying <b>-qhot=vector</b> with <b>-O3</b> implies <b>-qhot=level=1</b> .
arraypad	Instructs the compiler to pad any arrays where it infers there might be a benefit and to pad by whatever amount it chooses.

#### Related information in the XL C/C++ Compiler Reference



**-qhot**



**-qstrict**



**-qignerrno**



**-qarch**



**-qsimd**

## Getting the most out of -qhot

Here are some suggestions for using **-qhot**:

- Try using **-qhot** along with **-O3** for all of your code. It is designed to have a neutral effect when no opportunities for transformation exist. However, it increases compile time and might have little benefit if the program has no loop processing vectors or arrays. In this case, using **-O3 -qnohot** might be better.
- If the runtime performance of your code can significantly benefit from automatic inlining and memory locality optimizations, try using **-O4** with **-qhot=level=0** or **-qhot=novector**.
- If you encounter unacceptably long compile time (this can happen with complex loop nests), try **-qhot=level=0** or **-qnohot**.
- If your code size is unacceptably large, try reducing the inlining level or using **-qcompact** along with **-qhot**.
- You can compile some source files with the **-qhot** option and some files without the **-qhot** option, allowing the compiler to improve only the parts of your code that need optimization.
- Use **-qreport** along with **-qsimd=auto** to generate a loop transformation listing. The listing file identifies how loops are transformed in a section marked LOOP


TRANSFORMATION SECTION. Use the listing information as feedback about how the loops in your program are being transformed. Based on this information, you may want to adjust your code so that the compiler can transform loops more effectively. For example, you can use this section of the listing to identify non-stride-one references that may prevent loop vectorization.

- Use **-qreport** along with **-qhot** or any optimization option that implies **-qhot** to generate information about nested loops in the LOOP TRANSFORMATION SECTION of the listing file. In addition, when you use **-qprefetch=assistthread** to generate prefetching assist threads, a message Assist thread for data prefetching was generated is also displayed in this section of the report. To generate a list of aggressive loop transformations and parallelizations performed on loop nests in the LOOP TRANSFORMATION SECTION of the listing file, use **-qhot=level=2** and **-qsmp** together with **-qreport**.
- If you specify **-qassert=refalign**, you assert to the compiler that all pointers inside the compilation unit only point to data that is naturally aligned with respect to the length of the pointer types. With this assertion, the compiler might generate more efficient code. This assertion is particularly useful when you target a SIMD architecture with **-qhot=level=0** or **-qhot=level=1** with the **-qsimd=auto** option.

**Related information in the XL C/C++ Compiler Reference**

 **-qcompact**

 **-qhot**

 **-qsimd**

 **-qprefetch**

 **-qstrict**

## Using shared-memory parallelism (SMP)

Most IBM pSeries machines are capable of shared-memory parallel processing. You can compile with **-qsmp** to generate the threaded code needed to exploit this capability. The **-qsmp** option implies the **-qhot** option and an optimization level of **-O2** or higher.

The following table lists the most commonly used suboptions. Descriptions and syntax of all the suboptions are provided in **-qsmp** in the *XL C/C++ Compiler Reference*. An overview of automatic parallelization, as well as of OpenMP directives is provided in Chapter 12, “Parallelizing your programs,” on page 119.

*Table 16. Commonly used -qsmp suboptions*

suboption	Behavior
auto	Instructs the compiler to automatically generate parallel code where possible without user assistance. Any SMP programming constructs in the source code  , including OpenMP directives, are also recognized. This is the default setting if you do not specify any <b>-qsmp</b> suboptions, and it also implies the <b>opt</b> suboption.
omp	Instructs the compiler to enforce strict conformance to the OpenMP API for specifying explicit parallelism. Only language constructs that conform to the OpenMP standard are recognized. Note that <b>-qsmp=omp</b> is incompatible with <b>-qsmp=auto</b> .

Table 16. Commonly used *-qsmp* suboptions (continued)

suboption	Behavior
opt	Instructs the compiler to optimize as well as parallelize. The optimization is equivalent to <b>-O2 -qhot</b> in the absence of other optimization options.
noopt	All optimization is turned off. During development, it can be useful to turn off optimization to facilitate debugging.
<i>fine_tuning</i>	Other values for the suboption provide control over thread scheduling, locking, and etc.

#### Related information in the *XL C/C++ Compiler Reference*



**-O, -qoptimize**



**-qsmp**



**-qhot**

## Getting the most out of **-qsmp**

Here are some suggestions for using the **-qsmp** option:

- Before using **-qsmp** with automatic parallelization, test your programs using optimization and **-qhot** in a single-threaded manner.
- If you are compiling an OpenMP program and do not want automatic parallelization, use **-qsmp=omp:noauto**.
- Always use thread-safe compiler invocations (the **\_r** invocations) when using **-qsmp**.
- By default, the runtime environment uses all available processors. Do not set the **XLSMPOPTS=PARTHDS** or **OMP\_NUM\_THREADS** environment variables unless you want to use fewer than the number of available processors. You might want to set the number of executing threads to a small number or to 1 to ease debugging.
- If you are using a dedicated machine or node, consider setting the **SPINS** and **YIELDS** environment variables (suboptions of the **XLSMPOPTS** environment variable) to 0. Doing so prevents the operating system from intervening in the scheduling of threads across synchronization boundaries such as barriers.
- When debugging an OpenMP program, try using **-qsmp=noopt** (without **-O**) to make the debugging information produced by the compiler more precise.

#### Related information in the *XL C/C++ Compiler Reference*



**-qsmp**



**-qhot**



Invoking the compiler



**XLSMPOPTS**



Environment variables for parallel processing

## Using interprocedural analysis

Interprocedural analysis (IPA) enables the compiler to optimize across different files (whole-program analysis), and can result in significant performance improvements.

You can specify interprocedural analysis on the compilation step only or on both compilation and link steps in whole program mode. Whole program mode expands the scope of optimization to an entire program unit, which can be an executable or shared object. As IPA can significantly increase compile time, you should limit using IPA to the final performance tuning stage of development.

You enable IPA by specifying the **-qipa** option. The most commonly used suboptions and their effects are described in the following table. The full set of suboptions and syntax is described in the **-qipa** section of the *XL C/C++ Compiler Reference*.

The steps to use IPA are:

1. Do preliminary performance analysis and tuning before compiling with the **-qipa** option, because the IPA analysis uses a two-pass mechanism that increases compile and link time. You can reduce some compilation and link overhead by using the **-qipa=noobject** option.
2. Specify the **-qipa** option on both the compilation and the link steps of the entire application, or as much of it as possible. Use suboptions to indicate assumptions to be made about parts of the program *not* compiled with **-qipa**.

Table 17. Commonly used **-qipa** suboptions

Suboption	Behavior
level=0	Program partitioning and simple interprocedural optimization, which consists of: <ul style="list-style-type: none"> <li>• Automatic recognition of standard libraries.</li> <li>• Localization of statically bound variables and procedures.</li> <li>• Partitioning and layout of procedures according to their calling relationships. (Procedures that call each other frequently are located closer together in memory.)</li> <li>• Expansion of scope for some optimizations, notably register allocation.</li> </ul>
level=1	Inlining and global data mapping. Specifically: <ul style="list-style-type: none"> <li>• Procedure inlining.</li> <li>• Partitioning and layout of static data according to reference affinity. (Data that is frequently referenced together will be located closer together in memory.)</li> </ul> <p>This is the default level if you do not specify any suboptions with the <b>-qipa</b> option.</p>
level=2	Global alias analysis, specialization, interprocedural data flow: <ul style="list-style-type: none"> <li>• Whole-program alias analysis. This level includes the disambiguation of pointer dereferences and indirect function calls, and the refinement of information about the side effects of a function call.</li> <li>• Intensive intraprocedural optimizations. This can take the form of value numbering, code propagation and simplification, moving code into conditions or out of loops, and elimination of redundancy.</li> <li>• Interprocedural constant propagation, dead code elimination, pointer analysis, code motion across functions, and interprocedural strength reduction.</li> <li>• Procedure specialization (cloning).</li> <li>• Whole program data reorganization.</li> </ul>
inline=suboptions	Provides precise control over function inlining.

Table 17. Commonly used **-qipa** suboptions (continued)

Suboption	Behavior
<i><code>fine_tuning</code></i>	Other values for <b>-qipa</b> provide the ability to specify the behavior of library code, tune program partitioning, read commands from a file, etc.



Related information in the *XL C/C++ Compiler Reference*



-qipa

## Getting the most from **-qipa**

It is not necessary to compile everything with **-qipa**, but try to apply it to as much of your program as possible. Here are some suggestions:


- Specify the **-qipa** option on both the compile and link steps of the entire application. Although you can also use **-qipa** with libraries, shared objects, and executable files, be sure to use **-qipa** to compile the main and exported functions.
- When compiling and linking separately, use **-qipa=noobject** on the compile step for faster compilation.
- When specifying optimization options in a makefile, remember to use the compiler driver (**xlc**) to link, and to include all compiler options on the link step.
- As IPA can generate significantly larger object files than traditional compilations, ensure that there is enough space in the `/tmp` directory (at least 200 MB). You can use the `TMPDIR` environment variable to specify a directory with sufficient free space.
- Try varying the **level** suboption if link time is too long. Compiling with **-qipa=level=0** can still be very beneficial for little additional link time.
- Use **-qipa=list=long** to generate a report of functions that were previously inlined. If too few or too many functions are inlined, consider using **-qinline** or **-qnoinline**.  To control the inlining of specific functions, use **-qinline+function\_name** or **-qinline-function\_name**. 
- To generate data reorganization information in the listing file, specify the optimization level **-qipa=level=2** or **-O5** together with **-qreport**. During the IPA link pass, the data reorganization messages for program variable data will be produced to the data reorganization section of the listing file with the label `DATA REORGANIZATION SECTION`. Reorganizations include array splitting, array transposing, memory allocation merging, array interleaving, and array coalescing.

**Note:** While IPA's interprocedural optimizations can significantly improve performance of a program, they can also cause incorrect but previously functioning programs to fail. Here are examples of programming practices that can work by accident without aggressive optimization but are exposed with IPA:

- Relying on the allocation order or location of automatic variables, such as taking the address of an automatic variable and then later comparing it with the address of another local variable to determine the growth direction of a stack. The C language does not guarantee where an automatic variable is allocated, or its position relative to other automatic variables. Do not compile such a function with IPA.
- Accessing a pointer that is either invalid or beyond an array's bounds. Because IPA can reorganize global data structures, a wayward pointer which might have previously modified unused memory might now conflict with user-allocated storage.

- Dereferencing a pointer that has been cast to an incompatible type.

**Related information in the XL C/C++ Compiler Reference**

 `-qinline`

 `-qlist`

 `-qipa`

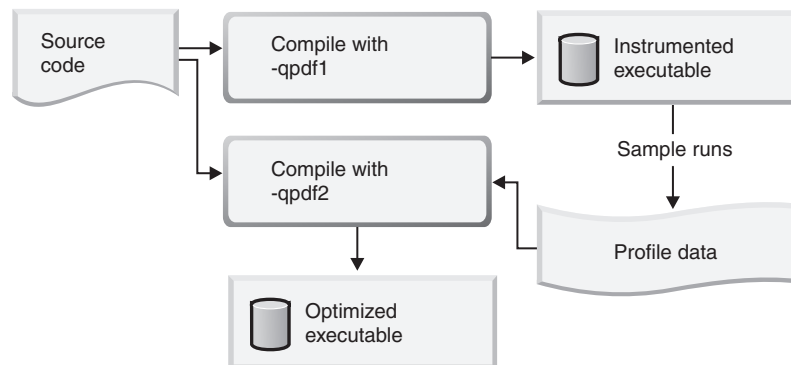
## Using profile-directed feedback

You can use profile-directed feedback (PDF) to tune the performance of your application for a typical usage scenario. The compiler optimizes the application based on an analysis of how often branches are taken and blocks of code are run.

Use PDF process as one of the last steps of optimization before putting the application into production. Optimization at all levels from **-O2** up can benefit from PDF. Other optimizations such as the **-qipa** option and optimization levels **-O4** and **-O5** can also benefit when using with PDF process.

The following diagram illustrates the PDF process:

Figure 2. Profile-directed feedback



To use the PDF process to optimize your application, follow these steps:

1. Compile some or all of the source files in a program with the **-qpdf1** option. You must specify at least the **-O2** optimization level.

### Notes:

- A PDF map file is generated at this step. It is used for the **showpdf** utility to display part of the profiling information in text or XML format. For details, see “Viewing profiling information with showpdf” on page 57. If you do not need to view the profiling information, specify the **-qnoshowpdf** option at this step so that the PDF map file is not generated. For details of **-qnoshowpdf**, see **-qshowpdf** in the *XL C/C++ Compiler Reference*.
- Although you can specify PDF optimization (**-qpdf**) as early in the optimization level as **-O2**, PDF optimization is recommended at **-O4** and higher.

- You do not have to compile all of the files of the programs with the **-qpdf1** option. In a large application, you can concentrate on those areas of the code that can benefit most from the optimization.
- When option **-O4**, **-O5**, or any level of option **-qipa** is in effect, and you specify the **-qpdf1** option at the link step but not at the compile step, the compiler issues a warning message. The message indicates that you must recompile your program to get all the profiling information.

**Restriction:** When you run an application that is compiled with **-qpdf1**, you must end the application using normal methods, including reaching the end of the execution for the main function and calling the `exit()` function in `libc (stdlib.h)` for C/C++ programs. System calls `exit()`, `_Exit()`, and `abort()` are considered abnormal termination methods and are not supported. Using abnormal program termination might result in incomplete instrumentation data generated by using the PDF file or PDF data not being generated at all.

2. Run the resulting application with a typical data set. When the application exits, profile information is written to one or more PDF files. You can train the resulting application multiple times with different data sets. The profiling information is accumulated to provide a count of how often branches are taken and blocks of code are run, based on the input data used. This step is called the PDF training step. By default, the PDF file is named `._pdf`, and it is placed in the current working directory or the directory specified by the `PDFDIR` environment variable. If the `PDFDIR` environment variable is set but the specified directory does not exist, the compiler issues a warning message. To override the defaults, use the **-qpdf1=pdfname** or **-qpdf1=exename** option.

If you recompile your program by using either of the **-qpdf1=level=0** or **-qpdf1=level=1** option, single-pass profiling is supported. The compiler removes the existing PDF file before generating a new application.

If you recompile your program by using **-qpdf1=level=2** option, multiple-pass profiling is supported. You can repeat compiling your program and training the resulting application, then new PDF files are generated up to five times.

#### Notes:

- When compiling your program with the **-qpdf1** or **-qpdf2** option, by default, the **-qipa** option is also invoked with **level=0**.
  - To avoid wasting compile and run time, make sure that the `PDFDIR` environment variable is set to an absolute path. Otherwise, you might run the application from a wrong directory, and the compiler cannot locate the profiling information files. When it happens, the program might not be optimized correctly or might be stopped by a segmentation fault. A segmentation fault might also happen if you change the value of the `PDFDIR` environment variable and run the application before finishing the PDF process.
  - Avoid using atypical data that can distort the analysis to infrequently executed code paths.
3. If you have several PDF files, use the **mergepdf** utility to combine these PDF files into one PDF file. For example, if you produce three PDF files that represent usage patterns that occur 53%, 32%, and 15% of the time respectively, you can use this command:

```
mergepdf -r 53 path1 -r 32 path2 -r 15 path3
```

#### Notes:

- Avoid mixing the PDF files created by different versions or PTF levels of the XL C/C++ compiler.

- You cannot edit PDF files that are generated by the resulting application. Otherwise, the performance or function of the generated executable application might be affected.
4. Recompile your program using the same compiler options as before, but change **-qpdf1** to **-qpdf2**. In this second compilation, the accumulated profiling information is used to fine-tune the optimizations. The resulting program contains no profiling overhead and runs at full speed.

#### Notes:

- If the compiler cannot read any PDF files in this step, the compiler issues a severe error message and stops compilation.
  - You are highly recommended to use the same optimization level at all compilation steps for a particular program. Otherwise, the PDF process cannot optimize your program correctly and might even slow it down. All compiler settings that affect optimization must be the same, including any supplied by configuration files.
  - You can modify your source code and use the **-qpdf1** and **-qpdf2** options to compile your program. Old profiling information can still be preserved and used during the second stage of the PDF process. The compiler issues a list of warnings but the compilation does not stop. An information message is also issued with a number in the range of 0 - 100 to indicate how outdated the old profiling information is.
  - When option **-O4**, **-O5**, or any level of option **-qipa** is in effect, and you specify the **-qpdf2** option at the link step but not at the compile step, the compiler issues a warning message. The message indicates that you must recompile your program to get all the profiling information.
  - When using the **-qreport** option with the **-qpdf2** option, you can get additional information in your listing file to help you tune your program. This information is written to the PDF Report section.
5. If you want to erase the PDF information, use the **cleanpdf** or **resetpdf** utility.

Instead of step 4, you can use the **-qpdf2** option to link the object files created during the **-qpdf1** phase without recompiling your program during the **-qpdf2** phase. This alternative approach can save considerable time and help tune large applications for optimization.

## Examples

The following example demonstrates that you can concentrate on compiling those codes that can benefit most from the optimization, instead of compiling all the code of applications with the **-qpdf1** option:

```
#Set the PDFDIR variable
export PDFDIR=$HOME/project_dir

#Compile most of the files with -qpdf1
xlc -qpdf1 -O3 -c file1.c file2.c file3.c

#This file does not need optimization
xlc -c file4.c

#Non-PDF object files such as file4.o can be linked
xlc -qpdf1 -O3 file1.o file2.o file3.o file4.o

#Run several times with different input data
./a.out < polar_orbit.data
./a.out < elliptical_orbit.data
./a.out < geosynchronous_orbit.data
```

```
#No need to recompile the source of non-PDF object files
#(file4.c).
xlc -qpdf2 -O3 -c file1.c file2.c file3.c
```

```
#Link all the object files into the final application
xlc -qpdf2 -O3 file1.o file2.o file3.o file4.o
```

The following example bypasses recompiling the source with the **-qpdf2** option:

```
#Compile source with -qpdf1
xlc -c -qpdf1 -O3 file1.c file2.c
```

```
#Link object files
xlc -qpdf1 -O3 file1.o file2.o
```

```
#Run with one set of input data
./a.out < sample.data
```

```
#Link the mix of pdf1 and pdf2 objects
xlc -qpdf2 -O3 file1.o file2.o
```

#### Related information in the *XL C/C++ Compiler Reference*



-qpdf1, -qpdf2



-O, -qoptimize



Runtime environment variables

## Viewing profiling information with showpdf

With the **showpdf** utility, you can view the following types of profiling information that is gathered from your application:

- Block-counter profiling
- Call-counter profiling
- Value profiling
- Cache-miss profiling, if you specified the **-qpdf1=level=2** option during the **-qpdf1** phase.

You can view the first two types of profiling information in either text or XML format. However, you can view value profiling and cache-miss profiling information only in XML format.

### Syntax

```
►► showpdf [pdfdir] [-f pdfname] [-m pdfmapdir] [-xml] ►►
```

### Parameters

#### pdfdir

is the directory that contains the profile-directed feedback (PDF) file. If the PDFDIR environment variable is not changed after the **-qpdf1** phase, the PDF map file is also contained in this directory. If this parameter is not specified, the compiler uses the value of the PDFDIR environment variable as the name of the directory.

#### pdfname

is the name of the PDF file. If this parameter is not specified, the compiler uses **.\_pdf** as the name of the PDF file.

**pdfmapdir**

is the directory that contains the PDF map file. If this parameter is not specified, the compiler uses the value of the PDFDIR environment variable as the name of the directory.

**-xml**

determines the display format of the PDF information. If this parameter is specified, the PDF information is displayed in XML format; otherwise it is displayed in text format. Because value profiling and cache-miss profiling information can be displayed only in XML format, the PDF report in XML format contains more information than the report in text format.

## Usage

A PDF map file that contains static information is generated during the **-qpdf1** phase, and a PDF file is generated during the execution of the resulting application. The **showpdf** utility needs both the PDF and PDF map files to display PDF information in either text or XML format.

If the **-qpdf1=level=2** option is specified during the **-qpdf1** phase, several PDF and PDF map files might be generated. Then if you want to view the profiling information, you need to run the **showpdf** utility for each pair of PDF and PDF map files.

By default, the PDF file is named `._pdf`, and the PDF map file is named `._pdf_map`. If the PDFDIR environment variable is set, the compiler places the PDF and PDF map files in the directory specified by PDFDIR. Otherwise, if the PDFDIR environment variable is not set, the compiler places these files in the current working directory. If the PDFDIR environment variable is set but the specified directory does not exist, the compiler issues a warning message. To override the defaults, use the **-qpdf1=pdfname** option to specify the paths and names for the PDF and PDF map files. For example, if you specify the **-qpdf1=pdfname=/home/joe/func** option, the resulting PDF file is named `func`, and the PDF map file is named `func_map`. Both of the files are placed in the `/home/joe` directory.

If the PDFDIR environment variable is changed between the **-qpdf1** phase and the execution of the resulting application, the PDF and PDF map files are generated in separate directories. In this case, you must specify the directories for both of these files to the **showpdf** utility.

**Notes:**

- PDF and PDF map files must be generated from the same compilation instance. Otherwise, the compiler issues an error.
- PDF and PDF map files must be generated during the same profiling process. It means that you cannot mix and match PDF and PDF map files that are generated from different profiling processes.
- You must use the same version and PTF level of the compiler to generate the PDF file and the PDF map file.
- The **showpdf** utility accepts only PDF files that are in binary format.
- You can use the PDF\_WL\_ID environment variable to distinguish the multiple sets of PDF counters that are generated by multiple training runs of the user program.

The following example shows how to use the **showpdf** utility to view the profiling information for a Hello World application:

The source for the program file `hello.c` is as follows:

```
#include <stdio.h>
void HelloWorld()
{
    printf("Hello World");
}
main()
{
    HelloWorld();
    return 0;
}
```

1. Compile the source file.  
`xlc -qpdf1 -O hello.c`
2. Run the resulting executable program **a.out** using a typical data set or several typical data sets.
3. If you want to view the profiling information for the executable file in text format, run the **showpdf** utility without any parameters.

`showpdf`

The result is as follows:

HelloWorld(67): 1 (hello.c)

Call Counters:

4 | 1 printf(69)

Call coverage = 100% ( 1/1 )

Block Counters:

2-4 | 1

5 |

5 | 1

Block coverage = 100% ( 2/2 )

-----  
main(68): 1 (hello.c)

Call Counters:

8 | 1 HelloWorld(67)

Call coverage = 100% ( 1/1 )

Block Counters:

6-9 | 1

10 |

Block coverage = 100% ( 1/1 )

Total Call coverage = 100% ( 2/2 )

Total Block coverage = 100% ( 3/3 )

If you want to view the profiling information in XML format, run the **showpdf** utility with the **-xml** parameter.

`showpdf -xml`

The result is as follows:

```
<?xml version="1.0" encoding="UTF-8" ?>
- <XLTransformationReport xmlns="http://www.ibm.com/2010/04/CompilerTransformation" version="1.0">
- <CompilationStep name="showpdf">
- <ProgramHierarchy>
- <FileList>
- <File id="1" name="hello.c">
- <RegionList>
- <Region id="67" name="HelloWorld" startLineNumber="2" />
- <Region id="68" name="main" startLineNumber="6" />
```

```

        </RegionList>
    </File>
</FileList>
</ProgramHierarchy>
<TransformationHierarchy />
- <ProfilingReports>
- <BlockCounterList>
- <BlockCounter regionId="67" execCount="1" coveredBlock="2" totalBlock="2">
- <BlockList>
    <Block index="3" execCount="1" startLineNumber="2" endLineNumber="4" />
    <Block index="2" execCount="0" startLineNumber="5" endLineNumber="5" />
    <Block index="4" execCount="1" startLineNumber="5" endLineNumber="5" />
</BlockList>
</BlockCounter>
- <BlockCounter regionId="68" execCount="1" coveredBlock="1" totalBlock="1">
- <BlockList>
    <Block index="3" execCount="1" startLineNumber="6" endLineNumber="9" />
    <Block index="2" execCount="0" startLineNumber="10" endLineNumber="10" />
</BlockList>
</BlockCounter>
</BlockCounterList>
- <CallCounterList>
- <CallCounter regionId="67" execCount="1" coveredCall="0" totalCall="0">
- <CallList>
    <Call name="printf" execCount="1" lineNumber="4" />
</CallList>
</CallCounter>
- <CallCounter regionId="68" execCount="1" coveredCall="0" totalCall="0">
- <CallList>
    <Call name="HelloWorld" execCount="1" lineNumber="8" />
</CallList>
</CallCounter>
</CallCounterList>
<ValueProfileList />
<CacheMissList />
</ProfilingReports>
</CompilationStep>
</XLTransformationReport>

```

**Related information in the *XL C/C++ Compiler Reference***



**-qpdf1, -qpdf2**



**-qshowpdf**

## Object level profile-directed feedback

### About this task

In addition to optimizing entire executables, profile-directed feedback (PDF) can also be applied to specific object files. This can be an advantage in applications where patches or updates are distributed as object files or libraries rather than as executables. Also, specific areas of functionality in your application can be optimized without you needing to go through the process of relinking the entire application. In large applications, you can save the time and trouble that otherwise need to be spent relinking the application.

The process for using object level PDF is essentially the same as the standard PDF process but with a small change to the **-qpdf2** step. For object level PDF, compile your program using the **-qpdf1** option, execute the resulting application with representative data, compile the program again with the **-qpdf2** option, but now also use the **-qnoipa** option so that the linking step is skipped.

The steps below outline this process:

1. Compile your program using the **-qpdf1** option. For example:

```
xlc -c -O3 -qpdf1 file1.c file2.c file3.c
```

In this example, we are using the optimization level **-O3** to indicate that we want a moderate level of optimization.

2. Link the object files to get an instrumented executable:  

```
xlc -O3 -qpdf1 file1.o file2.o file3.o
```
3. Run the instrumented executable with sample data that is representative of the data you want to optimize for.  

```
a.out < sample_data
```
4. Compile the program again using the **-qpdf2** option. Specify the **-qnoipa** option so that the linking step is skipped and PDF optimization is applied to the object files rather than to the entire executable.  

```
xlc -c -O3 -qpdf2 -qnoipa file1.c file2.c file3.c
```

The resulting output of this step are object files optimized for the sample data processed by the original instrumented executable. In this example, the optimized object files would be file1.o, file2.o, and file3.o. These can be linked using the system loader **ld** or by omitting the **-c** option in the **-qpdf2** step.

#### Notes:

- You must use the same optimization level in all the steps. In this example, the optimization level is **-O3**.
- If you want to specify a file name for the profile that is created, use the **pdfname** suboption in both the **-qpdf1** and **-qpdf2** steps. For example:  

```
xlc -O3 -qpdf1=pdfname=myprofile file1.c file2.c file3.c
```

Without the **pdfname** suboption, by default the file name is **.\_pdf**; the location of the file is the current working directory or whatever directory you have set using the **PDFDIR** environment variable. If the **PDFDIR** environment variable is set but the specified directory does not exist, the compiler issues a warning message.

- Because the **-qnoipa** option needs to be specified in the **-qpdf2** step so that linking of your object files is skipped, you cannot use interprocedural analysis (IPA) optimizations and object level PDF at the same time.

For details, see the **-qpdf1**, **-qpdf2** section in the XL C/C++ Compiler Reference.

---

## Handling table of contents (TOC) overflow

To handle table of contents (TOC) overflow, you can reduce the number of global symbols, enlarge the TOC access range, or apply interprocedural analysis. TOC is only for the 64-bit mode.

The addresses of global symbols in programs are stored in a data structure called TOC. To access a global symbol, the address of the global symbol must be retrieved from the TOC. The default TOC data structure has a fixed size that can store a fixed number of global symbols. For example, the IBM PowerPC architecture uses an instruction with a signed 16-bit offset for indirect address calculations, and limits the size of the TOC to 64 KB. A maximum of 16 K entries can be stored in the TOC in 32-bit mode and 8 K entries in 64-bit mode.

For large applications, it is common to have more global symbols than can be stored in the default TOC. If an application contains more TOC entries than the TOC can hold, the linker reports TOC overflow, indicating that an alternative mechanism must be used. Use the following approaches to handle TOC overflow:

- Reduce the number of global symbols in programs in the following ways:

- Change the source code. It is the best approach to reduce the number of global symbols.
- Specify the **-qminimaltoc** option.
- Apply the interprocedural analysis by specifying the **-qipa** option. For more information about the option, see “Using interprocedural analysis” on page 51 and “Getting the most from -qipa” on page 53.
- Enlarge the TOC access range by specifying the **-qplic=large** option.

## Options for reducing the number of global symbols

The best approach to handle table of contents (TOC) overflow is to reduce the number of global symbols so that the required number of TOC entries is also reduced.

You can reduce the number of global symbols by refining the source code. If possible, change the source code to remove unnecessary global variables and functions, mark them as static, or group global variables in structures. However, changing the source code can be time consuming and error prone. In fact, the compiler can finish these tasks automatically when link-time optimization is used at high optimization levels (**-O4** and **-O5**) or the optimization is applied explicitly with **-qipa** at both compile and link time. The optimization result is similar to what can be achieved through source changes but without widespread manual source changes.

To reduce the number of global symbols, you can also specify the **-qminimaltoc** option. When you specify this option, the compiler creates a separate table for each source file. The table contains the address of each global symbol that is used in the source file. Specifying the option ensures that the compiler creates only one TOC entry for each compilation unit. This option is effective only if the TOC entries are spread across multiple source files. If a single source file contains enough global symbols to cause TOC overflow, the option has no effect to help with TOC overflow.

### Notes:

- It is unnecessary to specify **-qminimaltoc** for each compilation unit.
- Use **-qminimaltoc** with discretion because it might lead to low performance. The use of **-qminimaltoc** introduces indirect reference and hence increases the time that is required to access a global symbol. Another drawback is that the memory requirements for the application might increase. For more information about the affected performance by the option, see “Performance considerations of handling TOC overflow” on page 63.

## Options for enlarging the TOC access range

Enlarging the table of contents (TOC) access range is an effective way to handle TOC overflow. Two instructions are used to access the TOC and group the ranges to consecutive TOC regions. The maximum 16-bit offset on IBM PowerPC supports a large TOC of 64 K TOC regions. With a maximum of 64 K entries in each TOC region, a large TOC can be 4 GB. It creates a limit of 1 G global symbols in a 32-bit environment and 500 M in a 64-bit environment. On POWER8 based systems, the two instructions are often executed together in the same time as one.

To enlarge a TOC, you can specify the **-qplic=large** option. Before you specify the options, reduce the number of TOC entries because a program that contains generated code can result in poor performance.

### **-qplic=large**

When **-qplic=large** is specified, the compiler always generates two instructions to get the address of a symbol, regardless of whether TOC overflow occurs or not. When the option is specified, all the symbols, including the symbols in the base TOC, require an extra instruction to compute the addresses. For offsets within the normal 64 KB base TOC size, the linker converts the first instruction to one that does nothing and takes no execution time. On POWER8, these two instructions are often merged into one instruction with a larger displacement. The linker does not insert a branch to out-of-line code for offsets. For more information about how the performance is affected by the option, see “Performance considerations of handling TOC overflow.”

**Note:** It is unnecessary to specify **-qplic=large** for each compilation unit.

## **Performance considerations of handling TOC overflow**

Performance must be considered when you handle table of contents (TOC) overflow. When you bypass TOC overflow, minimize any negative effects on runtime performance.

When TOC overflow occurs, the best solution is to reduce the number of global symbols by modifying the source code. You can also consider specifying the following options, depending on the performance requirement:

### **-qipa**

- **Advantage:** Applying the interprocedural analysis (IPA) process significantly reduces TOC pressure. In many cases, it completely eliminates TOC overflow. IPA does so by restructuring your program so that the number of global symbols is reduced.
- **Consideration:** IPA is implied at optimization levels **-O4** and **-O5**, but those also include other complex optimizations that are not relevant to commercial application development. One good alternative is **-qipa=level=0** that applies a minimal level of whole program optimization; however, you might need **-qipa=level=1** for large applications. The level 1 runs a more aggressive reduction of the TOC requirements, at the cost of a longer compilation process.

**Note:** For whole program analysis, you must specify the **-qipa** option at both the compile and link command lines.

### **-qminimaltoc**

- **Advantage:** If the source code contains only performance insensitive global symbols, use **-qminimaltoc** to compile the file. The option places all global symbols in a source file into a separate data structure, which is useful to reduce overall pressure on the TOC.
- **Consideration:** You must specify the option with discretion, particularly with files that contain frequently executed code. The use of the option can significantly affect performance when it is used to compile files that contain performance sensitive global symbols. When **-qminimaltoc** is specified, the program is larger and slower than it was.

**Note:** You do not need to specify **-qminimaltoc** on all compilation units. Minimize the negative performance by using this option only on compilation units that are not performance relevant.

**-qplic=large**

- **Advantage:** The **-qplic=large** option is usually the preferred solution, because it provides the best balance for accessing symbols in both the base and the extended TOC.
- **Consideration:** The option might affect performance because it uses two instructions to get the address of a symbol, regardless of whether TOC overflow occurs. On POWER8 based system, the two instructions are often executed together in the same time as one.

---

## Using compiler reports to diagnose optimization opportunities

You can use the **-qlistfmt** option to generate a compiler report in XML or HTML format that indicates some of the details of how your program was optimized. You can also use the **genhtml** tool to convert an existing XML report to HTML format. This information can be used to understand your application code and to tune your code for better performance.

The compiler report in XML format can be viewed in a browser that supports XSLT. If you compile with the **stylesheet** suboption, **-qlistfmt=xml=all:stylesheet=xlstyle.xsl**, the report contains a link to a stylesheet that renders the XML readable and provides you with opportunities to improve the optimization of your code. You can also create tools to parse this information.

By default, the name of the report is **a.html** in HTML format; and **a.xml** in XML format. You can use the **-qlistfmt=filename** option to override the default name.

### Inline reports

If compiled with **-qinline** and one of **-qlistfmt=xml=inlines**, **-qlistfmt=html=inlines**, **-qlistfmt=xml** or **-qlistfmt=html**, the compiler report that is generated includes a list of inline attempts during the compilation. The report also specifies the type of attempt and its outcome.

For each function that the compiler has attempted to inline, there is an indication of whether the inline was successful. The report might contain any number of explanations for a named function that has not been successfully inlined. Some examples of these explanations are:

- **FunctionTooBig** - The function is too big to be inlined.
- **RecursiveCall** - The function is not inlined because it is recursive.
- **ProhibitedByUser** - Inlining was not performed because of a user specified pragma or directive.
- **CallerIsNoopt** - No inlining was performed because the caller was compiled without optimization.
- **WeakAndNotExplicitlyInline** - The calling function is weak and not marked as inline.

For a complete list of the possible explanations, see the Inline optimization types section of the XML schema help file called **XMLContent.html** in the **/opt/ibm/xlC/13.1.0/listings/** directory, which also includes its Japanese and Chinese version, **XMLContent-Japanese.utf8.html** and **XMLContent-Chinese.utf8.html**.

## Loop transformations

If compiled with **-qhot** and one of **-qlistfmt=xml=transforms**, **-qlistfmt=html=transforms**, **-qlistfmt=xml** or **-qlistfmt=html**, the compiler report that is generated includes a list of the transformations performed on all loops in the file during the compilation. It also lists reasons why some transformations were not performed.

- Reasons why a loop cannot be automatically parallelized
- Reasons why a loop cannot be unrolled
- Reasons why SIMD vectorization failed

For a complete list of the possible transformation problems, see the Loop transformation types section of the XML schema help file called `XMLContent.html` in the `/opt/ibm/xlc/13.1.0/listings/` directory, which also includes its Japanese and Chinese version, `XMLContent-Japanese.utf8.html` and `XMLContent-Chinese.utf8.html`.

## Data reorganizations

If compiled with **-qhot** and one of **-qlistfmt=xml=data**, **-qlistfmt=html=data**, **-qlistfmt=xml** or **-qlistfmt=html**, the compiler report that is generated includes a list of data reorganizations performed on the program during compilation. Here are some examples of data reorganizations:

- Array splitting
- Array coalescing
- Array interleaving
- Array transposition
- Memory merge

For each of these reorganizations, the report contains details about the name of the data, file names, line numbers, and the region names.

## Profile-directed feedback reports

If compiled with **-qpdf2** and one of **-qlistfmt=xml=pdf**, **-qlistfmt=html=pdf**, **-qlistfmt=xml** or **-qlistfmt=html**, the compiler report that is generated includes the following information:

- Loop iteration counts
- Block and call counts
- Cache misses (if compiled with **-qpdf1=level=2**)

## Parsing compiler reports with development tools

Software development tools can be created to parse the compiler reports produced in XML format. These tools can help direct you to opportunities to improve the performance of your application.

The compiler includes an XML schema that you can use to create a tool to parse the compiler reports and display aspects of your code that may represent performance improvement opportunities. The schema, `xllisting.xsd`, is located in the `/opt/ibm/xlc/13.1.0/listings/` directory. This schema helps to present the information from the report in a tree structure.

You can also find a schema help file called `XMLContent.html` that helps you understand the details of the schema, and the Japanese and Chinese version of this file, `XMLContent-Japanese.utf8.html` and `XMLContent-Chinese.utf8.html`, in this directory.

---

## Marking variables as local or imported

The compiler assumes that all variables in applications are imported, but the use of `-qdatalocal` and `-qdataimported` can mark variables local or imported. The compiler optimizes applications that are based on the specification of static or dynamic binding for program variables.

### **-qdatalocal**

Local variables are stored in a special segment of memory that is uniquely bound to a program or shared library. Specify the `-qdatalocal` option to identify variables to be treated as local to a compiled program or shared library. You can specify the option with no parameters to indicate that all appropriate variables are local. Alternatively, you can append a list of colon-separated names to the option to treat only a subset of the program arguments as local.

When it can be, a variable that is marked as local is embedded directly into a structure that is called the table of contents (TOC) instead of in a separate global piece of memory. The prerequisite is that the variable's storage must be no more than the pointer size for it to be embedded in the TOC. Usually, pointers to data are stored in the TOC. The `-qdatalocal` option allows storage of data directly in the TOC, hence reducing data accesses from two load instructions to one load instruction.

### **-qdataimported**

Imported variables are stored according to the default memory allocation scheme. The `-qdataimported` option is the default data binding mechanism. Specifying the option implies that the data is visible to other program or shared library that is linked. As a result, specifying variable names as arguments to the `-qdataimported` option or compiling with the `-qdataimported` option without arguments in isolation has no effect.

The `-qdataimported` option is useful when you use it in combination with `-qdatalocal`. Because it is unlikely that you want to store all data in the TOC, the `-qdataimported` option can override `-qdatalocal` for variables external to a program or shared library. For example, the use of options `-qdatalocal -qdataimported=<variable>` stores all global data in the TOC except for `<variable>`.

**Related information in the *XL C/C++ Compiler Reference***



`-qdataimported`, `-qdatalocal`, `-qtocdata`

## Getting the most out of `-qdatalocal`

You can see some examples that illustrate the use of the `-qdatalocal` option.

In the source for the following program file, A1 and A2 are global variables:

```
int A1;
int A2;
int main(){
    A2=A1+1;
    return A2;
}
```

Here is an excerpt of the listing file that is created if you specify `-qlist` without `-qdatalocal`:

	000000			PDEF	main
4				PROC	
5	000000 lwz	80620004	1	L4A	gr3=.A1(gr2,0)
5	000004 lwz	80630000	1	L4A	gr3=A1(gr3,0)
5	000008 addi	38630001	1	AI	gr3=gr3,1
5	00000C lwz	80820008	1	L4A	gr4=.A2(gr2,0)
5	000010 stw	90640000	1	ST4A	A2(gr4,0)=gr3

Here is an excerpt of the listing file that is created if you specify `-qlist` with `-qdatalocal`:

	000000			PDEF	main
4				PROC	
5	000000 lwz	80620004	1	L4A	gr3=A1(gr2,0)
5	000004 addi	38630001	1	AI	gr3=gr3,1
5	000008 stw	90620008	1	ST4A	A2(gr2,0)=gr3



When you specify `-qdatalocal`, the data is accessed by a single load instruction because the A1 and A2 variables are embedded in the TOC. When you do not specify `-qdatalocal`, A1 and A2 variables are accessed by two load instructions. In this example, you can use `-qdatalocal=A1:A2` to specify local variables individually.

You can always see the >>>> OPTIONS SECTION <<<< of the `.lst` file that is created by `-qlist` to confirm the use of these options. For example, you can view `DATALOCAL=<variables>` or `DATALOCAL` when the option is specified.

#### Notes:

- On 64-bit Linux, TOC entries are pointer size. When you specify `-qdatalocal` without arguments, the option is ignored for variables that are larger than the pointer size. Conversely, data smaller than pointer size is word-aligned. See the following example of an `objdump` excerpt that shows when a `char` (`r3`) is marked local. The offset between the byte and the next data (`r4`) is still 4 bytes. The data is accessed by a load byte instruction instead of a regular load. For more information about how TOC stores data, see Handling table of contents (TOC) overflow.

```
10000380:      88 62 00 20      lbz      r3,32(r2)
10000384:      80 82 00 24      l        r4,36(r2)
r2 (base address of the TOC), r3 (char), r4 (int)
```

- The `-qdatalocal` option has no effect on 32-bit Linux.
- If you specify an unsuitable variable as a parameter to `-qdatalocal`, `-qdatalocal` is ignored. Unsuitable variables can be data that exceeds pointer-size bytes, or variables that do not exist. When you specify `-qdatalocal` for a variable that is not a TOC candidate, the storage for that variable defaults to `-qdataimported` and the variable is not stored in the TOC.
-  You must use the mangled names when you specify local variables. Otherwise, you might encounter an error message. 

- Mark variables as local with care. If you specify `-qdatalocal` without any arguments, expect all global variables to be candidates for TOC direct placement, even those variables that are marked as external. Variables with static linkage do not have the same issues.
- Since each TOC structure is unique to a module or shared library, the utility of the `-qdatalocal` option is limited to data within that module or shared library.
- For programs with multiple modules, switching between multiple TOC structures might dilute the speedup that is associated with this option.

**Related information in the XL C/C++ Compiler Reference**



`-qdataimported`, `-qdatalocal`, `-qtocdata`

## Other optimization options

Options are available to control particular aspects of optimization. They are often enabled as a group or given default values when you enable a more general optimization option or level.

For more information on these options, see the heading for each option in the *XL C/C++ Compiler Reference*.

Table 18. Selected compiler options for optimizing performance












Option	Description
<b>-qignerrno</b>	Allows the compiler to assume that <code>errno</code> is not modified by library function calls, so that such calls can be optimized. Also allows optimization of square root operations, by generating inline code rather than calling a library function. (For processors that support <code>sqrt</code> .)
<b>-qsmallstack</b>	Instructs the compiler to compact stack storage. Doing so might increase heap usage, which might increase execution time. However, it might be necessary for the program to run or to be optimally multithreaded.
<b>-qinline</b>	Controls inlining.
<b>-qunroll</b>	Independently controls loop unrolling. <b>-qunroll</b> is implicitly activated under <code>-O3</code> .
<b>-qtbtable</b>	Controls the generation of traceback table information.
 <b>-qnoeh</b>	Informs the compiler that no C++ exceptions will be thrown and that cleanup code can be omitted. If your program does not throw any C++ exceptions, use this option to compact your program by removing exception-handling code.
<b>-qnounwind</b>	Informs the compiler that the stack will not be unwound while any routine in this compilation is active. This option can improve optimization of non-volatile register saves and restores. In C++, the <b>-qnounwind</b> option implies the <b>-qnoeh</b> option. It should not be used if the program uses <code>setjmp/longjmp</code> or any other form of exception handling.
<b>-qstrict</b>	Disables all transformations that change program semantics. In general, compiling a program correctly with <b>-qstrict</b> and any levels of optimization produces the same results as without optimization.

Table 18. Selected compiler options for optimizing performance (continued)

Option	Description
<b>-qnostrict</b>	Allows the compiler to reorder floating-point calculations and potentially excepting instructions. A potentially excepting instruction is one that might raise an interrupt due to erroneous execution (for example, floating-point overflow, a memory access violation). <b>-qnostrict</b> is used by default for the <b>-O3</b> and higher optimization levels.
<b>-qprefetch</b>	Inserts prefetch instructions in compiled code to improve code performance. In situations where you are working with applications that generate a high cache-miss rate, you can use its suboption <b>assistthread</b> to generate prefetching assist threads (for example, <b>-qprefetch=assistthread</b> ). <b>-qnoprefetch</b> is the default option.

**Related information in the XL C/C++ Compiler Reference**

-  **-qignerrno**
-  **-qsmallstack**
-  **-qinline**
-  **-qunroll / #pragma unroll**
-  **-qinlgue**
-  **-qtbtable**
-  **-qeh (C++ only)**
-  **-qunwind**
-  **-qstrict**
-  **-qprefetch**



---

## Chapter 9. Debugging optimized code

Debugging optimized programs presents special usability problems. Optimization can change the sequence of operations, add or remove code, change variable data locations, and perform other transformations that make it difficult to associate the generated code with the original source statements.

For example:

### Data location issues

With an optimized program, it is not always certain where the most current value for a variable is located. For example, a value in memory may not be current if the most current value is being stored in a register. Most debuggers are incapable of following the removal of stores to a variable, and to the debugger it appears as though that variable is never updated, or possibly even never set. This contrasts with no optimization where all values are flushed back to memory and debugging can be more effective and usable.

### Instruction scheduling issues

With an optimized program, the compiler might reorder instructions. That is, instructions might not be executed in the order you would expect based on the sequence of lines in the original source code. Also, the sequence of instructions for a statement might not be contiguous. As you step through the program with a debugger, the program may appear as if it is returning to a previously executed line in the code (interleaving of instructions).

### Consolidating variable values

Optimizations can result in the removal and consolidation of variables. For example, if a program has two expressions that assign the same value to two different variables, the compiler may substitute a single variable. This can inhibit debug usability because a variable that a programmer is expecting to see is no longer available in the optimized program.

There are a couple of different approaches you can take to improve debug capabilities while also optimizing your program:

### Debug non-optimized code first

Debug a non-optimized version of your program first, then recompile it with your desired optimization options. See “Debugging in the presence of optimization” on page 72 for some compiler options that are useful in this approach.

### Use -g level

Use the **-g** level suboption to control the amount of debugging information made available. Increasing it improves debug capability, but prevents some optimizations.

### Use -qoptdebug

When compiling with **-O3** optimization level or higher, use the compiler option **-qoptdebug** to generate a pseudocode file that more accurately maps to how instructions and variable values will operate in an optimized program. With this option, when you load your program into a debugger, you will be debugging the pseudocode for the optimized program. See “Using -qoptdebug to help debug optimized programs” on page 73 for more information.

---

## Understanding different results in optimized programs

Here are some reasons why an optimized program might produce different results from one that has not undergone the optimization process:

- Optimized code can fail if a program contains code that is not valid. The optimization process relies on your application conforming to language standards.
- If a program that works without optimization fails when you optimize, check the cross-reference listing and the execution flow of the program for variables that are used before they are initialized. Compile with the **-qinitauto=hex\_value** option to try to produce the incorrect results consistently. For example, using **-qinitauto=FF** gives variables an initial value of "negative not a number" (-NAN). Any operations on these variables will also result in NAN values. Other bit patterns (*hex\_value*) may yield different results and provide further clues as to what is going on. Programs with uninitialized variables can appear to work properly when compiled without optimization, because of the default assumptions the compiler makes, but can fail when you optimize. Similarly, a program can appear to execute correctly after optimization, but fails at lower optimization levels or when run in a different environment. You can also use the **-qcheck=unset** and **-qinfo=unset** options to detect variables that are not or might not be initialized.
- Referring to an automatic-storage variable by its address after the owning function has gone out of scope leads to a reference to a memory location that can be overwritten as other auto variables come into scope as new functions are called.

Use with caution debugging techniques that rely on examining values in storage, unless the **-g8** or **-g9** option is used and the optimization level is **-O2**. The compiler might have deleted or moved a common expression evaluation. It might have assigned some variables to registers, so that they do not appear in storage at all.

---

## Debugging in the presence of optimization

Debug and compile your program with your desired optimization options. Test the optimized program before placing it into production. If the optimized code does not produce the expected results, you can attempt to isolate the specific optimization problems in a debugging session.

The following list presents options that provide specialized information, which can be helpful during the development of optimized code:

**-qlist** Instructs the compiler to emit an object listing. The object listing includes hex and pseudo-assembly representations of the generated instructions, traceback tables, and text constants.

**-qreport**

Instructs the compiler to produce a report of the loop transformations it performed, how the program was parallelized, what inlining was done, and some other transformations. For **-qreport** to generate a listing file, options **-qreport**, **-qhot**, **-qsmp**, **-qinline**, **-qsimd**, or other optimization options should also be specified.

**-qinfo=mt**

Reports potential synchronization issues in parallel code. For details, see **-qinfo**.

**-qinfo=unset**

Detects automatic variables that are used before they are set, and flags them with informational messages at compile time. For details, see `-qinfo`.

**-qipa=list**

Instructs the compiler to emit an object listing that provides information for IPA optimization.

**-qcheck**

Generates code that performs certain types of runtime checking.

**-qsmp=noopt**

If you are debugging SMP code, **-qsmp=noopt** ensures that the compiler performs only the minimum transformations necessary to parallelize your code and preserves maximum debug capability.

**-qoptdebug**

When used with high levels of optimization, produces files containing optimized pseudocode that can be read by a debugger.

**-qkeepparm**

Ensures that procedure parameters are stored on the stack even during optimization. This can negatively impact execution performance. The **-qkeepparm** option then provides access to the values of incoming parameters to tools, such as debuggers, simply by preserving those values on the stack.

**-qinitauto**

Instructs the compiler to emit code that initializes all automatic variables to a given value.

**-g**

Generates debugging information for use by a symbolic debugger. You can use different **-g** levels to debug optimized code by viewing or possibly modifying accessible variables at selected source locations in the debugger. Higher **-g** levels provide a more complete debug support, while lower levels provide higher runtime performance. For details, see `-g`.

In addition, you can also use the **snapshot** pragma to ensure that certain variables are visible to the debugger at points in your application. For details, see **#pragma ibm snapshot**.

---

## Using `-qoptdebug` to help debug optimized programs

The purpose of the **-qoptdebug** compiler option is to aid the debugging of optimized programs. It does this by creating pseudocode that maps more closely to the instructions and values of an optimized program than the original source code. When a program compiled with this option is loaded into a debugger, you will be debugging the pseudocode rather than your original source. By making optimizations explicit in pseudocode, you can gain a better understanding of how your program is really behaving under optimization. Files containing the pseudocode for your program are generated with the file suffix `.optdbg`. Only line debugging is supported for this feature.

Compile your program as in the following example:

```
xlc myprogram.c -O3 -qhot -g -qoptdebug
```

In this example, your source file is compiled to `a.out`. The pseudocode for the optimized program is written to a file called `myprogram.optdbg` which can be referred to while debugging your program.

### Notes:

- The **-g** or the **-qlinedebug** option must also be specified in order for the compiled executable to be debuggable. However, if neither of these options are specified, the pseudocode file `<output_file>.optdbg` containing the optimized pseudocode is still generated.
- The **-qoptdebug** option only has an effect when one or more of the optimization options **-qhot**, **-qsmp**, **-qpdf**, or **-qipa** are specified, or when the optimization levels that imply these options are specified; that is, the optimization levels **-O3**, **-O4**, and **-O5**. The example shows the optimization options **-qhot** and **-O3**.

## Debugging the optimized program

From the following examples, you can see how the compiler might apply optimizations to a simple program and how debugging it can differ from debugging your original source.

Example 1: Represents the original non-optimized code for a simple program. It presents an optimization opportunity to the compiler; the loop can be unrolled. In the optimized source, you can see iterations of the loop listed explicitly.

Example 2: Represents a listing of the optimized source as shown in the debugger. Note the unrolled loop and the consolidation of values assigned by the `x + y` expression.

Example 3: Shows an example of stepping through the optimized source using the debugger. Note, there is no longer a correspondence between the line numbers for these statements in the optimized source as compared to the line numbers in the original source.

### Example 1: Original code

```
#include "stdio.h"

void foo(int x, int y, char* w)
{
    char* s = w+1;
    char* t = w+1;
    int z = x + y;
    int d = x + y;
    int a = printf("TEST\n");

    for (int i = 0; i < 4; i++)
        printf("%d %d %d %s %s\n", a, z, d, s, t);
}

int main()
{
    char d[] = "DEBUG";
    foo(3, 4, d);
    return 0;
}
```

### Example 2: gdb debugger listing

```
(gdb) list
1          3 | void foo(long x, long y, char * w)
2          4 | {
3          9 |     a = printf("TEST\n");
4         12 |     printf("%d %d %d %s %s\n",a,x + y,x + y,
              |             ((char *)w + 1),((char *)w + 1));
5          |     printf("%d %d %d %s %s\n",a,x + y,x + y,
```

```

6          ((char *)w + 1),((char *)w + 1));
          printf("%d %d %d %s %s\n",a,x + y,x + y,
          ((char *)w + 1),((char *)w + 1));
7          printf("%d %d %d %s %s\n",a,x + y,x + y,
          ((char *)w + 1),((char *)w + 1));
8      13 |   return;
9          } /* function */
10
11
12      15 |   long main()
13      16 |   {
14      17 |       d$init$0 = "DEBUG";
15      18 |       $$PARM.x0 = 3;
16          $$PARM.y1 = 4;
17          $$PARM.w2 = &d;
18      9 |       a = printf("TEST\n");
19      12 |       printf("%d %d %d %s %s\n",a,$$PARM.x0 +
          $$PARM.y1,$$PARM.x0 + $$PARM.y1,((char *)$$PARM.w2 + 1),
          ((char *)$$PARM.w2 + 1));
20          printf("%d %d %d %s %s\n",a,$$PARM.x0 + $$PARM.y1,
          $$PARM.x0 + $$PARM.y1,((char *)$$PARM.w2 + 1),
          ((char *)$$PARM.w2 + 1));
21          printf("%d %d %d %s %s\n",a,$$PARM.x0 + $$PARM.y1,
          $$PARM.x0 + $$PARM.y1,((char *)$$PARM.w2 + 1),
          ((char *)$$PARM.w2 + 1));
22          printf("%d %d %d %s %s\n",a,$$PARM.x0 + $$PARM.y1,
          $$PARM.x0 + $$PARM.y1,((char *)$$PARM.w2 + 1),
          ((char *)$$PARM.w2 + 1));
23      19 |       rstr = 0;
24          return rstr;
25      20 |   } /* function */

```

### Example 3: Stepping through optimized source

```

(gdb) break 17
Breakpoint 2 at 0x10000694: file myprogram.o.optdbg, line 17.
(gdb) run
Starting program: /nfs/r3lp1/home/gklou/tmp/optdbg/a.out

```

Breakpoint 2, main () at myprogram.o.optdbg:18

```

18      9 |   a = printf("TEST\n");

```

```

(gdb) continue

```

Continuing.

TEST

5 7 7 EBUG EBUG

5 7 7 EBUG EBUG

5 7 7 EBUG EBUG

5 7 7 EBUG EBUG

Program exited normally.



---

## Chapter 10. Coding your application to improve performance

Chapter 8, “Optimizing your applications,” on page 39 discusses the various compiler options that the XL C/C++ compiler provides for optimizing your code with minimal coding effort. If you want to take your application a step further, to complement and take the most advantage of compiler optimizations, the following sections discuss C and C++ programming techniques that can improve performance of your code:

- “Finding faster input/output techniques”
- “Reducing function-call overhead”
- “Using delegating constructors (C++11)” on page 79
- “Using template explicit instantiation declarations (C++11)” on page 79
- “Managing memory efficiently” on page 80
- “Optimizing variables” on page 80
- “Manipulating strings efficiently” on page 81
- “Optimizing expressions and program logic” on page 82
- “Optimizing operations in 64-bit mode” on page 82
- “Tracing functions in your code” on page 83
- “Using rvalue references (C++11)” on page 87
- “Using visibility attributes (IBM extension)” on page 90

---

### Finding faster input/output techniques

There are a number of ways to improve your program's performance of input and output:

- If your file I/O accesses do not exhibit locality (that is truly random access such as in a database), implement your own buffering or caching mechanism on the low-level I/O functions.
- If you do your own I/O buffering, make the buffer a multiple of 4K, which is the minimum size of a page.
- Use buffered I/O to handle text files.
- If you know you have to process an entire file, determine the size of the data to be read in, allocate a single buffer to read it to, read the whole file into that buffer at once using read, and then process the data in the buffer. This reduces disk I/O, provided the file is not so big that excessive swapping will occur. Consider using the `mmap` function to access the file.


---

### Reducing function-call overhead

When you write a function or call a library function, consider the following guidelines:

- Call a function directly, rather than using function pointers.
- Use `const` arguments in inlined functions whenever possible. Functions with constant arguments provide more opportunities for optimization.
- Use the `#pragma expected_value` preprocessor directive so that the compiler can optimize for common values used with a function.
- Use the `#pragma isolated_call` preprocessor directive to list functions that have no side effects and do not depend on side effects.

- Use the `restrict` keyword for pointers that can never point to the same memory.
- Use **`#pragma disjoint`** within functions for pointers or reference parameters that can never point to the same memory.
- Declare a nonmember function as static whenever possible. This can speed up calls to the function and increase the likelihood that the function will be inlined.
-  Usually, you should not declare all your virtual functions inline. If all virtual functions in a class are inline, the virtual function table and all the virtual function bodies will be replicated in each compilation unit that uses the class.
-  When declaring functions, use the `const` specifier whenever possible.
-  Fully prototype all functions. A full prototype gives the compiler and optimizer complete information about the types of the parameters. As a result, promotions from unwidened types to widened types are not required, and parameters can be passed in appropriate registers.
-  Avoid using unprototyped variable argument functions.
- Design functions so that they have few parameters and the most frequently used parameters are in the leftmost positions in the function prototype.
- Avoid passing by value large structures or unions as function parameters or returning a large structure or a union. Passing such aggregates requires the compiler to copy and store many values. This is worse in C++ programs in which class objects are passed by value because a constructor and destructor are called when the function is called. Instead, pass or return a pointer to the structure or union, or pass it by reference.
- Pass non-aggregate types such as `int` and `short` or small aggregates by value rather than passing by reference, whenever possible.
- If your function exits by returning the value of another function with the same parameters that were passed to your function, put the parameters in the same order in the function prototypes. The compiler can then branch directly to the other function.
- Use the built-in functions, which include string manipulation, floating-point, and trigonometric functions, instead of coding your own. Intrinsic functions require less overhead and are faster than a function call, and often allow the compiler to perform better optimization.
-  Many functions from the C++ standard libraries are mapped to optimized built-in functions by the compiler.
-  Many functions from `string.h` and `math.h` are mapped to optimized built-in functions by the compiler.
- Selectively mark your functions for inlining, using the `inline` keyword. An inlined function requires less overhead and is generally faster than a function call. The best candidates for inlining are small functions that are called frequently from a few places, or functions called with one or more compile-time constant parameters, especially those that affect `if`, `switch` or `for` statements. You might also want to put these functions into header files, which allows automatic inlining across file boundaries even at low optimization levels. Be sure to inline all functions that only load or store a value, or use simple operators such as comparison or arithmetic operators. Large functions and functions that are called rarely are generally not good candidates for inlining. Neither are medium size functions that are called from many places.

- Avoid breaking your program into too many small functions. If you must use small functions, seriously consider using the **-qipa** compiler option, which can automatically inline such functions, and uses other techniques for optimizing calls between functions.
-  Avoid virtual functions and virtual inheritance unless required for class extensibility. These language features are costly in object space and function invocation performance.

**Related information in the XL C/C++ Compiler Reference**



#pragma expected\_value



-qisolated\_call / #pragma isolated\_call



#pragma disjoint



-qipa

---

## Using delegating constructors (C++11)

**Note:** IBM supports selected features of C++11, known as C++0x before its ratification. IBM will continue to develop and implement the features of this standard. The implementation of the language level is based on IBM's interpretation of the standard. Until IBM's implementation of all the C++11 features is complete, including the support of a new C++11 standard library, the implementation may change from release to release. IBM makes no attempt to maintain compatibility, in source, binary, or listings and other compiler interfaces, with earlier releases of IBM's implementation of the new C++11 features.

Use the delegating constructors feature to concentrate common initializations in one constructor. This helps reduce the code size and make the program more readable and maintainable.

This technique is described in “Using delegating constructors (C++11)” on page 21.

---

## Using template explicit instantiation declarations (C++11)

**Note:** IBM supports selected features of C++11, known as C++0x before its ratification. IBM will continue to develop and implement the features of this standard. The implementation of the language level is based on IBM's interpretation of the standard. Until IBM's implementation of all the C++11 features is complete, including the support of a new C++11 standard library, the implementation may change from release to release. IBM makes no attempt to maintain compatibility, in source, binary, or listings and other compiler interfaces, with earlier releases of IBM's implementation of the new C++11 features.






Use the explicit instantiation declarations feature to suppress the implicit instantiation of a template specialization or its members. This helps reduce the collective size of the object files and shorten compile time.

This technique is described in “Using explicit instantiation declarations (C++11)” on page 28.

---

## Managing memory efficiently

Because C++ objects are often allocated from the heap and have limited scope, memory use affects performance more in C++ programs than it does in C programs. For that reason, consider the following guidelines when you develop C++ applications:

- In a structure, declare the largest aligned members first. Members of similar alignment should be grouped together where possible.
- In a structure, place variables near each other if they are frequently used together.
-  Ensure that objects that are no longer needed are freed or otherwise made available for reuse. One way to do this is to use an *object manager*. Each time you create an instance of an object, pass the pointer to that object to the object manager. The object manager maintains a list of these pointers. To access an object, you can call an object manager member function to return the information to you. The object manager can then manage memory usage and object reuse.
- Storage pools are a good way of keeping track of used memory (and reclaiming it) without having to resort to an object manager or reference counting. Do not use storage pools for objects with non-trivial destructors, because in most implementations the destructors cannot be run when the storage pool is cleared.
-  Avoid copying large, complicated objects.
-  Avoid performing a *deep copy* if a *shallow copy* is all you require. For an object that contains pointers to other objects, a shallow copy copies only the pointers and not the objects to which they point. The result is two objects that point to the same contained object. A deep copy, however, copies the pointers and the objects they point to, as well as any pointers or objects contained within that object, and so on. A deep copy must be performed in multithreaded environments, because it reduces sharing and synchronization.
-  Use virtual methods only when absolutely necessary.
-  Use the "Resource Acquisition is Initialization" (RAII) pattern.
- Use `shared_ptr` and `weak_ptr`.

---

## Optimizing variables

Consider the following guidelines:

- Use local variables, preferably automatic variables, as much as possible.  
The compiler must make several worst-case assumptions about global variables. For example, if a function uses external variables and also calls external functions, the compiler assumes that every call to an external function could use and change the value of every external variable. If you know that a global variable is not read or affected by any function call, and this variable is read several times with function calls interspersed, copy the global variable to a local variable and then use this local variable.
- If you must use global variables, use static variables with file scope rather than external variables whenever possible. In a file with several related functions and static variables, the optimizer can gather and use more information about how the variables are affected.
- If you must use external variables, group external data into structures or arrays whenever it makes sense to do so. All elements of an external structure use the same base address. Do not group variables whose addresses are taken with variables whose addresses are not taken.

- The **#pragma isolated\_call** preprocessor directive can improve the runtime performance of optimized code by allowing the compiler to make less pessimistic assumptions about the storage of external and static variables. Isolated call functions with constant or loop-invariant parameters can be moved out of loops, and multiple calls with the same parameters can be replaced with a single call.
- Avoid taking the address of a variable. If you use a local variable as a temporary variable and must take its address, avoid reusing the temporary variable for a different purpose. Taking the address of a local variable can inhibit optimizations that would otherwise be done on calculations involving that variable.
- Use constants instead of variables where possible. The optimizer is able to do a better job reducing runtime calculations by doing them at compile time instead. For instance, if a loop body has a constant number of iterations, use constants in the loop condition to improve optimization (for (i=0; i<4; i++) can be better optimized than for (i=0; i<x; i++)). An enumeration declaration can be used to declare a named constant for maintainability.
- Use register-sized integers (long data type) for scalars to avoid sign extension instructions after each change in 64-bit mode. For large arrays of integers, consider using one- or two-byte integers or bit fields.
- Use the smallest floating-point precision appropriate to your computation.

**Related information in the XL C/C++ Compiler Reference**





-qisolated\_call / #pragma isolated\_call

---

## Manipulating strings efficiently

The handling of string operations can affect the performance of your program.

- When you store strings into allocated storage, align the start of the string on an 8-byte boundary.
- Keep track of the length of your strings. If you know the length of a string, you can use mem functions instead of str functions. For example, memcpy is faster than strcpy because it does not have to search for the end of the string.
- If you are certain that the source and target do not overlap, use memcpy instead of memmove. This is because memcpy copies directly from the source to the destination, while memmove might copy the source to a temporary location in memory before copying to the destination (depending on the length of the string).
- When manipulating strings using mem functions, faster code can be generated if the *count* parameter is a constant rather than a variable. This is especially true for small count values.
- Make string literals read-only, whenever possible. When the same string is used multiple times, making it read-only improves certain optimization techniques, reduces memory usage, and shortens compile time. You can explicitly set strings to read-only by using **#pragma strings (readonly)** in your source files or **-qro** (this is enabled by default  **c** except when compiling with cc  **c** ) to avoid changing your source files.

**Related information in the XL C/C++ Compiler Reference**



-qro / #pragma strings

---

## Optimizing expressions and program logic

Consider the following guidelines:

- If components of an expression are used in other expressions and they include function calls or there are function calls between the uses, assign the duplicated values to a local variable.

- Avoid forcing the compiler to convert numbers between integer and floating-point internal representations. For example:

```
float array[10];
float x = 1.0;
int i;
for (i = 0; i < 9; i++) {      /* No conversions needed */
    array[i] = array[i]*x;
    x = x + 1.0;
}
for (i = 0; i < 9; i++) {      /* Multiple conversions needed */
    array[i] = array[i]*i;
}
```


When you must use mixed-mode arithmetic, code the integer and floating-point arithmetic in separate computations whenever possible.

- Do not use global variables as loop indices or bounds.
- Avoid goto statements that jump into the middle of loops. Such statements inhibit certain optimizations.
- Improve the predictability of your code by making the fall-through path more probable. Code such as:

```
if (error) {handle error} else {real code}
```

should be written as:

```
if (!error) {real code} else {error}
```

- If one or two cases of a switch statement are typically executed much more frequently than other cases, break out those cases by handling them separately before the switch statement. If possible, replace the switch statement by checking whether the value is in range to be obtained from an array.
-  Use try blocks for exception handling only when necessary because they can inhibit optimization.
- Keep array index expressions as simple as possible.

---

## Optimizing operations in 64-bit mode

The ability to handle larger amounts of data directly in physical memory rather than relying on disk I/O is perhaps the most significant performance benefit of 64-bit machines. However, some applications compiled in 32-bit mode perform better than when they are recompiled in 64-bit mode. Some reasons for this include:

- 64-bit programs are larger. The increase in program size places greater demands on physical memory.
- 64-bit long division is more time-consuming than 32-bit integer division.
- 64-bit programs that use 32-bit signed integers as array indexes or loop counts might require additional instructions to perform sign extension each time the array is referenced or the loop count is incremented.

Some ways to compensate for the performance liabilities of 64-bit programs include:

- Avoid performing mixed 32-bit and 64-bit operations. For example, adding a 32-bit data type to a 64-bit data type requires that the 32-bit be sign-extended to clear or set the upper 32-bit of the register. This slows the computation.
- Use long types instead of signed, unsigned, and plain int types for variables which will be frequently accessed, such as loop counters and array indexes. Doing so frees the compiler from having to truncate or sign-extend array references, parameters during function calls, and function results during returns.

---

## Tracing functions in your code

You can instruct the compiler to insert calls to user-defined tracing functions to aid in debugging or timing the execution of other functions.

Using tracing functions in your program requires the following steps:

1. Writing tracing functions.
2. Specifying which functions to trace with the **-qfunctrace** option.

Using the **-qfunctrace** option causes the compiler to insert calls to these tracing functions at key points in the function body; however you are responsible for defining these tracing functions. The following list describes at which points the tracing functions are called:

- The compiler inserts calls to the tracing function at the entry point of a function. The line number passed to the routine is the line number of the first executable statement in the instrumented function.
- The compiler inserts calls to the tracing function at the exit point of a function. The line number that is passed to the function is the line number of the statement causing the exit in the instrumented function.
- The catch tracing function is called at the beginning of the C++ catch block when the exception occurs.

You can use the **-qnofunctrace** compiler option or the `#pragma nofunctrace` pragma to disable function tracing.

### How to write tracing functions

To trace functions in your code, define the following tracing functions:

- `__func_trace_enter` is the entry point tracing function.
- `__func_trace_exit` is the exit point tracing function.
- `__func_trace_catch` is the catch tracing function.

The prototypes of these functions are as follows:

- `void __func_trace_enter(const char *const function_name, const char *const file_name, int line_number, void **const user_data);`
- `void __func_trace_exit(const char *const function_name, const char *const file_name, int line_number, void **const user_data);`
- `void __func_trace_catch(const char *const function_name, const char *const file_name, int line_number, void **const user_data);`

In the preceding tracing functions, the descriptions for their variables are as follows:

- `function_name` is the name of the function you want to trace.
- `file_name` is the name of the file.

- `line_number` is the line number at entry or exit point of the function. This is a 4-byte number.
- `user_data` is the address of a static pointer variable. The static pointer variable is generated by the compiler and initialized to NULL; in addition, because the pointer variable is static, its address is the same for all instrumentation calls inside the same function.

#### Notes:

- The exit function is not called if the function has an abnormal exit. The abnormal exit can be caused by actions such as raising a signal, throwing a C++ exception, or calling the `exit()` or `abort()` functions.
- The **-qfunctrace** option does not support `setjmp` and `longjmp`. For example, a call to `longjmp()` that leaves `function1` and returns from `setjmp()` in `function2` will have a missing call to `__func_trace_exit` in `function1` and a missing a call to `__func_trace_enter` in `function2`.
- The catch function is called at the point where the C++ exception is caught by user code.
- To define tracing functions in C++ programs, use the `extern "C"` linkage directive before your function definition.
- The function calls are only inserted into the function definition, and if a function is inlined, no tracing is done within the inlined code.
- If you develop a multithreaded program, make sure the tracing functions have the proper synchronization and do not cause deadlock. Calls to the tracing functions are not thread-safe.
- If you specify a function that does not exist with the option, the function is ignored.

## Rules

The following rules apply when you trace functions in your code:

- When optimization is enabled, line numbers might not be accurate.
- The tracing function must not call any instrumented function; otherwise an infinite loop might occur.
- If you instruct the compiler to trace recursive functions, make sure that your tracing functions can handle recursion.
- Inlined functions are not instrumented.
- Tracing functions are not instrumented.
- Compiler-generated functions are not instrumented, except for the outlined functions generated by optimization such as OpenMP. In those cases, the name of the outlined function contains the name of the original user function as prefix.
- Tracing functions might be called during static initialization. You must be careful that anything used in the tracing functions is initialized before the first possible call to the tracing function.

## Examples

The following C example shows how you can trace functions in your code using function prototypes. Assume you want to trace the entry and exit points of `function1` and `function2`, as well as how much time it takes the compiler to trace them in the following code:

**Main program file: t1.c**

```

#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <time.h>
#ifdef __cplusplus
extern "C"
#endif
void __func_trace_enter(const char *function_name, const char *file_name,
                      int line_number, void** const user_data){
    if((*user_data)==NULL)
        (*user_data)=(time_t *)malloc(sizeof(time_t));
    (*(time_t *)*user_data)=time(NULL);
    printf("begin function: name=%s file=%s line=%d\n",function_name,file_name,
          line_number);
}
#ifdef __cplusplus
extern "C"
#endif
void __func_trace_exit(const char *function_name, const char*file_name,
                     int line_number, void** const user_data){
    printf("end function: name=%s file=%s line=%d. It took %g seconds\n",
          function_name,file_name,line_number, difftime(time(NULL),
        *(time_t *)*user_data));
}
void function2(void){
    sleep(3);
}
void function1(void){
    sleep(5);
    function2();
}
int main(){
    function1();
}

```

Compile the main program source file as follows:

```
xlc t1.c -qfunctrace+function1:function2
```

Run executable a.out to output function trace results:

```

begin function: name=function1 file=t.c line=27
begin function: name=function2 file=t.c line=24
end function: name=function2 file=t.c line=25. It took 3 seconds
end function: name=function1 file=t.c line=29. It took 8 seconds

```

As you see from the preceding example, the `user_data` parameter is defined to use the system time as basis for time calculation. The following steps explain how `user_data` is defined to achieve this goal:

1. The function reserves a memory area for storing the value of `user_data`.
2. The system time is used as the value for `user_data`.
3. In the `__func_trace_exit` function, the `difftime` function uses `user_data` to calculate time differences. The result is displayed in the form of It took %g seconds in the output.

The following C++ example shows how tracing functions are called. The following example traces class `myStack`, function `foo`, and disables tracing for `int main()` using `#pragma nofunctrace`:

#### Main program file: t2.cpp

```

#include <iostream>
#include <vector>
#include <stdexcept>

```

```

#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <time.h>
extern "C"
void __func_trace_enter(const char *function_name, const char *file_name,
                       int line_number, void** const user_data){
    if((*user_data)==NULL)
        (*user_data)=(time_t *)malloc(sizeof(time_t));
    (*(time_t *)*user_data)=time(NULL);
    printf("enter function: name=%s file=%s line=%d\n",function_name,file_name,
          line_number);
}
extern "C"
void __func_trace_exit(const char *function_name, const char*file_name,
                      int line_number, void** const user_data){
    printf("exit function: name=%s file=%s line=%d. It took %g seconds\n",
          function_name, file_name, line_number, difftime(time(NULL),
          *(time_t *)*user_data));
}
extern "C"
void __func_trace_catch(const char *function_name, const char*file_name,
                       int line_number, void** const user_data){
    printf("catch function: name=%s file=%s line=%d. It took %g seconds\n",
          function_name, file_name, line_number, difftime(time(NULL),
          *(time_t *)*user_data));
}

template <typename T> class myStack{
private:
    std::vector<T> elements;
public:
    void push(T const&);
    void pop();
};

template <typename T>
void myStack<T>::push(T const& value){
    sleep(3);
    std::cout<< "\tpush(" << value << ")" <<std::endl;
    elements.push_back(value);
}
template <typename T>
void myStack<T>::pop(){
    sleep(5);
    std::cout<< "\tpop()" <<std::endl;
    if(elements.empty()){
        throw std::out_of_range("myStack is empty");
    }
    elements.pop_back();
}

void foo(){
    myStack<int> intValues;
    myStack<float> floatValues;
    myStack<double> doubleValues;
    intValues.push(4);
    floatValues.push(5.5f);
    try{
        intValues.pop();
        floatValues.pop();
        doubleValues.pop(); // cause exception
    } catch(std::exception const& e){
        std::cout<<"\tException: "<<e.what()<<std::endl;
    }
    std::cout<<"\tdone"<<std::endl;
}

```

```
#pragma nofunctrace(main)
int main(){
    foo();
}
```

Compile the main program source file as follows:

```
xlc t2.cpp -qfunctrace+myStack:foo
```

Run executable a.out to output function trace results:

```
enter function: name=_Z3foov file=t2.cpp line=56
enter function: name=_ZN7myStackIiE4pushERKi file=t2.cpp line=42
    push(4)
exit function: name=_ZN7myStackIiE4pushERKi file=t2.cpp line=45. It took 3 seconds
enter function: name=_ZN7myStackIfE4pushERKf file=t2.cpp line=42
    push(5.5)
exit function: name=_ZN7myStackIfE4pushERKf file=t2.cpp line=45. It took 3 seconds
enter function: name=_ZN7myStackIiE3popEv file=t2.cpp line=48
    pop()
exit function: name=_ZN7myStackIiE3popEv file=t2.cpp line=54. It took 5 seconds
enter function: name=_ZN7myStackIfE3popEv file=t2.cpp line=48
    pop()
exit function: name=_ZN7myStackIfE3popEv file=t2.cpp line=54. It took 5 seconds
enter function: name=_ZN7myStackIdE3popEv file=t2.cpp line=48
    pop()
catch function: name=_Z3foov file=t2.cpp line=65. It took 21 seconds
    Exception: myStack is empty
done
exit function: name=_Z3foov file=t2.cpp line=69. It took 21 seconds
```

## Related information

- For details about the **-qfunctrace** compiler option, see **-qfunctrace** in the *XL C/C++ Compiler Reference*.
- See **#pragma nofunctrace** in the *XL C/C++ Compiler Reference* for details about the **#pragma nofunctrace**.

---

## Using rvalue references (C++11)

**Note:** IBM supports selected features of C++11, known as C++0x before its ratification. IBM will continue to develop and implement the features of this standard. The implementation of the language level is based on IBM's interpretation of the standard. Until IBM's implementation of all the C++11 features is complete, including the support of a new C++11 standard library, the implementation may change from release to release. IBM makes no attempt to maintain compatibility, in source, binary, or listings and other compiler interfaces, with earlier releases of IBM's implementation of the new C++11 features.

In C++11, you can overload functions based on the value categories of arguments and similarly have lvalueness detected by template argument deduction. You can also have an rvalue bound to an rvalue reference and modify the rvalue through the reference. This enables a programming technique with which you can reuse the resources of expiring objects and therefore improve the performance of your libraries, especially if you use generic code with class types, for example, template data structures. Additionally, the value category can be considered when writing a forwarding function.

## Move semantics

When you want to optimize the use of temporary values, you can use a move operation in what is known as destructive copying. Consider the following string concatenation and assignment:

```
std::string a, b, c;  
c = a + b;
```

In this program, the compiler first stores the result of `a + b` in an internal temporary variable, that is, an rvalue.

The signature of a normal copy assignment operator is as follows:

```
string& operator = (const string&)
```

With this copy assignment operator, the assignment consists of the following steps:

1. Copy the temporary variable into `c` using a deep-copy operation.
2. Discard the temporary variable.

Deep copying the temporary variable into `c` is not efficient because the temporary variable is discarded at the next step.

To avoid the needless duplication of the temporary variable, you can implement an assignment operator that moves the variable instead of copying the variable. That is, the argument of the operator is modified by the operation. A move operation is faster because it is done through pointer manipulation, but it requires a reference through which the source variable can be manipulated. However, `a + b` is a temporary value, which is not easily differentiated from a const-qualified value in C++ before C++11 for the purposes of overload resolution.

With rvalue references, you can create a move assignment operator as follows:

```
string& operator= (string&&)
```

With this move assignment operator, the memory allocated for the underlying C-style string in the result of `a + b` is assigned to `c`. Therefore, it is not necessary to allocate new memory to hold the underlying string in `c` and to copy the contents to the new memory.

The following code can be an implementation of the string move assignment operator:

```
string& string::operator=(string&& str)  
{  
    // The named rvalue reference str acts like an lvalue  
    std::swap(_capacity, str._capacity);  
    std::swap(_length, str._length);  
  
    // char* _str points to a character array and is a  
    // member variable of the string class  
    std::swap(_str, str._str);  
    return *this;  
}
```

However, in this implementation, the memory originally held by the string being assigned to is not freed until `str` is destroyed. The following implementation that uses a local variable is more memory efficient:

```
string& string::operator=(string&& parm_str)  
{  
    // The named rvalue reference parm_str acts like an lvalue
```

```

    string sink_str;
    std::swap(sink_str, parm_str);
    std::swap(*this, sink_str);
    return *this;
}

```

In a similar manner, the following program is a possible implementation of a string concatenation operator:

```

string operator+(string&& a, const string& b)
{
    return std::move(a+=b);
}

```

**Note:** The `std::move` function only casts the result of `a+=b` to an rvalue reference, without moving anything. The return value is constructed using a move constructor because the expression `std::move(a+=b)` is an rvalue. The relationship between a move constructor and a copy constructor is analogous to the relationship between a move assignment operator and a copy assignment operator.

## Perfect forwarding

The `std::forward` function is a helper template, much like `std::move`. It returns a reference to its function argument, with the resulting value category determined by the template type argument. In an instantiation of a forwarding function template, the value category of an argument is encoded as part of the deduced type for the related template type parameter. The deduced type is passed to the `std::forward` function.

The wrapper function in the following example is a forwarding function template that forwards to the `do_work` function. Use `std::forward` in forwarding functions on the calls to the target functions. The following example also uses the `decltype` and trailing return type features to produce a forwarding function that forwards to one of the `do_work` functions. Calling the wrapper function with any argument results in a call to a `do_work` function if a suitable overload function exists. Extra temporaries are not created and overload resolution on the forwarding call resolves to the same overload as it would if the `do_work` function were called directly.

```

struct s1 *do_work(const int&);           // #1
struct s2 *do_work(const double&);       // #2
struct s3 *do_work(int&&);               // #3
struct s4 *do_work(double&&);            // #4
template <typename T> auto wrapper(T && a)->
    decltype(do_work(std::forward<T>(*static_cast<typename std::remove_reference<T>
::type*>(0))))
{
    return do_work(std::forward<T>(a));
}
template <typename T> void tPtr(T *t);
int main()
{
    int x;
    double y;
    tPtr<s1>(wrapper(x));    // calls #1
    tPtr<s2>(wrapper(y));    // calls #2
    tPtr<s3>(wrapper(0));    // calls #3
    tPtr<s4>(wrapper(1.0));  // calls #4
}




```

**Related information in the XL C/C++ Compiler Reference**



`-qlanglvl`

**Related information in the XL C/C++ Language Reference**

-  Reference collapsing(C++11)
-  The decltype(expression) type specifier (C++11)
-  Trailing return type (C++11)

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## Using visibility attributes (IBM extension)

Visibility attributes describe whether and how an entity defined in one module can be referenced or used in other modules. Visibility attributes affect entities with external linkage only, and cannot increase the visibility of other entities. By specifying visibility attributes for entities, you can export only the entities that are necessary to shared libraries. With this feature, you can get the following benefits:

- Decrease the size of shared libraries.
- Reduce the possibility of symbol collision.
- Allow more optimization for the compile and link phases.
- Improve the efficiency of dynamic linking.

### Supported types of entities

#### C++

The compiler supports visibility attributes for the following entities:

- function
- variable
- structure/union/class
- enumeration
- template
- namespace

#### C++

#### C




The compiler supports visibility attributes for the following entities:

- function
- variable








**Note:** Data types in the C language do not have external linkage, so you cannot specify visibility attributes for C data types.

#### C

**Related information in the *XL C/C++ Compiler Reference***

-  -qvisibility (IBM extension)
-  -qmkshrobj
-  #pragma GCC visibility push, #pragma GCC visibility pop (IBM extension)

**Related information in the *XL C/C++ Language Reference***

-  The visibility variable attribute (IBM extension)
-  The visibility function attribute (IBM extension)
-  The visibility type attribute (C++ only) (IBM extension)
-  The visibility namespace attribute (C++ only) (IBM extension)
-  Internal linkage
-  External linkage
-  No linkage

## Types of visibility attributes

The following table describes different visibility attributes.

*Table 19. Visibility attributes*

Attribute	Description
default	Indicates that external linkage entities have the default attribute in object files. These entities are exported in shared libraries, and can be preempted.
protected	Indicates that external linkage entities have the protected attribute in object files. These entities are exported in shared libraries, but cannot be preempted.
hidden	Indicates that external linkage entities have the hidden attribute in object files. These entities are not exported in shared libraries, but their addresses can be referenced indirectly through pointers.
internal	Indicates that external linkage entities have the internal attribute in object files. These entities are not exported in shared libraries, and their addresses are not available to other modules in shared libraries.
<b>Notes:</b> <ul style="list-style-type: none"> <li>In this release, the hidden and internal visibility attributes are the same. The addresses of the entities that are specified with either of these visibility attributes can be referenced indirectly through pointers.</li> </ul>	

Example: Differences among the default, protected, hidden, and internal visibility attributes

```
//a.c
#include <stdio.h>
void __attribute__((visibility("default"))) func1(){
    printf("func1 in the shared library");
}
void __attribute__((visibility("protected"))) func2(){
    printf("func2 in the shared library");
}
void __attribute__((visibility("hidden"))) func3(){
    printf("func3 in the shared library");
}
void __attribute__((visibility("internal"))) func4(){
    printf("func4 in the shared library");
}

//a.h
extern void func1();
extern void func2();
extern void func3();
extern void func4();
```

```

//b.c
#include "a.h"
void temp(){
    func1();
    func2();
}

//b.h
extern void temp();

//main.c
#include "a.h"
#include "b.h"

void func1(){
    printf("func1 in b.c");
}
void func2(){
    printf("func2 in b.c");
}
void main(){
    temp();
    // func3(); // error
    // func4(); // error
}

```

You can use the following commands to create a shared library named `libtest.so`:

```

xlc -c -qpic a.c b.c
xlc -qmkshrobj -o libtest.so a.o b.o

```

Then, you can dynamically link `libtest.so` during run time by using the following commands:

```

xlc main.c -L. -ltest -brtl -bexpall -o main
./main

```

The output of the example is:

```

func1 in b.c
func2 in the shared library

```

The visibility attribute of function `func1()` is default, so it is preempted by the function with the same name in `main.c`. The visibility attribute of function `func2()` is protected, so it cannot be preempted. The compiler always calls `func2()` that is defined in the shared library `libtest.so`. The visibility attribute of function `func3()` is hidden, so it is not exported in the shared library. The compiler issues a link error to indicate that the definition of `func3()` cannot be found. The same issue is with function `func4()` whose visibility attribute is internal.

## Rules of visibility attributes

### Priority of visibility attributes

The visibility attributes have a priority sequence, which is default < protected < hidden < internal. You can see Example 3 and Example 9 for reference.

### Rules of determining the visibility attributes



The visibility attribute of an entity is determined by the following rules:

1. If the entity has an explicitly specified visibility attribute, the specified visibility attribute takes effect.
2. Otherwise, if the entity has a pair of enclosing pragma directives, the visibility attribute that is specified by the pragma directives takes effect.
3. Otherwise, the setting of the **-qvisibility** option takes effect.

C

C++

The visibility attribute of an entity is determined by the following rules:

1. If the entity has an explicitly specified visibility attribute, the specified visibility attribute takes effect.
2. Otherwise, if the entity is a template instantiation or specialization, and the template has a visibility attribute, the visibility attribute of the entity is propagated from that of the template. See Example 1.
3. Otherwise, if the entity has any of the following enclosing contexts, the visibility attribute of this entity is propagated from that of the nearest context. See Example 2. For the details of propagation rules, see “Propagation rules (C++ only)” on page 98.
  - structure/class
  - enumeration
  - namespace
  - pragma directives

**Restriction:** Pragma directives do not affect the visibility attributes of class members and template specializations.

4. Otherwise, the visibility attribute of the entity is determined by the following visibility attribute settings. The visibility attribute that has the highest priority is the actual visibility attribute of the entity. See Example 3. For the priority of the visibility attributes, see Priority of visibility attributes.
  - The setting of the **-qvisibility** option.
  - The visibility attribute of the type of the entity, if the entity is a variable and its type has a visibility attribute.
  - The visibility attribute of the return type of the entity, if the entity is a function and its return type has a visibility attribute.
  - The visibility attributes of the parameter types of the entity, if the entity is a function and its parameter types have visibility attributes.
  - The visibility attributes of template arguments or template parameters of the entity, if the entity is a template and its arguments or parameters have visibility attributes.

#### Example 1

In the following example, template `template<typename T, typename U> B{}` has the protected visibility attribute. The visibility attribute is propagated to those of template specialization `template<> class B<char, char>{}`, partial specialization `template<typename T> class B<T, float>{}`, and all the types of template instantiations.

```
class __attribute__((visibility("internal"))) A{ vis_v_a;    //internal
//protected
```

```

template<typename T, typename U>
class __attribute__((visibility("protected"))) B{
    public:
        void func(){}
};

//protected
template<>
class B<char, char>{
    public:
        void func(){}
};

//protected
template<typename T>
class B<T, float>{
    public:
        void func(){}
};

B<int, int> a;    //protected
B<A, int> b;      //protected
B<char, char> c;  //protected
B<int, float> d;  //protected
B<A, float> e;    //protected

int main(){
    a.func();
    b.func();
    c.func();
    d.func();
    e.func();
}

```

## Example 2

In the following example, the nearest enclosing context of function `func()` is class `B`, so the visibility attribute of `func()` is propagated from that of class `B`, which is hidden. The nearest enclosing context of class `A` is the pragma directives whose setting is protected, so the visibility of class `A` is protected.

```

namespace __attribute__((visibility("internal"))) ns{
#pragma GCC visibility push(protected)
    class A{
        class __attribute__((visibility("hidden"))) B{
            int func(){};
        };
    };
#pragma GCC visibility pop
};

```

## Example 3

In the following example, the visibility attribute specified by the **-qvisibility** option is protected. The type of variable `vis_v_d` is class `CD`, whose visibility attribute is default. The visibility attribute that has a higher priority of these two attributes is protected, so the actual visibility attribute of variable `vis_v_d` is protected. The same rule applies to the determination of the visibility attributes of variables `vis_v_p`, `vis_v_h`, and `vis_v_i`. For functions `vis_f_fun1`, `vis_f_fun2`, and `vis_f_fun3`, their visibility attributes are determined by those of their parameter types, return types, and the setting of the **-qvisibility** option. For template functions `vis_f_template1` and `vis_f_template2`, their visibility attributes are determined by those of their template arguments, template parameters, function

parameter types, return types, and the setting of the **-qvisibility** option. The visibility attribute that has the highest priority takes effect.

```
//The -qvisibility=protected option is specified
class __attribute__((visibility("default"))) CD {} vis_v_d; //protected
class __attribute__((visibility("protected"))) CP {} vis_v_p; //protected
class __attribute__((visibility("hidden"))) CH {} vis_v_h; //hidden
class __attribute__((visibility("internal"))) CI {} vis_v_i; //internal

void vis_f_fun1(CH a, CP b, CD c, CI d) {} //internal
void vis_f_fun2(CD a) {} //protected
CH vis_f_fun3(CI a, CP b) {} //internal








template<class T, class U> T vis_f_template1(T t, U u){}
template<class T, int N> void vis_f_template2(T t, int i){}

int main(){
    vis_f_template1<CD, CH>(vis_v_d, vis_v_p); //hidden
    vis_f_template2<CD, 10>(vis_v_p, 10); // protected
}
```

C++

## Rules and restrictions of using the visibility attributes

When you specify visibility attributes for entities, consider the following rules and restrictions:

- You can specify visibility attributes only for entities that have external linkage. The compiler issues a warning message when you set the visibility attribute for entities with other linkages, and ignore the specified visibility attribute. See Example 4.
- You cannot specify different visibility attributes in the same declaration or definition of an entity; otherwise, the compiler issues an error message. See Example 5.
- If an entity has more than one declaration that is specified with different visibility attributes, the visibility attribute of the entity is the first visibility attribute that the compiler processes. See Example 6.
- You cannot specify visibility attributes in the typedef statements. See Example 7.
-  If type T has a visibility attribute, types T\*, T&, and T&& have the same visibility attribute with that of type T. See Example 8.
-  If a class and its enclosing classes do not have explicitly specified visibilities, and the visibility attribute of the class has a lower priority than those of its nonstatic member types and its bases classes, the compiler issues a warning message. See Example 9. For the priority of the visibility attributes, see Priority of visibility attributes. 
-  The visibility attribute of a namespace does not apply for the namespace with the same name. See Example 10. 
-  If you specify a visibility attribute for a global new or delete operator, the compiler issues a warning message to ignore the visibility attribute unless the visibility attribute is default. See Example 11. 

### Example 4

In this example, the compiler ignores the visibility attributes of variables m, i, and j, because m and i have internal linkage, and j has no linkage.

```
static int m __attribute__((visibility("protected")));
int n __attribute__((visibility("protected")));

int main(){
    int i __attribute__((visibility("protected")));
    static int j __attribute__((visibility("protected")));
}
```

#### Example 5

In this example, the compiler issues an error message to indicate that you cannot specify two different visibility attributes at the same time in the definition of variable m.

```
//error
int m __attribute__((visibility("hidden"))) __attribute__((visibility("protected")));
```

#### Example 6

In this example, the first declaration of function fun() that the compiler processes is extern void fun() \_\_attribute\_\_((visibility("hidden"))), so the visibility attribute of fun() is hidden.

```
extern void fun() __attribute__((visibility("hidden")));
extern void fun() __attribute__((visibility("protected")));

int main(){
    fun();
}
```

#### Example 7

In this example, the visibility attribute of variable vis\_v\_ti is default, which is not affected by the setting in the typedef statement.

```
//The -qvisibility=default option is specified.
typedef int __attribute__((visibility("protected"))) INT;
INT vis_v_ti = 1;
```



#### Example 8

In this example, the visibility attribute of class CP is protected, so the visibility attribute of CP\* and CP& is also protected.

```
class __attribute__((visibility("protected"))) CP {} vis_v_p;
class CP* vis_v_p_p = &vis_v_p; //protected
class CP& vis_v_l_r_p = vis_v_p; //protected
```

#### Example 9

In this example, the compiler accepts the default visibility attribute of class Derived1 because the visibility attribute is explicitly specified for class Derived1. The compiler also accepts the protected visibility attribute of class Derived2 because the visibility attribute is propagated from that of the enclosing class A. Class Derived3 does not have an explicitly specified visibility attribute or an enclosing class, and its visibility attribute is default. The compiler issues a warning message because the visibility attribute of class Derived3 has a lower priority than those of its parent class Base and the nonstatic member function fun().

```

//The -qvisibility=default option is specified.
//base class
struct __attribute__((visibility("hidden"))) Base{
    int vis_f_fun(){
        return 0;
    }
};

//Ok
struct __attribute__((visibility("default"))) Derived1: public Base{
    int vis_f_fun(){
        return Base::vis_f_fun();
    };
}vis_v_d;

//Ok
struct __attribute__((visibility("protected"))) A{
    struct Derived2: public Base{
        int vis_f_fun(){
            __attribute__((visibility("protected")))
        };
    }
};

//Warning
struct Derived3: public Base{
    //Warning
    int fun() __attribute__((visibility("protected"))){};
};

```

### Example 10

In this example, the visibility attribute of the definition of namespace X does not apply to the extension of namespace X.

```

//The -qvisibility=default option is specified.
//namespace definition
namespace X __attribute__((visibility("protected"))){
    int a; //protected
    int b; //protected
}
//namespace extension
namespace X {
    int c; //default
    int d; //default
}
//equivalent to namespace X
namespace Y {
    int __attribute__((visibility("protected"))) a; //protected
    int __attribute__((visibility("protected"))) b; //protected
    int c; //default
    int d; //default
}

```

### Example 11

In this example, the new and delete operators defined outside of class A are global functions, so the explicitly specified hidden visibility attribute does not take effect. The new and delete operations defined within class A are local ones, so you can specify visibility attributes for them.

```

#include <stddef.h>
//default
void* operator new(size_t) throw (std::bad_alloc) __attribute__((visibility("hidden")))
{
    return 0;
}

```

```

};
void operator delete(void*) throw () __attribute__((visibility("hidden"))){}

class A{
public:
    //hidden
    void* operator new(size_t) throw (std::bad_alloc) __attribute__((visibility("hidden")))
    {
        return 0;
    };
    void operator delete(void*) throw () __attribute__((visibility("hidden"))){}
};

```

C++

## Propagation rules (C++ only)

Visibility attributes can be propagated from one entity to other entities. The following table lists all the cases for visibility propagation.

Table 20. Propagation of visibility attributes

Original entity	Destination entities	Example
namespace	named namespaces that are defined in the original namespace	<pre> namespace A __attribute__((visibility("hidden"))){     // Namespace B has the hidden visibility attribute,     // which is propagated from namespace A.     namespace B{}     // The unnamed namespace does not have a visibility     // attribute.     namespace{} } </pre>
namespace	classes that are defined in the original namespace	<pre> namespace A __attribute__((visibility("hidden"))){     // Class B has the hidden visibility attribute,     // which is propagated from namespace A.     class B;     // Object x has the hidden visibility attribute,     // which is propagated from namespace A.     class{} x; } </pre>
namespace	functions that are defined in the original namespace	<pre> namespace A __attribute__((visibility("hidden"))){     // Function fun() has the hidden visibility     // attribute, which is propagated from namespace A.     void fun(){}; } </pre>
namespace	objects that are defined in the original namespace	<pre> namespace A __attribute__((visibility("hidden"))){     // Variable m has the hidden visibility attribute,     // which is propagated from namespace A.     int m; } </pre>
class	member classes	<pre> class __attribute__((visibility("hidden"))) A{     // Class B has the hidden visibility attribute,     // which is propagated from class A.     class B{}; } </pre>

Table 20. Propagation of visibility attributes (continued)

Original entity	Destination entities	Example
class	member functions or static member variables	<pre> class __attribute__((visibility("hidden"))) A{     // Function fun() has the hidden visibility     // attribute, which is propagated from class A.     void fun(){};     // Static variable m has the hidden visibility     // attribute, which is propagated from class A.     static int m; } </pre>
template	template instantiations/ template specifications/ template partial specializations	<pre> template&lt;typename T, typename U&gt; class __attribute__((visibility("hidden"))) A{     public:         void fun(){}; };  // Template instantiation class A&lt;int, char&gt; has the // hidden visibility attribute, which is propagated // from template class A(T,U). class A&lt;int, char&gt;{     public:         void fun(){}; };  // Template specification // template&lt;&gt; class A&lt;double, double&gt; has the hidden // visibility attribute, which is propagated // from template class A(T,U). template&lt;&gt; class A&lt;double, double&gt;{     public:         void fun(){}; };  // Template partial specification // template&lt;typename T&gt; class A&lt;T, char&gt; has the // hidden visibility attribute, which is propagated // from template class A(T,U). template&lt;typename T&gt; class A&lt;T, char&gt;{     public:         void fun(){}; }; </pre>
template argument/ parameter	template instantiations/ template specifications/ template partial specializations	<pre> template&lt;typename T&gt; void fun1(){} template&lt;typename T&gt; void fun2(T){}  class M __attribute__((visibility("hidden"))){} m;  // Template instantiation fun1&lt;M&gt;() has the hidden // visibility attribute, which is propagated from // template argument M. fun1&lt;M&gt;();  // Template instantiation fun2&lt;M&gt;(M) has the hidden // visibility attribute, which is propagated from // template parameter m. fun2(m);  // Template specification fun1&lt;M&gt;() has the hidden // visibility attribute, which is propagated from // template argument M. template&lt;&gt; void fun1&lt;M&gt;(); </pre>

Table 20. Propagation of visibility attributes (continued)

Original entity	Destination entities	Example
inline function	static local variables	<pre>inline void __attribute__((visibility("hidden"))) fun(){     // Variable m has the hidden visibility attribute,     // which is propagated from inline function fun().     static int m = 4; }</pre>
type	entities of the original type	<pre>class __attribute__((visibility("hidden"))) A {};  // Object x has the hidden visibility attribute, // which is propagated from class A. class A x;</pre>
function return type	function	<pre>class __attribute__((visibility("hidden"))) A{}; // Function fun() has the hidden visibility attribute, // which is propagated from function return type A. A fun();</pre>
function parameter type	function	<pre>class __attribute__((visibility("hidden"))) A{}; // Function fun(class A) has the hidden visibility // attribute, which is propagated from function // parameter type A. void fun(class A);</pre>

## Specifying visibility attributes using the `-qvisibility` option

You can use the `-qvisibility` option to globally set visibility attributes for external linkage entities in your program. The entities have the visibility attribute that is specified by the `-qvisibility` option if they do not get visibility attributes from pragma directives, explicitly specified attributes, or propagation rules.

## Specifying visibility attributes using pragma preprocessor directives

You can selectively set visibility attributes for entities by using pairs of the `#pragma GCC visibility push` and `#pragma GCC visibility pop` preprocessor directives throughout your source program.

The compiler supports nested visibility pragma preprocessor directives. If entities are included in several pairs of the nested `#pragma GCC visibility push` and `#pragma GCC visibility pop` directives, the nearest pair of directives takes effect. See Example 1.

You must not specify the visibility pragma directives for header files. Otherwise, your program might exhibit undefined behaviors. See Example 2.

➤ **C++** Visibility pragma directives `#pragma GCC visibility push` and `#pragma GCC visibility pop` affect only namespace-scope declarations. Class members and template specializations are not affected. See Example 3 and Example 4. **C++** ◀

## Examples

### Example 1

In this example, the function and variables have the visibility attributes that are specified by their nearest pairs of pragma preprocessor directives.

```
#pragma GCC visibility push(default)
namespace ns
{
    void vis_f_fun() {} //default
# pragma GCC visibility push(internal)
    int vis_v_i; //internal
# pragma GCC visibility push(protected)
    int vis_v_j; //protected
# pragma GCC visibility push(hidden)
    int vis_v_k; //hidden
# pragma GCC visibility pop
# pragma GCC visibility pop
# pragma GCC visibility pop
}
#pragma GCC visibility pop
```

## Example 2

In this example, the compiler issues a link error message to indicate that the definition of the `printf()` library function cannot be found.

```
#pragma GCC visibility push(hidden)
#include <stdio.h>
#pragma GCC visibility pop

int main(){
    printf("hello world!");
    return 0;
}
```

➤ C++

## Example 3

In this example, the visibility attribute of class members `vis_v_i` and `vis_f_fun()` is hidden. The visibility attribute is propagated from that of the class, but is not affected by the pragma directives.

```
class __attribute__((visibility("hidden"))) A{
#pragma GCC visibility push(protected)
public:
    static int vis_v_i;
    void vis_f_fun() {}
#pragma GCC visibility pop
} vis_v_a;
```

## Example 4

In this example, the visibility attribute of function `vis_f_fun()` is hidden. The visibility attribute is propagated from that of the template specialization or partial specialization, but is not affected by the pragma directives.

```
namespace ns{
#pragma GCC visibility push(hidden)
template <typename T, typename U> class TA{
public:
    void vis_f_fun(){}
};
#pragma GCC visibility pop

#pragma GCC visibility push(protected)
//The visibility attribute of the template specialization is hidden.
template <> class TA<char, char>{
public:
```

```

        void vis_f_fun(){}
    };
#pragma GCC visibility pop

#pragma GCC visibility push(default)
//The visibility attribute of the template partial specialization is hidden.
template <typename T> class TA<T, long>{
    public:
        void vis_f_fun(){}
};
#pragma GCC visibility pop

```

C++ ◀

---

## Chapter 11. Using the high performance libraries

IBM XL C/C++ for Linux, V13.1 is shipped with a set of libraries for high-performance mathematical computing:

- The Mathematical Acceleration Subsystem (MASS) is a set of libraries of tuned mathematical intrinsic functions that provide improved performance over the corresponding standard system math library functions. MASS is described in “Using the Mathematical Acceleration Subsystem libraries (MASS).”
- The Basic Linear Algebra Subprograms (BLAS) are a set of routines which provide matrix/vector multiplication functions tuned for PowerPC architectures. The BLAS functions are described in “Using the Basic Linear Algebra Subprograms – BLAS” on page 115.

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### Using the Mathematical Acceleration Subsystem libraries (MASS)

XL C/C++ is shipped with a set of Mathematical Acceleration Subsystem (MASS) libraries for high-performance mathematical computing.

The MASS libraries consist of a library of scalar C/C++ functions described in “Using the scalar library” on page 104, a set of vector libraries tuned for specific architectures described in “Using the vector libraries” on page 106,, and a set of SIMD libraries tuned for specific architectures described in “Using the SIMD libraries” on page 111. The functions contained in both scalar and vector libraries are automatically called at certain levels of optimization, but you can also call them explicitly in your programs. Note that accuracy and exception handling might not be identical in MASS functions and system library functions.

The MASS functions must run with the default rounding mode and floating-point exception trapping settings.

When you compile programs with any of the following sets of options:

- **-qhot -qignerrno -qnostrict**
- **-qhot -qignerrno -qstrict=nolibrary**
- **-qhot -O3**
- **-O4**
- **-O5**

the compiler automatically attempts to vectorize calls to system math functions by calling the equivalent MASS vector functions (with the exceptions of functions `vdnint`, `vdint`, `vcosin`, `vscosin`, `vqdr`, `vsqdr`, `vrqdr`, `vsrqdr`, `vpopcnt4`, `vpopcnt8`, `vexp2`, `vexp2m1`, `vexp2`, `vexp2m1`, `vlog2`, `vlog2lp`, `vslog2`, and `vslog2lp`). If it cannot vectorize, it automatically tries to call the equivalent MASS scalar functions. For automatic vectorization or scalarization, the compiler uses versions of the MASS functions contained in the XLOPT library `libxlopt.a`.


In addition to any of the preceding sets of options, when the **-qipa** option is in effect, if the compiler cannot vectorize, it tries to inline the MASS scalar functions before deciding to call them.

“Compiling and linking a program with MASS” on page 114 describes how to compile and link a program that uses the MASS libraries, and how to selectively use the MASS scalar library functions in conjunction with the regular system libraries.

**Note:** On Linux, 32-bit and 64-bit objects cannot be combined in the same library, so two versions of each of the scalar, vector and SIMD, vector and SIMD libraries are shipped with the compiler:

Application type	Scalar libraries	Vector libraries	SIMD libraries
32-bit applications	libmass.a	libmassvp*.a	libmass_simd*.a
64-bit applications	libmass_64.a	libmassvp*_64.a	libmass_simd_64.a

#### Related external information

 Mathematical Acceleration Subsystem website, available at <http://www.ibm.com/software/awdtools/mass/>

## Using the scalar library

The MASS scalar libraries `libmass.a` (32-bit) and `libmass_64.a` (64-bit) contain an accelerated set of frequently used math intrinsic functions that provide improved performance over the corresponding standard system library functions. The MASS scalar functions are used when explicitly linking `libmass.a` or `libmass_64.a`.

If you want to explicitly call the MASS scalar functions, you can take the following steps:

1. Provide the prototypes for the functions (except `anint`, `cosisin`, `dnint`, `sincos`, and `rsqrt`), by including `math.h` in your source files.
2. Provide the prototypes for `anint`, `cosisin`, `dnint`, `sincos`, and `rsqrt`, by including `mass.h` in your source files.
3. Link the MASS scalar library `libmass.a` (or the 64-bit version, `libmass_64.a`) with your application. For instructions, see “Compiling and linking a program with MASS” on page 114.

The MASS scalar functions accept double-precision parameters and return a double-precision result, or accept single-precision parameters and return a single-precision result, except `sincos` which gives 2 double-precision results. They are summarized in Table 21.

Table 21. MASS scalar functions

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
<code>acos</code>	<code>acosf</code>	Returns the arccosine of x	<code>double acos (double x);</code>	<code>float acosf (float x);</code>
<code>acosh</code>	<code>acoshf</code>	Returns the hyperbolic arccosine of x	<code>double acosh (double x);</code>	<code>float acoshf (float x);</code>
	<code>anint</code>	Returns the rounded integer value of x		<code>float anint (float x);</code>
<code>asin</code>	<code>asinf</code>	Returns the arcsine of x	<code>double asin (double x);</code>	<code>float asinf (float x);</code>
<code>asinh</code>	<code>asinhf</code>	Returns the hyperbolic arcsine of x	<code>double asinh (double x);</code>	<code>float asinhf (float x);</code>

Table 21. MASS scalar functions (continued)

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
atan2	atan2f	Returns the arctangent of $x/y$	double atan2 (double x, double y);	float atan2f (float x, float y);
atan	atanf	Returns the arctangent of $x$	double atan (double x);	float atanf (float x);
atanh	atanhf	Returns the hyperbolic arctangent of $x$	double atanh (double x);	float atanhf (float x);
cbrt	cbrtf	Returns the cube root of $x$	double cbrt (double x);	float cbrtf (float x);
copysign	copysignf	Returns $x$ with the sign of $y$	double copysign (double x, double y);	float copysignf (float x);
cos	cosf	Returns the cosine of $x$	double cos (double x);	float cosf (float x);
cosh	coshf	Returns the hyperbolic cosine of $x$	double cosh (double x);	float coshf (float x);
cosisin		Returns a complex number with the real part the cosine of $x$ and the imaginary part the sine of $x$ .	double_Complex cosisin (double);	
dnint		Returns the nearest integer to $x$ (as a double)	double dnint (double x);	
erf	erff	Returns the error function of $x$	double erf (double x);	float erff (float x);
erfc	erfcf	Returns the complementary error function of $x$	double erfc (double x);	float erfcf (float x);
exp	expf	Returns the exponential function of $x$	double exp (double x);	float expf (float x);
expm1	expm1f	Returns (the exponential function of $x$ ) - 1	double expm1 (double x);	float expm1f (float x);
hypot	hypotf	Returns the square root of $x^2 + y^2$	double hypot (double x, double y);	float hypotf (float x, float y);
lgamma	lgammaf	Returns the natural logarithm of the absolute value of the Gamma function of $x$	double lgamma (double x);	float lgammaf (float x);
log	logf	Returns the natural logarithm of $x$	double log (double x);	float logf (float x);
log10	log10f	Returns the base 10 logarithm of $x$	double log10 (double x);	float log10f (float x);
log1p	log1pf	Returns the natural logarithm of $(x + 1)$	double log1p (double x);	float log1pf (float x);
pow	powf	Returns $x$ raised to the power $y$	double pow (double x, double y);	float powf (float x, float y);
rsqrt		Returns the reciprocal of the square root of $x$	double rsqrt (double x);	


Table 21. MASS scalar functions (continued)

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
sin	sinf	Returns the sine of x	double sin (double x);	float sinf (float x);
sincos		Sets *s to the sine of x and *c to the cosine of x	void sincos (double x, double* s, double* c);	
sinh	sinhf	Returns the hyperbolic sine of x	double sinh (double x);	float sinhf (float x);
sqrt		Returns the square root of x	double sqrt (double x);	
tan	tanf	Returns the tangent of x	double tan (double x);	float tanf (float x);
tanh	tanhf	Returns the hyperbolic tangent of x	double tanh (double x);	float tanhf (float x);

#### Notes:

- The trigonometric functions (sin, cos, tan) return NaN (Not-a-Number) for large arguments (where the absolute value is greater than  $2^{50}\pi$ ).
- In some cases, the MASS functions are not as accurate as the ones in the `libm.a` library, and they might handle edge cases differently (`sqrt(Inf)`, for example).
- See the Mathematical Acceleration Subsystem website for accuracy comparisons with `libm.a`.

#### Related external information

 Mathematical Acceleration Subsystem website, available at <http://www.ibm.com/software/awdtools/mass/>

## Using the vector libraries

If you want to explicitly call any of the MASS vector functions, you can do so by including `massv.h` in your source files and linking your application with the appropriate vector library. (Information about linking is provided in “Compiling and linking a program with MASS” on page 114.)

#### **libmassvp5.a**

Contains functions that have been tuned for the POWER5 architecture.

#### **libmassvp6.a**

Contains functions that have been tuned for the POWER6® architecture.

#### **libmassvp7.a**

Contains functions that have been tuned for the POWER7 architecture.

#### **libmassvp8.a**

Contains functions that have been tuned for the POWER8 architecture.

The single-precision and double-precision floating-point functions contained in the vector libraries are summarized in Table 22 on page 107. The integer functions contained in the vector libraries are summarized in Table 23 on page 110. Note that in C and C++ applications, only call by reference is supported, even for scalar arguments.

With the exception of a few functions (described in the following paragraph), all of the floating-point functions in the vector libraries accept three parameters:

- A double-precision (for double-precision functions) or single-precision (for single-precision functions) vector output parameter
- A double-precision (for double-precision functions) or single-precision (for single-precision functions) vector input parameter
- An integer vector-length parameter.

The functions are of the form

*function\_name* (*y*,*x*,*n*)

where *y* is the target vector, *x* is the source vector, and *n* is the vector length. The parameters *y* and *x* are assumed to be double-precision for functions with the prefix *v*, and single-precision for functions with the prefix *vs*. As an example, the following code:

```
#include <massv.h>

double x[500], y[500];
int n;
n = 500;
...
vexp (y, x, &n);
```

outputs a vector *y* of length 500 whose elements are  $\exp(x[i])$ , where  $i=0,\dots,499$ .

The functions *vdiv*, *vsincos*, *vpow*, and *vatan2* (and their single-precision versions, *vsdiv*, *vssincos*, *vspow*, and *vsatan2*) take four arguments. The functions *vdiv*, *vpow*, and *vatan2* take the arguments (*z*,*x*,*y*,*n*). The function *vdiv* outputs a vector *z* whose elements are  $x[i]/y[i]$ , where  $i=0,\dots,n-1$ . The function *vpow* outputs a vector *z* whose elements are  $x[i]^{y[i]}$ , where  $i=0,\dots,n-1$ . The function *vatan2* outputs a vector *z* whose elements are  $\text{atan}(x[i]/y[i])$ , where  $i=0,\dots,n-1$ . The function *vsincos* takes the arguments (*y*,*z*,*x*,*n*), and outputs two vectors, *y* and *z*, whose elements are  $\sin(x[i])$  and  $\cos(x[i])$ , respectively.

In *vcosisin*(*y*,*x*,*n*) and *vscosisin*(*y*,*x*,*n*), *x* is a vector of *n* elements and the function outputs a vector *y* of *n* \_\_Complex elements of the form  $(\cos(x[i]), \sin(x[i]))$ .

Table 22. MASS floating-point vector functions

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
<i>vacos</i>	<i>vsacos</i>	Sets <i>y</i> [ <i>i</i> ] to the arc cosine of <i>x</i> [ <i>i</i> ], for $i=0,\dots,n-1$	<code>void vacos (double y[], double x[], int *n);</code>	<code>void vsacos (float y[], float x[], int *n);</code>
<i>vacosh</i>	<i>vsacosh</i>	Sets <i>y</i> [ <i>i</i> ] to the hyperbolic arc cosine of <i>x</i> [ <i>i</i> ], for $i=0,\dots,n-1$	<code>void vacosh (double y[], double x[], int *n);</code>	<code>void vsacosh (float y[], float x[], int *n);</code>
<i>vasin</i>	<i>vsasin</i>	Sets <i>y</i> [ <i>i</i> ] to the arc sine of <i>x</i> [ <i>i</i> ], for $i=0,\dots,n-1$	<code>void vasin (double y[], double x[], int *n);</code>	<code>void vsasin (float y[], float x[], int *n);</code>
<i>vasinh</i>	<i>vsasinh</i>	Sets <i>y</i> [ <i>i</i> ] to the hyperbolic arc sine of <i>x</i> [ <i>i</i> ], for $i=0,\dots,n-1$	<code>void vasinh (double y[], double x[], int *n);</code>	<code>void vsasinh (float y[], float x[], int *n);</code>
<i>vatan2</i>	<i>vsatan2</i>	Sets <i>z</i> [ <i>i</i> ] to the arc tangent of <i>x</i> [ <i>i</i> ]/ <i>y</i> [ <i>i</i> ], for $i=0,\dots,n-1$	<code>void vatan2 (double z[], double x[], double y[], int *n);</code>	<code>void vsatan2 (float z[], float x[], float y[], int *n);</code>
<i>vatanh</i>	<i>vsatanh</i>	Sets <i>y</i> [ <i>i</i> ] to the hyperbolic arc tangent of <i>x</i> [ <i>i</i> ], for $i=0,\dots,n-1$	<code>void vatanh (double y[], double x[], int *n);</code>	<code>void vsatanh (float y[], float x[], int *n);</code>

Table 22. MASS floating-point vector functions (continued)

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
vcbrt	vscbrt	Sets $y[i]$ to the cube root of $x[i]$ , for $i=0,..,*n-1$	void vcbrt (double y[], double x[], int *n);	void vscbrt (float y[], float x[], int *n);
vcos	vscos	Sets $y[i]$ to the cosine of $x[i]$ , for $i=0,..,*n-1$	void vcos (double y[], double x[], int *n);	void vscos (float y[], float x[], int *n);
vcosh	vscosh	Sets $y[i]$ to the hyperbolic cosine of $x[i]$ , for $i=0,..,*n-1$	void vcosh (double y[], double x[], int *n);	void vscosh (float y[], float x[], int *n);
vcosisin	vscosisin	Sets the real part of $y[i]$ to the cosine of $x[i]$ and the imaginary part of $y[i]$ to the sine of $x[i]$ , for $i=0,..,*n-1$	void vcosisin (double _Complex y[], double x[], int *n);	void vscosisin (float _Complex y[], float x[], int *n);
vdint		Sets $y[i]$ to the integer truncation of $x[i]$ , for $i=0,..,*n-1$	void vdint (double y[], double x[], int *n);	
vddiv	vsdiv	Sets $z[i]$ to $x[i]/y[i]$ , for $i=0,..,*n-1$	void vddiv (double z[], double x[], double y[], int *n);	void vsdiv (float z[], float x[], float y[], int *n);
vdnint		Sets $y[i]$ to the nearest integer to $x[i]$ , for $i=0,..,*n-1$	void vdnint (double y[], double x[], int *n);	
verf	vserf	Sets $y[i]$ to the error function of $x[i]$ , for $i=0,..,*n-1$	void verf (double y[], double x[], int *n);	void vs erf (float y[], float x[], int *n);
verfc	vserfc	Sets $y[i]$ to the complimentary error function of $x[i]$ , for $i=0,..,*n-1$	void verfc (double y[], double x[], int *n);	void vs erfc (float y[], float x[], int *n);
vexp	vsexp	Sets $y[i]$ to the exponential function of $x[i]$ , for $i=0,..,*n-1$	void vexp (double y[], double x[], int *n);	void vsexp (float y[], float x[], int *n);
vexp2	vsexp2	Sets $y[i]$ to 2 raised to the power of $x[i]$ , for $i=1,..,*n-1$	void vexp2 (double y[], double x[], int *n);	void vsexp2 (float y[], float x[], int *n);
vexpm1	vsexpm1	Sets $y[i]$ to (the exponential function of $x[i]$ )-1, for $i=0,..,*n-1$	void vexpm1 (double y[], double x[], int *n);	void vsexpm1 (float y[], float x[], int *n);
vexp2m1	vsexp2m1	Sets $y[i]$ to (2 raised to the power of $x[i]$ ) - 1, for $i=1,..,*n-1$	void vexp2m1 (double y[], double x[], int *n);	void vsexp2m1 (float y[], float x[], int *n);
vhypot	vshypot	Sets $z[i]$ to the square root of the sum of the squares of $x[i]$ and $y[i]$ , for $i=0,..,*n-1$	void vhypot (double z[], double x[], double y[], int *n);	void vshypot (float z[], float x[], float y[], int *n);
vlog	vslog	Sets $y[i]$ to the natural logarithm of $x[i]$ , for $i=0,..,*n-1$	void vlog (double y[], double x[], int *n);	void vslog (float y[], float x[], int *n);

Table 22. MASS floating-point vector functions (continued)

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
vlog2	vslog2	Sets $y[i]$ to the base-2 logarithm of $x[i]$ , for $i=1,..,*n-1$	void vlog2 (double y[], double x[], int *n);	void vslog2 (float y[], float x[], int *n);
vlog10	vslog10	Sets $y[i]$ to the base-10 logarithm of $x[i]$ , for $i=0,..,*n-1$	void vlog10 (double y[], double x[], int *n);	void vslog10 (float y[], float x[], int *n);
vlog1p	vslog1p	Sets $y[i]$ to the natural logarithm of $(x[i]+1)$ , for $i=0,..,*n-1$	void vlog1p (double y[], double x[], int *n);	void vslog1p (float y[], float x[], int *n);
vlog21p	vslog21p	Sets $y[i]$ to the base-2 logarithm of $(x[i]+1)$ , for $i=1,..,*n-1$	void vlog21p (double y[], double x[], int *n);	void vslog21p (float y[], float x[], int *n);
vpow	vspow	Sets $z[i]$ to $x[i]$ raised to the power $y[i]$ , for $i=0,..,*n-1$	void vpow (double z[], double x[], double y[], int *n);	void vspow (float z[], float x[], float y[], int *n);
vqdrft	vsqdrft	Sets $y[i]$ to the fourth root of $x[i]$ , for $i=0,..,*n-1$	void vqdrft (double y[], double x[], int *n);	void vsqdrft (float y[], float x[], int *n);
vrbrft	vsrbrft	Sets $y[i]$ to the reciprocal of the cube root of $x[i]$ , for $i=0,..,*n-1$	void vrbrft (double y[], double x[], int *n);	void vsrbrft (float y[], float x[], int *n);
vrec	vsrec	Sets $y[i]$ to the reciprocal of $x[i]$ , for $i=0,..,*n-1$	void vrec (double y[], double x[], int *n);	void vsrec (float y[], float x[], int *n);
vrqdrft	vsrqdrft	Sets $y[i]$ to the reciprocal of the fourth root of $x[i]$ , for $i=0,..,*n-1$	void vrqdrft (double y[], double x[], int *n);	void vsrqdrft (float y[], float x[], int *n);
vrqrt	vsrqrt	Sets $y[i]$ to the reciprocal of the square root of $x[i]$ , for $i=0,..,*n-1$	void vrqrt (double y[], double x[], int *n);	void vsrqrt (float y[], float x[], int *n);
vsin	vssin	Sets $y[i]$ to the sine of $x[i]$ , for $i=0,..,*n-1$	void vsin (double y[], double x[], int *n);	void vssin (float y[], float x[], int *n);
vsincos	vssincos	Sets $y[i]$ to the sine of $x[i]$ and $z[i]$ to the cosine of $x[i]$ , for $i=0,..,*n-1$	void vsincos (double y[], double z[], double x[], int *n);	void vssincos (float y[], float z[], float x[], int *n);
vsinh	vssinh	Sets $y[i]$ to the hyperbolic sine of $x[i]$ , for $i=0,..,*n-1$	void vsinh (double y[], double x[], int *n);	void vssinh (float y[], float x[], int *n);
vsqrt	vssqrt	Sets $y[i]$ to the square root of $x[i]$ , for $i=0,..,*n-1$	void vsqrt (double y[], double x[], int *n);	void vssqrt (float y[], float x[], int *n);
vtan	vstan	Sets $y[i]$ to the tangent of $x[i]$ , for $i=0,..,*n-1$	void vtan (double y[], double x[], int *n);	void vstan (float y[], float x[], int *n);
vtanh	vstanh	Sets $y[i]$ to the hyperbolic tangent of $x[i]$ , for $i=0,..,*n-1$	void vtanh (double y[], double x[], int *n);	void vstanh (float y[], float x[], int *n);

Integer functions are of the form *function\_name* ( $x[]$ ,  $*n$ ), where  $x[]$  is a vector of 4-byte (for vpopcnt4) or 8-byte (for vpopcnt8) numeric objects (integral or floating-point), and  $*n$  is the vector length.

Table 23. MASS integer vector library functions

Function	Description	Prototype
vpopcnt4	Returns the total number of 1 bits in the concatenation of the binary representation of $x[i]$ , for $i=0,\dots,*n-1$ , where $x$ is a vector of 32-bit objects.	unsigned int vpopcnt4 (void *x, int *n)
vpopcnt8	Returns the total number of 1 bits in the concatenation of the binary representation of $x[i]$ , for $i=0,\dots,*n-1$ , where $x$ is a vector of 64-bit objects.	unsigned int vpopcnt8 (void *x, int *n)

## Overlap of input and output vectors

In most applications, the MASS vector functions are called with disjoint input and output vectors; that is, the two vectors do not overlap in memory. Another common usage scenario is to call them with the same vector for both input and output parameters (for example, `vsin (y, y, &n)`). Other kinds of overlap (where input and output vectors are neither disjoint nor identical) should be avoided, since they may produce unexpected results:

- For calls to vector functions that take one input and one output vector (for example, `vsin (y, x, &n)`):  
The vectors  $x[0:n-1]$  and  $y[0:n-1]$  must be either disjoint or identical, or unexpected results may be obtained.
- For calls to vector functions that take two input vectors (for example, `vatan2 (y, x1, x2, &n)`):  
The previous restriction applies to both pairs of vectors  $y,x1$  and  $y,x2$ . That is,  $y[0:n-1]$  and  $x1[0:n-1]$  must be either disjoint or identical; and  $y[0:n-1]$  and  $x2[0:n-1]$  must be either disjoint or identical.
- For calls to vector functions that take two output vectors (for example, `vsincos (y1, y2, x, &n)`):  
The above restriction applies to both pairs of vectors  $y1,x$  and  $y2,x$ . That is,  $y1[0:n-1]$  and  $x[0:n-1]$  must be either disjoint or identical; and  $y2[0:n-1]$  and  $x[0:n-1]$  must be either disjoint or identical. Also, the vectors  $y1[0:n-1]$  and  $y2[0:n-1]$  must be disjoint.

## Alignment of input and output vectors

To get the best performance from the POWER7 and POWER8 vector libraries, align the input and output vectors on 16-byte boundaries.

## Consistency of MASS vector functions

All the functions in the MASS vector libraries are consistent, in the sense that a given input value will always produce the same result, regardless of its position in the vector, and regardless of the vector length.

**Related information in the XL C/C++ Compiler Reference**



-D

**Related external information**



Mathematical Acceleration Subsystem website, available at <http://www.ibm.com/software/awdtools/mass/>

## Using the SIMD libraries

The MASS SIMD library `libmass_simdp7.a`, `libmass_simdp7_64.a`, `libmass_simdp8.a` or `libmass_simdp8_64.a` contains a set of frequently used math intrinsic functions that provide improved performance over the corresponding standard system library functions. If you want to use the MASS SIMD functions, you can do so as follows:

1. Provide the prototypes for the functions by including `mass_simd.h` in your source files.
2. Link the MASS SIMD library `libmass_simdp7.a`, `libmass_simdp7_64.a`, `libmass_simdp8.a` or `libmass_simdp8_64.a` with your application. For instructions, see “Compiling and linking a program with MASS” on page 114.

The single/double-precision MASS SIMD functions accept single/double-precision arguments and return single/double-precision results. They are summarized in Table 24.

Table 24. MASS SIMD functions

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
<code>acosd2</code>	<code>acosf4</code>	Computes the arc cosine of each element of <code>vx</code> .	<code>vector double acosd2 (vector double vx);</code>	<code>vector float acosf4 (vector float vx);</code>
<code>acoshd2</code>	<code>acoshf4</code>	Computes the arc hyperbolic cosine of each element of <code>vx</code> .	<code>vector double acoshd2 (vector double vx);</code>	<code>vector float acoshf4 (vector float vx);</code>
<code>asind2</code>	<code>asinf4</code>	Computes the arc sine of each element of <code>vx</code> .	<code>vector double asind2 (vector double vx);</code>	<code>vector float asinf4 (vector float vx);</code>
<code>asinhd2</code>	<code>asinhf4</code>	Computes the arc hyperbolic sine of each element of <code>vx</code> .	<code>vector double asinhd2 (vector double vx);</code>	<code>vector float asinhf4 (vector float vx);</code>
<code>atand2</code>	<code>atanf4</code>	Computes the arc tangent of each element of <code>vx</code> .	<code>vector double atand2 (vector double vx);</code>	<code>vector float atanf4 (vector float vx);</code>
<code>atan2d2</code>	<code>atan2f4</code>	Computes the arc tangent of each element of <code>vx/vy</code> .	<code>vector double atan2d2 (vector double vx, vector double vy);</code>	<code>vector float atan2f4 (vector float vx, vector float vy);</code>
<code>atanhd2</code>	<code>atanhf4</code>	Computes the arc hyperbolic tangent of each element of <code>vx</code> .	<code>vector double atanhd2 (vector double vx);</code>	<code>vector float atanhf4 (vector float vx);</code>
<code>cbrtd2</code>	<code>cbrtf4</code>	Computes the cube root of each element of <code>vx</code> .	<code>vector double cbrtd2 (vector double vx);</code>	<code>vector float cbrtf4 (vector float vx);</code>
<code>cosd2</code>	<code>cosf4</code>	Computes the cosine of each element of <code>vx</code> .	<code>vector double cosd2 (vector double vx);</code>	<code>vector float cosf4 (vector float vx);</code>
<code>coshd2</code>	<code>coshf4</code>	Computes the hyperbolic cosine of each element of <code>vx</code> .	<code>vector double coshd2 (vector double vx);</code>	<code>vector float coshf4 (vector float vx);</code>

Table 24. MASS SIMD functions (continued)

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
cosisind2	cosisinf4	Computes the cosine and sine of each element of x, and stores the results in y and z as follows:  cosisind2 (x,y,z) sets y and z to {cos(x1), sin(x1)} and {cos(x2), sin(x2)} where x={x1,x2}.  cosisinf4 (x,y,z) sets y and z to {cos(x1), sin(x1), cos(x2), sin(x2)} and {cos(x3), sin(x3), cos(x4), sin(x4)} where x={x1,x2,x3,x4}.	void cosisind2 (vector double x, vector double *y, vector double *z)	void cosisinf4 (vector float x, vector float *y, vector float *z)
divd2	divf4	Computes the quotient vx/vy.	vector double divd2 (vector double vx, vector double vy);	vector float divf4 (vector float vx, vector float vy);
erfcd2	erfcf4	Computes the complementary error function of each element of vx.	vector double erfcd2 (vector double vx);	vector float erfcf4 (vector float vx);
erfd2	erff4	Computes the error function of each element of vx.	vector double erfd2 (vector double vx);	vector float erff4 (vector float vx);
expd2	expf4	Computes the exponential function of each element of vx.	vector double expd2 (vector double vx);	vector float expf4 (vector float vx);
exp2d2	exp2f4	Computes 2 raised to the power of each element of vx.	vector double exp2d2 (vector double vx);	vector float exp2f4 (vector float vx);
expm1d2	expm1f4	Computes (the exponential function of each element of vx) - 1.	vector double expm1d2 (vector double vx);	vector float expm1f4 (vector float vx);
exp2m1d2	exp2m1f4	Computes (2 raised to the power of each element of vx) -1.	vector double exp2m1d2 (vector double vx);	vector float exp2m1f4 (vector float vx);
hypotd2	hypotf4	For each element of vx and the corresponding element of vy, computes $\sqrt{x*x+y*y}$ .	vector double hypotd2 (vector double vx, vector double vy);	vector float hypotf4 (vector float vx, vector float vy);
lgammad2	lgammaf4	Computes the natural logarithm of the absolute value of the Gamma function of each element of vx .	vector double lgammad2 (vector double vx);	vector float lgammaf4 (vector float vx);

Table 24. MASS SIMD functions (continued)

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
logd2	logf4	Computes the natural logarithm of each element of vx.	vector double logd2 (vector double vx);	vector float logf4 (vector float vx);
log2d2	log2f4	Computes the base-2 logarithm of each element of vx.	vector double log2d2 (vector double vx);	vector float log2f4 (vector float vx);
log10d2	log10f4	Computes the base-10 logarithm of each element of vx.	vector double log10d2 (vector double vx);	vector float log10f4 (vector float vx);
log1pd2	log1pf4	Computes the natural logarithm of each element of (vx + 1).	vector double log1pd2 (vector double vx);	vector float log1pf4 (vector float vx);
log21pd2	log21pf4	Computes the base-2 logarithm of each element of (vx + 1).	vector double log21pd2 (vector double vx);	vector float log21pf4 (vector float vx);
powd2	powf4	Computes each element of vx raised to the power of the corresponding element of vy.	vector double powd2 (vector double vx, vector double vy);	vector float powf4 (vector float vx, vector float vy);
qdrtd2	qdrtf4	Computes the quad root of each element of vx.	vector double qdrtd2 (vector double vx);	vector float qdrtf4 (vector float vx);
rcbrtd2	rcbrtf4	Computes the reciprocal of the cube root of each element of vx.	vector double rcbrtd2 (vector double vx);	vector float rcbrtf4 (vector float vx);
recipd2	recipf4	Computes the reciprocal of each element of vx.	vector double recipd2 (vector double vx);	vector float recipf4 (vector float vx);
rqdrtd2	rqdrtf4	Computes the reciprocal of the quad root of each element of vx.	vector double rqdrtd2 (vector double vx);	vector float rqdrtf4 (vector float vx);
rsqrtd2	rsqrtf4	Computes the reciprocal of the square root of each element of vx.	vector double rsqrtd2 (vector double vx);	vector float rsqrtf4 (vector float vx);
sincosd2	sincosf4	Computes the sine and cosine of each element of vx.	void sincosd2 (vector double vx, vector double *vs, vector double *vc);	void sincosf4 (vector float vx, vector float *vs, vector float *vc);
sind2	sinf4	Computes the sine of each element of vx.	vector double sind2 (vector double vx);	vector float sinf4 (vector float vx);
sinhd2	sinhf4	Computes the hyperbolic sine of each element of vx.	vector double sinhd2 (vector double vx);	vector float sinhf4 (vector float vx);
sqrtd2	sqrtf4	Computes the square root of each element of vx.	vector double sqrtd2 (vector double vx);	vector float sqrtf4 (vector float vx);

Table 24. MASS SIMD functions (continued)

Double-precision function	Single-precision function	Description	Double-precision function prototype	Single-precision function prototype
tand2	tanf4	Computes the tangent of each element of vx.	vector double tand2 (vector double vx);	vector float tanf4 (vector float vx);
tanh2	tanhf4	Computes the hyperbolic tangent of each element of vx.	vector double tanhd2 (vector double vx);	vector float tanhf4 (vector float vx);

## Compiling and linking a program with MASS

To compile an application that calls the functions in the scalar, SIMD, or vector MASS libraries, specify the wanted one or more of the following library names on the `-l` linker option:

- 32-bit: **libmass**, **mass\_simdp7** or **mass\_simdp8**, and/or one of **massvp4**, **massvp5**, **massvp6**, **massvp7**, **massvp8**
- 64-bit: **libmass\_64**, **mass\_simdp7\_64** or **mass\_simdp8\_64**, and/or one of **massvp4\_64**, **massvp5\_64**, **massvp6\_64**, **massvp7\_64**, **massvp8\_64**

For example, if the MASS libraries are installed in the default directory, you can specify one of the following:

**Link with scalar library libmass.a and vector library libmassvp8.a (32-bit code)**

```
xlc -qarch=pwr8 prog.c -o prog -lmass -lmassvp8
```

**Link with SIMD library libmass\_simdp8.a (32-bit code)**

```
xlc -qarch=pwr8 prog.c -o prog -lmass_simdp8
```

**Link with scalar library libmass\_64 and vector library libmassvp8\_64.a (64-bit code)**

```
xlc -qarch=pwr8 prog.c -o prog -lmass_64 -lmassvp8_64 -q64
```

**Link with SIMD library libmass\_simdp8\_64.a (64-bit code)**

```
xlc -qarch=pwr8 prog.c -o prog -lmass_simdp8_64 -q64
```

## Using libmass.a with the math system library

If you want to use the **libmass.a** or **libmass\_64.a** scalar library for some functions and the normal math library **libm.a** for other functions, follow this procedure to compile and link your program:

1. Use the **ar** command to extract the object files of the wanted functions from **libmass.a** or **libmass\_64.a**. For most functions, the object file name is the function name followed by **.s32.o** for 32-bit mode or **.s64.o** for 64-bit mode.<sup>1</sup> For example, to extract the object file for the **tan** function in 32-bit mode, the command would be:  

```
ar -x tan.s32.o libmass.a
```
2. Archive the extracted object files into another library:  

```
ar -qv libfasttan.a tan.s32.o
```

```
ranlib libfasttan.a
```
3. Create the final executable using **xlc**, specifying **-lfasttan** instead of **-lmass**:  

```
xlc sample.c -o sample -Ldir_containing_libfasttan -lfasttan
```

This links only the **tan** function from MASS (now in **libfasttan.a**) and the remainder of the math functions from the standard system library.

### Exceptions:

1. The `sin` and `cos` functions are both contained in the object files `sincos.s32.o` and `sincos.s64.o`. The `cosisin` and `sincos` functions are both contained in the object files `cosisin.s32.o` and `cosisin.s64.o`.
2. The XL C/C++ `pow` function is contained in the object files `dxy.s32.o` and `dxy.s64.o`.

**Note:** The `cos` and `sin` functions will both be exported if either one is exported. `cosisin` and `sincos` will both be exported if either one is exported.

---

## Using the Basic Linear Algebra Subprograms – BLAS

Four Basic Linear Algebra Subprograms (BLAS) functions are shipped with the XL C/C++ compiler in the `libxlopt` library. The functions consist of the following:

- `sgemv` (single-precision) and `dgemv` (double-precision), which compute the matrix-vector product for a general matrix or its transpose
- `sgemm` (single-precision) and `dgemm` (double-precision), which perform combined matrix multiplication and addition for general matrices or their transposes

Because the BLAS routines are written in Fortran, all parameters are passed to them by reference, and all arrays are stored in column-major order.

**Note:** Some error-handling code has been removed from the BLAS functions in `libxlopt`, and no error messages are emitted for calls to these functions.

“BLAS function syntax” describes the prototypes and parameters for the XL C/C++ BLAS functions. The interfaces for these functions are similar to those of the equivalent BLAS functions shipped in IBM's Engineering and Scientific Subroutine Library (ESSL); for more information and examples of usage of these functions, see *Engineering and Scientific Subroutine Library Guide and Reference*, available at the Engineering and Scientific Subroutine Library (ESSL) and Parallel ESSL web page.

“Linking the `libxlopt` library” on page 117 describes how to link to the XL C/C++ `libxlopt` library if you are also using a third-party BLAS library.

### BLAS function syntax

The prototypes for the `sgemv` and `dgemv` functions are as follows:

```
void sgemv(const char *trans, int *m, int *n, float *alpha,
           void *a, int *lda, void *x, int *incx,
           float *beta, void *y, int *incy);
void dgemv(const char *trans, int *m, int *n, double *alpha,
           void *a, int *lda, void *x, int *incx,
           double *beta, void *y, int *incy);
```

The parameters are as follows:

*trans*

is a single character indicating the form of the input matrix *a*, where:

- 'N' or 'n' indicates that *a* is to be used in the computation
- 'T' or 't' indicates that the transpose of *a* is to be used in the computation

*m* represents:

- the number of rows in input matrix *a*
- the length of vector *y*, if 'N' or 'n' is used for the *trans* parameter

- the length of vector  $x$ , if 'T' or 't' is used for the *trans* parameter

The number of rows must be greater than or equal to zero, and less than the leading dimension of the matrix  $a$  (specified in  $lda$ )

$n$  represents:

- the number of columns in input matrix  $a$
- the length of vector  $x$ , if 'N' or 'n' is used for the *trans* parameter
- the length of vector  $y$ , if 'T' or 't' is used for the *trans* parameter

The number of columns must be greater than or equal to zero.

$alpha$

is the scaling constant for matrix  $a$

$a$  is the input matrix of float (for sgemv) or double (for dgemv) values

$lda$

is the leading dimension of the array specified by  $a$ . The leading dimension must be greater than zero. The leading dimension must be greater than or equal to 1 and greater than or equal to the value specified in  $m$ .

$x$  is the input vector of float (for sgemv) or double (for dgemv) values.

$incx$

is the stride for vector  $x$ . It can have any value.

$beta$

is the scaling constant for vector  $y$

$y$  is the output vector of float (for sgemv) or double (for dgemv) values.

$incy$

is the stride for vector  $y$ . It must not be zero.

**Note:** Vector  $y$  must have no common elements with matrix  $a$  or vector  $x$ ; otherwise, the results are unpredictable.

The prototypes for the sgemm and dgemm functions are as follows:

```
void sgemm(const char *transa, const char *transb,
           int *l, int *n, int *m, float *alpha,
           const void *a, int *lda, void *b, int *ldb,
           float *beta, void *c, int *ldc);

void dgemm(const char *transa, const char *transb,
           int *l, int *n, int *m, double *alpha,
           const void *a, int *lda, void *b, int *ldb,
           double *beta, void *c, int *ldc);
```

The parameters are as follows:

$transa$

is a single character indicating the form of the input matrix  $a$ , where:

- 'N' or 'n' indicates that  $a$  is to be used in the computation
- 'T' or 't' indicates that the transpose of  $a$  is to be used in the computation

$transb$

is a single character indicating the form of the input matrix  $b$ , where:

- 'N' or 'n' indicates that  $b$  is to be used in the computation
- 'T' or 't' indicates that the transpose of  $b$  is to be used in the computation

$l$  represents the number of rows in output matrix  $c$ . The number of rows must be greater than or equal to zero, and less than the leading dimension of  $c$ .

*n* represents the number of columns in output matrix *c*. The number of columns must be greater than or equal to zero.

*m* represents:

- the number of columns in matrix *a*, if 'N' or 'n' is used for the *transa* parameter
- the number of rows in matrix *a*, if 'T' or 't' is used for the *transa* parameter

and:

- the number of rows in matrix *b*, if 'N' or 'n' is used for the *transb* parameter
- the number of columns in matrix *b*, if 'T' or 't' is used for the *transb* parameter

*m* must be greater than or equal to zero.

*alpha*  
is the scaling constant for matrix *a*

*a* is the input matrix *a* of float (for sgemm) or double (for dgemm) values

*lda*  
is the leading dimension of the array specified by *a*. The leading dimension must be greater than zero. If *transa* is specified as 'N' or 'n', the leading dimension must be greater than or equal to 1. If *transa* is specified as 'T' or 't', the leading dimension must be greater than or equal to the value specified in *m*.

*b* is the input matrix *b* of float (for sgemm) or double (for dgemm) values.

*ldb*  
is the leading dimension of the array specified by *b*. The leading dimension must be greater than zero. If *transb* is specified as 'N' or 'n', the leading dimension must be greater than or equal to the value specified in *m*. If *transa* is specified as 'T' or 't', the leading dimension must be greater than or equal to the value specified in *n*.

*beta*  
is the scaling constant for matrix *c*

*c* is the output matrix *c* of float (for sgemm) or double (for dgemm) values.

*ldc*  
is the leading dimension of the array specified by *c*. The leading dimension must be greater than zero. If *transb* is specified as 'N' or 'n', the leading dimension must be greater than or equal to 0 and greater than or equal to the value specified in *l*.

**Note:** Matrix *c* must have no common elements with matrices *a* or *b*; otherwise, the results are unpredictable.

## Linking the libxlopt library

By default, the libxlopt library is linked with any application you compile with the XL C/C++ compiler. However, if you are using a third-party BLAS library, but want to use the BLAS routines shipped with libxlopt, you must specify the libxlopt library before any other BLAS library on the command line at link time. For example, if your other BLAS library is called libblas.a, you would compile your code with the following command:

```
xlc app.c -lxlopt -lblas
```

The compiler will call the `sgemv`, `dgemv`, `sgemm`, and `dgemm` functions from the `libxlopt` library, and all other BLAS functions in the `libblas.a` library.

---

## Chapter 12. Parallelizing your programs

The compiler offers you the following methods of implementing shared memory program parallelization:

- Automatic parallelization of countable program loops, which are defined in “Countable loops” on page 120. An overview of the compiler's automatic parallelization capabilities is provided in “Enabling automatic parallelization” on page 121.
- Explicit parallelization of C and C++ program code using pragma directives compliant to the OpenMP Application Program Interface specification. An overview of the OpenMP directives is provided in “Using OpenMP directives” on page 123.

All methods of program parallelization are enabled when the **-qsmp** compiler option is in effect without the **omp** suboption. You can enable strict OpenMP compliance with the **-qsmp=omp** compiler option, but doing so will disable automatic parallelization.

**Note:** The **-qsmp** option must only be used together with thread-safe compiler invocation modes (those that contain the **\_r** suffix).

Parallel regions of program code are executed by multiple threads, possibly running on multiple processors. The number of threads created is determined by environment variables and calls to library functions. Work is distributed among available threads according to scheduling algorithms specified by the environment variables. For any of the methods of parallelization, you can use the **XLSMPOPTS** environment variable and its suboptions to control thread scheduling; for more information on this environment variable, see *XLSMPOPTS* in the *XL C/C++ Compiler Reference*. If you are using OpenMP constructs, you can use the OpenMP environment variables to control thread scheduling; for information on OpenMP environment variables, see *OpenMP environment variables for parallel processing* in the *XL C/C++ Compiler Reference*. For more information on OpenMP built-in functions, see *Built-in functions for parallel processing* in the *XL C/C++ Compiler Reference*.

For details about the OpenMP constructs, environment variables, and runtime routines, refer to the *OpenMP Application Program Interface Specification*, available at <http://www.openmp.org>.

### Related information:

“Using shared-memory parallelism (SMP)” on page 50

**Related information in the *XL C/C++ Compiler Reference***



**XLSMPOPTS**



**OpenMP environment variables for parallel processing**



**Built-in functions for parallel processing**

### Related external information



**OpenMP Application Program Interface Language Specification**, available at <http://www.openmp.org>

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## Countable loops

Loops are considered to be countable if they take any of the following forms:

### Countable for loop syntax with single statement

►►—for—(iteration\_variable—;—exit\_condition—;—increment\_expression—)——►  
►—statement——►◄◄

### Countable for loop syntax with statement block

►►—for—(iteration\_variable—;—expression—)——►  
►—{ declaration\_list statement\_list increment\_expression statement\_list }——►◄◄

### Countable while loop syntax

►►—while—(—exit\_condition—)——►  
►—{ declaration\_list statement\_list increment\_expression }——►◄◄

### Countable do while loop syntax

►►—do—{ declaration\_list statement\_list increment\_expression }—while—(—exit\_condition—)——►◄◄

The following definitions apply to these syntax diagrams:

*iteration\_variable*

is a signed integer that has either automatic or register storage class, does not have its address taken, and is not modified anywhere in the loop except in the *increment\_expression*.

*exit\_condition*

takes the following form:

|—increment\_variable—<=—expression——|  
|<—|  
|>=—|  
|>—|

where *expression* is a loop-invariant signed integer expression. *expression* cannot reference external or static variables, pointers or pointer expressions, function calls, or variables that have their address taken.

*increment\_expression*

takes any of the following forms:

- ++*iteration\_variable*
- --*iteration\_variable*
- *iteration\_variable*++
- *iteration\_variable*--
- *iteration\_variable* += *increment*

- $iteration\_variable -= increment$
- $iteration\_variable = iteration\_variable + increment$
- $iteration\_variable = increment + iteration\_variable$
- $iteration\_variable = iteration\_variable - increment$

where *increment* is a loop-invariant signed integer expression. The value of the expression is known at run time and is not 0. *increment* cannot reference external or static variables, pointers or pointer expressions, function calls, or variables that have their address taken.

---

## Enabling automatic parallelization

The compiler can automatically locate and parallelize all countable loops where possible in your program code. A loop is considered to be countable if it has any of the forms shown in “Countable loops” on page 120, and:

- There is no branching into or out of the loop.
- The *increment\_expression* is not within a critical section.

In general, a countable loop is automatically parallelized only if all of the following conditions are met:

- The order in which loop iterations start or end does not affect the results of the program.
- The loop does not contain I/O operations.
- Floating point reductions inside the loop are not affected by round-off error, unless the **-qnostrict** option is in effect.
- The **-qnostrict\_induction** compiler option is in effect.
- The **-qsmp=auto** compiler option is in effect.
- The compiler is invoked with a thread-safe compiler invocation mode (those that contain the **\_r** suffix).

---

## Data sharing attribute rules

The rules of data sharing attributes determine the attributes of variables that are referenced in **parallel** and **task** directives, and **worksharing** regions.

### Data sharing attribute rules for variables referenced in a construct

The data sharing attributes of variables that are referenced in a construct can be classified into the following categories:

- Predetermined data sharing attributes
- Explicitly determined data sharing attributes
- Implicitly determined data sharing attributes

Specifying a variable in a **firstprivate**, **lastprivate**, or **reduction** clause of an enclosed construct initiates an implicit reference to the variable in the enclosing construct. Such implicit references also follow the data sharing attribute rules.

Some variables and objects have predetermined data sharing attributes as follows:

- Variables that are specified in **threadprivate** directives are **threadprivate**.
- Variables with automatic storage duration that are declared in a scope inside the construct are **private**.

- Objects with dynamic storage duration are shared.
- Static data members are shared.
- The loop iteration variables in the associated for loops of a `for` or `parallel for` construct are private.
- Variables with `const`-qualified types are shared if they have no mutable member.
- For variables with static storage duration, if they are declared in a scope inside the construct, they are shared.

Variables with predetermined data sharing attributes cannot be specified in data sharing attribute clauses. However, in the following situations, specifying a predetermined variable in a data sharing attribute clause is allowed and overrides the variable's predetermined data sharing attributes.

- The loop iteration variables in the associated for loops of a `for` or `parallel for` construct can be specified in a `private` or `lastprivate` clause.
- For variables with `const`-qualified type, if they have no mutable member, they can be specified in a `firstprivate` clause.

Variables that meet the following conditions have explicitly determined data sharing attributes:

- The variables are referenced in a construct.
- The variables are specified in a data sharing attribute clause on the construct.

Variables that meet all the following conditions have implicitly determined data sharing attributes:

- The variables are referenced in a construct.
- The variables do not have predetermined data sharing attributes.
- The variables are not specified in a data sharing attribute clause on the construct.

For variables that have implicitly determined data sharing attributes, the rules are as follows:

- In a `parallel` or `task` construct, the data sharing attributes of the variables are determined by the `default` clause, if present.
- In a `parallel` construct, if no `default` clause is present, the variables are shared.
- For constructs other than `task`, if no `default` clause is present, the variables inherit their data sharing attributes from the enclosing context.
- In a `task` construct, if no `default` clause is present, variables that are determined to be shared in the enclosing context by all implicit tasks bound to the current team are shared.
- In a `task` construct, if no `default` clause is present, variables whose data sharing attributes are not determined by the rules above are `firstprivate`.

### **Data sharing attribute rules for variables referenced in a region but not in a construct**

The data sharing attributes of variables that are referenced in a region, but not in a construct, are determined as follows:

- If variables with static storage duration are declared in called routines in the region, the variables are shared.
- Variables with `const`-qualified types are shared if they have no mutable member and are declared in called routines.

- File-scope or namespace-scope variables referenced in called routines in the region are shared unless they are specified in a `threadprivate` directive.
- Objects with dynamic storage duration are shared.
- Static data members are shared unless they are specified in a `threadprivate` directive.
- The formal arguments of called routines in the region that are passed by reference inherit the data sharing attributes of the associated actual arguments.
- Other variables declared in called routines in the region are private.

## Using OpenMP directives

OpenMP directives exploit shared memory parallelism by defining various types of parallel regions. Parallel regions can include both iterative and non-iterative segments of program code.

The **#pragma omp** pragmas fall into these general categories:

1. The **#pragma omp** pragmas that let you define parallel regions in which work is done by threads in parallel (**#pragma omp parallel**). Most of the OpenMP directives either statically or dynamically bind to an enclosing parallel region.
2. The **#pragma omp** pragmas that let you define how work is distributed or shared across the threads in a parallel region (**#pragma omp sections**, **#pragma omp for**, **#pragma omp single**, **#pragma omp task**).
3. The **#pragma omp** pragmas that let you control synchronization among threads (**#pragma omp atomic**, **#pragma omp master**, **#pragma omp barrier**, **#pragma omp critical**, **#pragma omp flush**, **#pragma omp ordered**) .
4. The **#pragma omp** pragmas that let you define the scope of data visibility across parallel regions within the same thread (**#pragma omp threadprivate**).
5. The **#pragma omp** pragmas for synchronization (**#pragma omp taskwait**, **#pragma omp barrier**)

### OpenMP directive syntax



Adding certain clauses to the **#pragma omp** pragmas can fine tune the behavior of the parallel or work-sharing regions. For example, a `num_threads` clause can be used to control a parallel region pragma.

The **#pragma omp** pragmas generally appear immediately before the section of code to which they apply. The following example defines a parallel region in which iterations of a for loop can run in parallel:

```
#pragma omp parallel
{
    #pragma omp for
    for (i=0; i<n; i++)
        ...
}
```

This example defines a parallel region in which two or more non-iterative sections of program code can run in parallel:

```

#pragma omp parallel
{
    #pragma omp sections
    {
        #pragma omp section
        structured_block_1
        ...
        #pragma omp section
        structured_block_2
        ...
        ....
    }
}

```

For a pragma-by-pragma description of the OpenMP directives, refer to *Pragma directives for parallel processing* in the *XL C/C++ Compiler Reference*.

#### Related information in the XL C/C++ Compiler Reference



Pragma directives for parallel processing



OpenMP built-in functions



OpenMP environment variables for parallel processing

---

## Shared and private variables in a parallel environment

Variables can have either shared or private context in a parallel environment. Variables in shared context are visible to all threads running in associated parallel regions. Variables in private context are hidden from other threads. Each thread has its own private copy of the variable, and modifications made by a thread to its copy are not visible to other threads.

The default context of a variable is determined by the following rules:

- Variables with static storage duration are shared.
- Dynamically allocated objects are shared.
- Variables with automatic storage duration that are declared in a parallel region are private.
- Variables in heap allocated memory are shared. There can be only one shared heap.
- All variables defined outside a parallel construct become shared when the parallel region is encountered.
- Loop iteration variables are private within their loops. The value of the iteration variable after the loop is the same as if the loop were run sequentially.
- Memory allocated within a parallel loop by the `alloca` function persists only for the duration of one iteration of that loop, and is private for each thread.

The following code segments show examples of these default rules:

```

int E1;                                /* shared static */

void main (argc,...) {                  /* argc is shared */
    int i;                               /* shared automatic */

    void *p = malloc(...);              /* memory allocated by malloc */
                                        /* is accessible by all threads */
                                        /* and cannot be privatized */

    #pragma omp parallel firstprivate (p)
    {

```

```

int b;                                /* private automatic */
static int s;                         /* shared static      */

#pragma omp for
for (i =0;...) {
    b = 1;                            /* b is still private here ! */
    foo (i);                          /* i is private here because it */
                                      /* is an iteration variable    */
}

#pragma omp parallel
{
    b = 1;                            /* b is shared here because it */
                                      /* is another parallel region  */
}

int E2;                              /*shared static */

void foo (int x) {
    /* x is private for the parallel */
    /* region it was called from    */
}

int c;                               /* the same */
... }

```

Some OpenMP clauses let you specify visibility context for selected data variables. A brief summary of data scope attribute clauses are listed below:

Data scope attribute clause	Description
private	The <b>private</b> clause declares the variables in the list to be private to each thread in a team.
firstprivate	The <b>firstprivate</b> clause provides a superset of the functionality provided by the private clause. The private variable is initialized by the original value of the variable when the parallel construct is encountered.
lastprivate	The <b>lastprivate</b> clause provides a superset of the functionality provided by the private clause. The private variable is updated after the end of the parallel construct.
shared	The <b>shared</b> clause declares the variables in the list to be shared among all the threads in a team. All threads within a team access the same storage area for shared variables.
reduction	The <b>reduction</b> clause performs a reduction on the scalar variables that appear in the list, with a specified operator.
default	The <b>default</b> clause allows the user to affect the data-sharing attribute of the variables appeared in the parallel construct.

For more information, see the OpenMP directive descriptions in "Pragma directives for parallel processing" in the *XL C/C++ Compiler Reference*. You can also refer to the *OpenMP Application Program Interface Language Specification*, which is available at <http://www.openmp.org>.

**Related information in the XL C/C++ Compiler Reference**

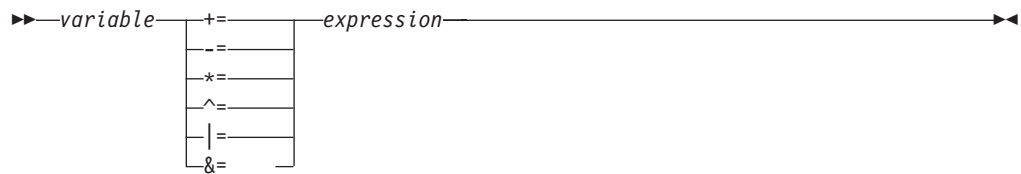
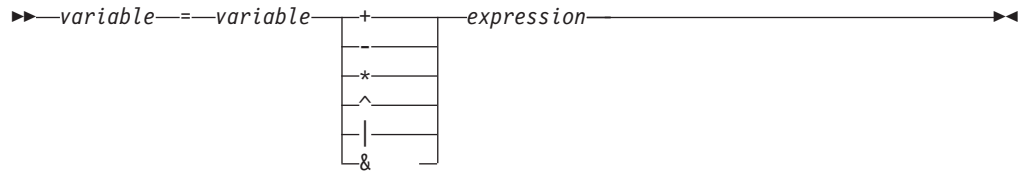


Pragma directives for parallel processing

---

## Reduction operations in parallelized loops

The compiler can recognize and properly handle most reduction operations in a loop during both automatic and explicit parallelization. In particular, it can handle reduction statements that have either of the following forms:



where:

*variable*

is an identifier designating an automatic or register variable that does not have its address taken and is not referenced anywhere else in the loop, including all loops that are nested. For example, in the following code, only `S` in the nested loop is recognized as a reduction:

```
int i,j, S=0;
for (i= 0 ;i < N; i++) {
    S = S+ i;
    for (j=0;j< M; j++) {
        S = S + j;
    }
}
```

*expression*

is any valid expression.

OpenMP directives provide you with mechanisms to specify reduction variables explicitly.

---

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